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Description of Animal Welfare and Feeding Management Parameters on Dairy Cattle Farms

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Universidade de Santiago de Compostela
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Asdo.:……………………………..
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D. Luis Angel Quintela Arias y Dña. Mónica Barrio López, Doctores por la USC, y Dña. Noelia Silva-del-Rio, Doctora por la UW-Madison,

INFORMAN

Que la Tesis Doctoral titulada "Description of Animal Welfare and Feeding Management Parameters on Dairy Cattle Farms", de la que es autora la Licenciada en Veterinaria Dña. YOLANDA TRILLO DONO, ha sido realizada bajo nuestra dirección en el Departamento de Patoloxía Animal de la Universidade de Santiago de Compostela y el el Departamento de Population Health and Reproduction de la Escuela de Veterinaria en la Universidad de California, Davis.

Y para que conste firman el presente informe en Lugo a 25 de Abril del 2016.

Fdo. Luis A. Quintela Arias Fdo. Mónica Barrio López Fdo. Noelia Silva-del-Río

A Mamá y a Papá

A Nati y a Marcos

A mis mentores

Y, a todas las personas que me rodean

Este viaje ha sido largo. Los retrasos y apuros, decepciones y alegrías, idas y venidas, marcarán un antes y un después en mi vida. Lo que he aprendido en conocimientos no se puede igualar al crecimiento personal que he experimentado. Ello no sería posible sin personas.

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STRUCTURE

This dissertation describes several management practices and measures related with the animal welfare and cow comfort on dairy cattle farms.

Firstly, a ***general introduction*** provides the reader a basis of the animal welfare, regulations in the UE, and implications on cow well-being as well as measurements and management practices on farm involved on the welfare and comfort of the cow.

The ***objectives*** of this study were addressed over three chapters that make up the bulk of the thesis.

Chapter 1 describes animal-based, facility-based and management practices parameters in 73 Lugo farms (Galicia, Spain).

Chapters 2 and 3 describe several feeding management practices parameters in 26 California farms (USA). This included loading errors during ration preparation and, ration preparation and delivery times respectively.

The three chapters are focused on benchmarking parameters to find opportunities to improve management practices involved on the cow well-being. Each chapter is organized with the common structure of a scientific paper. Chapter 2 was accepted for publication on the Journal Dairy Science, while Chapter 1 and 3 were sent for publication. Original articles are included as ***annexes*** at the end of the thesis.

Finally, the ***conclusions*** and ***summary*** of the thesis are reported in English and Spanish languages following guidelines required for International Thesis Nomination.

GENERAL

INTRODUCTION

Consumers show a growing interest in the quality of products, animal production systems and distribution channels, including issues such as animal welfare, food safety and environmental pollution (Broom, 2010). Those demands refer to a large extent to the upstream farm stages of the so-called supply chain, requiring that those consumer's preferences be incorporated in all stages involved. That is known as traceability "from farm to table" developed by the European Commission under the General Food Law, Regulation (EC) No 178/2002.

On a dairy farm, the environment surrounding the animals, such as facilities design and management practices may determine the status of the animal well-being and cow comfort. Auditing and monitoring programs will reflect the development of a dairy farm over time. Furthermore, a benchmarking process may help identify opportunities to improve within and across farms.

1. Definition of Animal Welfare

Animal welfare is a subjective concept and it can be addressed from different points of view. It is a multi-faceted issue which implies important scientific, ethical, economic and political dimensions (Lund et al., 2006). The scientific definition of animal welfare address the ability of an animal to cope physiologically, behaviorally, cognitively and emotionally with its physiochemical and social life environment.

Regarding animal welfare in production animals, several authors (Broom, 1996; Duncan, 1996) focused on the state of an animal, including animal's feelings as well as bodily state. Measure of suffer may be difficult, however considering well-being as the result of the adaptation to the environment, it is possible to quantify changes of the animal, including body and behavior, or around the animal, such as environment, facilities and management practices, over time.

2. Implications of the Animal Welfare

Recent crises such as bovine spongiform encephalopathy or BSE, swine fever, foot and mouth disease and avian influenza, have further increased awareness that animal production is more than just an industry. A frequent and worrying question is whether or not animal production has become unsustainable for people, animals and the environment alike. Indeed, a growing ethical concern related to production processes can be identified as a major trend in European food consumer behavior (Steenkamp, 1996).

Understanding how individual animals respond to stress is important in terms of labor safety (Kosaco and Immura, 1999), production (Burrow, 1997), and animal welfare (Grandin, 1997).

Improving animal welfare makes livestock handling safer, reduces labor requirements when using friendly equipment, increases the economic value of cull animals, promotes the use of livestock identification and trace back and increases the value of the products (Grandin, 2000). Ferguson et al. (2001) studied the positive effect of the quality management on the quality product referred to beef palatability. When animals are subjected to severe periods of stress even for short term, such as prior to slaughter, meat became pale, soft and exudative (PSE). However, in a long period of stress it became dark, firm and dry (DFD). The programs implemented by supermarkets and restaurants to inspect farms and slaughter facilities have resulted in great improvements in how animals are managed (Grandin, 2005, 2007).

In biology, the stress is the unspecific answer of the organism facing external demands when animals are subjected to hostile environmental conditions, alteration in climate or management (Gwasdauskas et al, 1975). The animal can adapt, in exchange for a biological cost, or fail to adapt, sick or dying. Only when the animal adapts without requiring a biological cost, it is considered a satisfactory well-being.

The reaction of the animal to stressors depends on the duration and intensity of the stressors as well as the animal's previous experience to the agents, stimulus or conditions, the physiological status and immediate environmental restraints (Grandin, 1997). In general, chronic stress is considered to have a greater potential impact on animal health and welfare than acute stress, because the animals are exposed and reacting to the stressor(s) for longer periods, thereby causing prolonged disruption to homeostasis and related biologic processes (Earley et al., 2010).

2.1. Physiological implications

Stress is commonly defined as a state of real or perceived threat to homeostasis. Maintenance of homeostasis in the presence of aversive stimuli (stressors) requires activation of a complex range of responses involving the endocrine, nervous, and immune systems, collectively known as the stress response (Chrousos and Gold, 1992).

Activation of the stress response initiates a number of behavioral and physiological changes that improve an individual's chance of survival when faced with homeostatic challenges. Behavioral effects of the stress response include increased awareness, improved cognition, euphoria, and enhanced analgesia which will be translated into abnormal behavior, such as stereotypes or rigid behaviors (Chrousos and Gold, 1992; Charmandari et al., 2005). Physiological adaptations include increased cardiovascular tone, respiratory rate, and intermediate metabolism, along with inhibition of general vegetative functions such as feeding, digestion, growth, reproduction, and immunity (Sapolsky et al., 2000; Habid et al., 2001). Due to the wide array of physiologic and potentially pathogenic effects of the stress response, a number of neuronal and endocrine systems function to tightly regulate this adaptive process.

The stress response consists of a set of physiologic mechanisms designed to return to homeostasis. Two distinct systems link the initial perception of the stressor to this response, that is the sympathetic adrenomedullary (SAM) axis and the hypothalamic–pituitary–adrenocortical (HPA) axis. Both, central and peripheral activation, involves the orchestrated interplay of short-term (acute) behavioral and endocrine responses that prepare animals for an immediate response to environmental adjustment, whereas long-term (chronic) responses involve a substantial adjustment of neuroendocrine, immune, and metabolic responses to the stressor in the brain (Habid et al., 2001; Charmandari et al., 2005).

The General Adaptation Syndrome (GAS) is responsible for develop the adaptation mechanisms for the survival which involves alarm, resistance and exhaustion. The goal of these systems is to maintain homeostasis, to buffer the internal environment from the external environment by the parasympathetic system (Chrousos and Gold, 1992; De Kloet et al., 2005; McEwen, 2012).

The first stage of the GAS is the fight or flight response or acute stress responses which consist on the activation of the sympathetic nervous system to respond a threat. Adrenaline and noradrenaline are released from the medulla of the adrenal glands leading to increased alertness. The release is triggered by acetylcholine from preganglionic sympathetic nerves. These catecholamine hormones facilitate immediate physical reactions by triggering increases in heart rate and breathing, constricting blood vessels and tightening muscles. The body begins to convert stored glycogen into glucose. An abundance of catecholamines at neuroreceptor sites facilitates reliance on spontaneous or intuitive behaviors often related to combat or escape (De Kloet et al., 2005).

The ensuing physiological changes constitute a major part of the acute stress response. The other major player in the acute stress response is the HPA axis. The HPA axis responds to a variety of stressors by synthesizing and releasing four key hormones, namely, corticotrophin-releasing factor or hormone (CRH), arginine-vasopressin (AVP), adrenocorticotrophic hormone (ACTH), and glucocorticoids. Glucocorticoids serve as the final effectors of the

HPA axis and are critically involved in modulating the response to any psychologic or physical stressors (Sapolsky et al., 2000).

The alarm phase is many times enough to help overcome stress in the first place. However, if the stressor last for several hours or more, the body enters the resistance phase, the second stage of the GAS. Parasympathetic nervous system returns many physiological functions to normal levels while body focuses resources against the stressor. Blood glucose levels remain high, cortisol and adrenalin continue to circulate at elevated levels, but outward appearance of organism seems normal. If this adaptation process continues for a prolonged period of time without periods of relaxation and rest to counter balance the stress response, sufferers become prone to fatigue, concentration lapses, irritability and lethargy as the effort to sustain arousal slides into negative stress. Stressor continues beyond body's capacity, the glucose levels decrease as the adrenals become depleted and leading to decreased stress tolerance. That is the third stage of the GAS; organism exhausts resources and becomes susceptible to disease and death (De Kloet et al., 2005; McEwen, 2012).

The long-term, chronic stress, usually 24 to 48 hours, may impact on production animals affecting the growth, the immune system production and reproduction (Lay et al., 1992; Buckham Sporer et al., 2008). Those deficiencies can continue after the stimulus from stressor has been diminished or eliminated (MC Donald, 1989).

The stress affect on the growth by decreasing activity from the digestive tract and it promotes hyperglycemia because the rest of the body is not allowed to use the glucose reservoirs and even destroy part of the cells to obtain glucose precursors increasing the lipid and protein catabolism at plasma, muscle and adipose tissue level, mainly (Charmandari et al., 2005).

Effects of stress on immunity (immunosuppression) run via this HPA axis and, in cattle, the synthetic glucocorticoid dexamethasone induces neutrophilia, eosinopenia, lymphopenia, monocytosis and leucocytosis. Glucocorticoids repress the expression of neutrophil adhesion molecules, thereby preventing migration to underlying tissue, leading to neutrophilia and increased mastitis susceptibility (Tempelman et al., 2002). Stress hormones may suppress the production of Tumor Necrosis Factor-alpha by monocytes and this could contribute to the higher susceptibility of cattle to Gram-negative bacterial infections of the udder during stress (Diez-Fraile et al., 2000).

During routine milking, the concentration of plasma cortisol increases physiological in cows. Central inhibition of milk ejection is caused by inhibit of oxytocin from the pituitary gland, and occasionally occurs in cattle production as a result of various stresses, in which decreased levels of oxytocin, and increased levels of β-endorphin, cortisol, ACTH, and catecholamines in blood plasma (Bruckmaier, 2005).

Stressors affect reproductive functions through actions at the hypothalamus as well as impairing pituitary LH release induced by GnRH (Dobson and Smith, 1995). Stress will cause the release of ACTH from the anterior pituitary which, in turn, stimulates release of cortisol and other glucocorticoids from the adrenal cortex. Glucocorticoids inhibit the release of LH. Therefore, if an animal is under stress during a critical period of the oestrus cycle (late proestrus or oestrus) a glucocorticoid induced suppression of LH is likely to either delay or prevents ovulation (Charmandari et al., 2005).

2.2. Productive and economical implications

Stress from metabolic problems may decrease the cow's resistance and compromise immune system function. Disease such as mastitis, lameness, metritis, retained placenta, left displaced abomasum, ketosis, and milk fever and affect production and reproduction performance which is translated into economical losses (Liang, 2013). Diseases occurring early in lactation may lead to delayed conception. Cows may be culled directly or indirectly as a consequence of disease (via low milk production or delayed conception) and some cows die of the diseases being considered. Milk loss, treatment costs, and culling costs were the largest three cost categories identified within those seven diseases (Liang, 2013). The value of dead cow, decreased production and extra labor, and compromised animal welfare, suffering before death or euthanasia (Thomsen and Houe, 2006).

Considering heat stress, annual loss, based on a milk price of \$13/cwt, were determined of \$897 million for the dairy industry in the United States (St-Pierre et al. 2003). In California dairies the average dry matter intake (DMI) reduction was calculated of 145 kg/cow/year and a decrease in milk production of about 294 kg/cow/year (St-Pierre et al., 2003). Those dairies also increased 12 days open on average and almost a 1% increase in reproductive culling. Furthermore, implications on reproduction were higher than in milk production on several studies (De Vries, 2004; Flamenbaum and Galon, 2010), e.g. in Florida and Israel the milk production loss was of at most 15% and 7% respectively and a reduction in conception rate of at most 53% and 51% respectively. In addition, embryo loss is 3.7 times more likely in times of heat stress (Thatcher et al., 1986). However, it is estimated that heat load can be reduced from 30 to 50% with well-designed shade and increasing production by 10% (Collier et al., 2006).

The Farm Animal Welfare Committee (FAWC, 2011) reported the impact of economics on farm animal welfare and concluded economics can be used to analyze and appraise policy decisions concerning animal welfare to try to achieve farm animal welfare objectives as effectively and efficiently as possible.

3. Animal Welfare legislation in the UE

The Amsterdam Treaty provides the legislative framework of the EU community under which each member state must abide. A section on animal welfare was appended to the treaty, in order to provide an integrated approach to the development of a community wide protocol on the protection of animals in the EU.

While the treaty provides a broad legislative scope, there is also secondary legislation in the form of Regulations, Directives and Decisions regarding animal welfare in the EU. Other instruments to establish animal welfare objectives include Recommendations and Opinions. Those laws are adopted by the Europe Union (EU), European Council (EC), in conjunction or not with European Parliament or the Commission. The European Food Safety Authority (EFSA) often provides both opinions and recommendations on animal welfare. Recommendations in the EFSA Scientific Opinion on dairy cow welfare were formulated around hazards and these, by definition, relate to the animal's environment and how it is managed.

The EFSA is the risk assessment body regarding food and feed safety. It is independent from government and industry, though it works in close collaboration with national authorities and in open consultation with its stakeholders, including animal protection stakeholders. EFSA provides independent scientific advice and clear communication on existing and emerging risks. It was established by Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002, which lays down the general principles and requirements of food law. The activities of EFSA are carried out by the Panel on Animal Health and Welfare (AHAW). The Panel provides independent scientific advice to the European Commission, European Parliament and Member States on all aspects of animal health and welfare for food producing animals. Its scientific opinions focus on identifying methods to reduce unnecessary pain, distress and suffering for animals and to increase welfare "where possible". They cover the impact of housing, nutrition and feeding, management and genetic selection on the following topics: 1) behavior, fear and pain; 2) metabolic and reproductive disorders; 3) udder problem; 4) leg and locomotion; 5) overall welfare.

Furthermore, the OIE is the intergovernmental organization responsible for improving animal health worldwide. Since it was created, the OIE has played a key role as the sole international reference organization for animal health, directly collaborates with the Veterinary Services of all its Member Countries.

The EC has played a key role in developing standards for Europe, the Five Freedoms, which are noted internationally. These standards are based on both scientific evidence and practical experience and also emphasize the importance of the relationship between animal health and animal welfare. Originally developed in the UK, the Five Freedoms have been adopted as voluntary guidelines that the legislation of all countries should adopt.

The overall framework for EU action on animal welfare is set out in rolling action plans. There was the Community Action Plan on the Protection and Welfare of Animals 2006-2010, and a Second EU Strategy on the Welfare and Protection of Animals 2011-2015 was adopted in December 2011.

There are a significant number of laws and directives regarding animal welfare in the EU. Individual Member States also have their own regulations and directives which enforce the EU-wide legislation. The EU's regulatory framework for animal husbandry offers general, basic protection to all farm animals within the EU. However, Member States are free to adopt more rigorous national legislation.

3.1. Animal Welfare legislation for dairy cattle in the UE

The European Convention for the Protection of Animals kept for Farming Purposes (CE Farming Convention) is aimed at the practices of industrial stock breeding. The CE Farming Convention, purportedly drafted based on ethical principles, applies to the keeping, care and housing of animals, and in particular to animals in modern intensive stock farming systems. The general standard of treatment under the CE Farming Convention requires that:

- Animals shall be housed and provided with food, water and care in a manner which having regard to their species and to their degree of development, adaptation and domestication is appropriate to the physiological and ethological needs in accordance with established experience and scientific knowledge.

- To meet ethological needs, it is necessary that an animal be able to behave in a way consistent with its normal behavior in a natural setting.

- To meet physiological and ethological needs, it is not only necessary to satisfy physical needs for survival, but also to meet behavioral and psychological parameters, so that an animal can live in a way consistent with its nature.

Other requirements of the CE Farming Convention include standards relating to freedom of movement, feeding of animals, lighting, temperature and ventilation conditions where animals are confined and inspection requirements. These requirements can presumably be met by any number of types of regulations and the Convention does not attempt to define precisely how the standards are to be met.

The Committee endeavored to elaborate principles which are precise enough to prevent a completely free interpretation, but wide enough to allow for different needs. The underlying idea is to avoid any unnecessary suffering or injury and to secure conditions that shall be inconformity with physiological and ethological needs of the individual animals.

The EU Community-wide legislation affecting on farm animal welfare of dairy cattle is collected on:

- Council Directive 98/58/EC of 20 July 1998 concerning the protection of animals kept for farming purposes. This provides a basic framework requiring member states to enact legislation obliging owners or keepers to ensure the welfare of animals in their care and to ensure that the animals are not caused any unnecessary pain, suffering or injury. These rules reflect the so-called 'Five Freedoms' as adopted by the FAWC in the UK. This directive lays down the minimum welfare standards for the protection of all farmed animals.

- Commission Decision 2000/50/EC of 17 December 1999 concerning minimum requirements for the inspection of holdings on which animals are kept for farming purposes (repealed).

- Council Directive 91/629/EEC of 19 November 1991 laying down minimum standards for the protection of calves.

Furthermore, there is a project, Welfare Quality® (2009), funded by EU and designed by scientific researches to integrate the animal welfare on farm in the feeding chain to achieve social expectations and market requirements, as well as to provide practical science based tools and strategies to improve the welfare of farm animals and at slaughter.

The Welfare Quality® principles and criteria are based on the Five Freedom: good feeding involving absence of prolonged hunger and thirst; good housing, considering comfort around resting, thermal comfort and easy of movement; good health which includes absence of injuries, disease and pain induced by management procedures; appropriate behavior based on expression of social and others behaviors, good human-animal relationship and absence of general fear.

The Welfare Quality® project focused on measuring the magnitude of the outcomes, facilitating an assessment of dairy cow welfare irrespective of housing system and management. In contrast, the EFSA Scientific Opinion on dairy cow welfare focused on identifying the hazards that lead to these negative welfare outcomes and then making recommendations to reduce or eliminate them.

Despite of the legislation, there is not yet a certification of animal welfare on dairies extended over the UE. In contrast, in the USA, The National Dairy Farm Program have reached almost 80% of the dairy farms involved in this voluntary program which operates as an education, evaluation and verification program for dairy animal well-being. It is made through the Dairy Animal Care Manual**,** which assessment is similar to the Animal Welfare Quality® Protocol 2009.

3.2. Animal Welfare legislation in Spain

In Spain, Decree 2715/78 of October 27th transferred all responsibilities for animal protection to the Ministry of Agriculture. The basic organizational structure of the Ministry of Agriculture, Food and Environment, is developed by Royal Decree 1130/2008, of July 4th, (BOE July 8th), it attaches to the General Department of Operations and Systems Traceability Agricultural and Livestock Resources department competence in animal welfare.

The implementation of the rules by the Autonomous Communities is according to the statutes of autonomy. Basic general rules on animal welfare on farms are Royal Decree 348/2000 of March 10, modified by RD 441/01 of the Council of 27 April. The decree is the transposition into Spanish law (32/2007, 7th November) of Directive 98/58 / EC, which includes the principles of provision of housing, food, water and the physiological and behavioral needs of the animals care, according to the experience and scientific knowledge gained. It also includes requirements for the animal keepers and, among others, it provides the obligation of a logbook on the holding in which all medical treatments performed, and the

number of dead animals discovered in the inspections should be carried out regularly are scored. Such registration should be kept for at least three years.
In addition to this general law, there are specific regulations establishing conditions for rearing calves under 6 month characteristics.

4. Welfare Assessment in Dairy Cattle

Welfare assessment systems, for use in dairy farms, may differ according to both the definition of animal welfare, and the purpose of the welfare assessment. Therefore, it may varied with the objective to certificate or control the level of welfare on specific farms, to evaluate the welfare in different production systems, or to serve as an advisory tool that allows the farmer to identify, prevent or solve welfare problems on farm (Johnsen et al., 2001). Thus choice of welfare indicators and methods of measurement reflects the basic considerations of how animal welfare is understood.

Experience from previous studies (Sandøe et al., 1997) indicates a large variation between herds as regards animal welfare due to the effect of interactions between production system and management. Consequently, to improve animal welfare, there is a need for methods assessing animal welfare at herd level and allow the farmer to assess the development over time and to respond appropriately (Von Borell et al., 2001; Grandin, 2010).

These evaluations should be based on multi-criteria approaches; since no single measure can unequivocally be related to the welfare status. Therefore, animal welfare measurements may form the basis for the identification of causes of well-being problems (Welfare Quality®, 2009).

Using the animal welfare assessment on farm as a tool to describe potential hazards and to identify Critical Control Points (CCP) may help farmers in controlling and monitoring the production process

(Grandin, 2000). The critical limits for each identified CCP must involve a measurable parameter (von Borell et al., 2001).

4.1. Measurements of Dairy-Cattle well-being

Selection and development of reliable and feasible measures for on farm assessment protocols could be challenging. Many indicators may possibly be relevant for inclusion in an operational welfare assessment system.

The recently adopted EU Strategy for the Protection and Welfare of Animals 2012-2015 highlights that the possibility of using scientifically validated outcome-based indicators complementing perspectives requirements in EU legislation will be considered when necessary (European Commission, 2012). The factors that affect an animal's welfare include the physical environment, resources available to the animal and the management practices of the farm. Depending on its characteristics (breed, sex, age, etc.) the animal will respond to these inputs and animal's responses are assessed using animal-based measures.

Measurements considered on the Welfare Quality® assessment are described as valid, because scientific based, repeatable, since same results regardless of time and observer and, feasible due to easily observation within areas on a reasonable time. Three areas of assessment have been developed and several measurements were included on each area:

1. Animal based indicators: injuries, body condition scoring, fear responses, lameness assessment, mortalities, milk quality, production records and health records.

2. Resource based measures: feed and water, space allowance, shade and shelter, flooring and housing system.

3. Management practices: maintenance records, herd health plans, emergency plans, training and skills and record keeping.

Animal-based measures are likely to highlight the most important and urgent welfare problems, and so focus priorities for remedial action. Resource- and management-based measures are more likely to highlight the potential risk of reduced welfare in the future and help to identify the reasons underlying current animal welfare problems. Thus, both animal-based and non-animal-based measures are needed in a control or assessment protocol (EFSA, 2012).

Previous assessments of animal welfare relied mainly on resource-based parameters, i.e. measures taken regarding the environment in which the animals are kept (Bartussek, 2001; Bracke et al., 2002). However, actual research are mostly focus on animal-based measures aim to directly measure the actual welfare status of the animal and thus include indirectly the effect of resource and management factors as well, because of their effect on the animal (Whay et al., 2003; von Keyserlingk et al., 2012).

The Welfare Quality® protocol involves 53 measurements assessed by questioning, direct observation of animals, management systems or records or a combination of both. However, observational assessments may be the cheapest and the fastest way to evaluate the animal well-being on farm.

4.1.1. Animal-based measurements

The Welfare Quality® comprises records of several animal-based measurements , i.e. cow diseases through clinical observations, coughing, nasal discharge, ocular discharge, hampered respiration, diarrhea, vulvar discharge, body condition, lameness, integument alterations, animal injuries suffered as result of housing equipment during lying down, hygiene, milk somatic cell count (SCC), mortality, dystocia, downer cows, disbudding/dehorning, tail docking, agonistic behaviors and avoidance distance at the feeding rack, lying time, time to lie down and animals lying partly or completely outside the lying area. However, most studies based on animal welfare (Whay et al., 2003; Cook, 2003; Main et al., 2003; Shearer, 2005; Espejo et al., 2006; Roche et al., 2009; Kielland et al., 2009; von Keyserlingk et al., 2012) mainly use observable and quantifiable measurements of the cow's body, i.e. body condition, injuries, lameness and body hygiene. Those scores may be the basis for a reference of cow health, cow comfort and management practices (Schreiner and Ruegg, 2003; Tucker et al., 2003, 2004; Chapinal et al., 2013; Barrientos et al., 2013; Garro et al., 2014).

Body condition scoring (BCS) is a quantitative tool for determining if an animal is too thin, too fat or in ideal condition depending upon stage of lactation (Coleen and Heinrichs, 2004). Advantages of this method might be found on the independence of the physiological status, rumen fill, cow's size or breed. Further, it is easy to learn and apply (no special equipments) and difference between observers might be minimal if training and, it is also semi quantitative avoiding terms as "thin" or "fat". The scale used to measure BCS differs between systems, but low values always reflect emaciation and high values equate to obesity. As many measures are taken of the cow, it enhances the importance of the cow condition to production, reproduction, and cow health (Bewley and Schultz, 2008; Roche et al., 2009). BCS may be a valid indicator of animal welfare, but further research is required to determine the effect of BCS and BCS change on how a cow "feels" (Roche et al., 2009). Cows might be at an ideal BCS at dry off and might be fed to maintain this condition until calving. Gillund et al. (2001) confirmed the importance of BCS monitoring because ketotic cows lost significantly more body condition over a prolonged period of time than sound cows. The economic loss of one cow with subclinical ketosis is estimated to be $78 (Geishauser et al., 2001) and the average herd annual cost for an incidence rate of 41% in 100 cows was estimated on $3,198 (Duffield, 2000).

Injuries of the skin were described on several studies and score systems were developed for different zones of the skin and housing type (Busato et al., 2000; Huxley and Whay, 2006; Fulwider et al., 2007; Kielland et al., 2009). Skin alterations are consequence of various causes, housing conditions and/or spacing and calving parity (Kielland et al., 2009). Hocks injuries, on the tarsal joints, are defined as hairless patches and lesions/swellings in an area extremely exposed and sensitive to pressure when the cow is lying down on a hard and/or abrasive surface with poor hygiene. These lesions cause pain and may force the animal to stand up or lie down for longer intervals (Haley et al., 2001).

Lameness is usually evaluated through scores to determine the level of severity lame. Sprecher et al. (1997) developed a locomotion scoring system (1 to 5) relatively easy for dairy producers to implement. Scores are based upon observation of the cow standing and walking with special emphasis on the cow's back posture. Cows should be scored when they are standing and walking on a flat surface that provides adequate traction. Due to the complexity of the locomotion assessment, studies are still developing and improving the score system (Thomsen et al., 2012; Hoffman et al., 2014), as they consider more cows signs to define the severity.

Lameness causes pain (Whay et al., 1997; O'Callaghan, 2003) that results in changes in cow behavior (Galindo and Broom, 2002) and it is therefore a significant threat to the well-being of dairy cows. Lameness can be developed through different diseases of the claw infections (foot root, sole ulcera, sole abscess and laminitis), injury, and penetration of foreign objects into the foot tissue or claw overgrowth. Also, several factors may result in increased incidence of non-infectious lesions of the hoof including inadequate management practices and poor facility design such as claw trimming (Raven, 1989; Shearer et al., 2005), flooring surfaces characteristic and conditions like grooving, slope, worn or slippery, and dirtiness (Cook, 2005; Kloosterman, 2005) and time standing

(Nordlund et al., 2004; Cook et al., 2004; Shearer, 2005; Fregonesi et al., 2007; Schefers, 2008). Furthermore, nutritional factors may contribute to lameness, i.e. feeding excessive amounts of rumen fermentable carbohydrates and/or protein, lack of effective fiber, sorting, inconsistent feeding times and inadequate trace mineral status as well as abrupt transition from dry cow to lactating cow both nutrition and environment (Nocek, 1997; Nocek et al., 2000; Cook et al., 2004; Cook, 2005). Further, lameness was related to reproduction failure, decreased milk production, increased culling risk, treatment costs and increased labor requirements (Sprecher et al., 1997; Warnick et al., 2001; Hernandez et al., 2002a; Hernandez et al., 2002b; Melendez et al., 2002; Juarez et al., 2003; Morris et al., 2011). Direct effects of lameness account for 15% of culling in U.S. dairy herds (Cha et al., 2010). Based on these data, it has been estimated the indirect effects of lameness on production and reproduction could account for an additional 49% of culling in US dairy herds.

Body hygiene is an indicator of the environmental cleanliness at herd level. Contamination is transferred to the udder through the manure on the bed, contact with dirty rear legs, and splashes from the walking surfaces or tail contamination (Rousing et al., 2000; Fregonesi et al., 2007). Several methods of hygiene scoring have been documented for scoring different zones of the cows' coat but mainly focus on the rear limb, i.e. lower leg, udder and upper leg/flank (e.g. Cook, 2002; Schreiner and Ruegg, 2003; Reneau et al., 2005). Some of those systems have been used to prove that poor hygiene results in udder health problems, as manure may compromise the cow comfort increasing intramammary infections risk (Reneau et al., 2005).

Dirtiness is associated with increased risk of lameness and mastitis caused by poor slurry systems, lack of bedding materials, overstocking and poor stall dimensions (Philipot et al., 1994; Borderas et al., 2004; Fulwider et al., 2007; Schreiner and Ruegg, 2003). In those last three cases, cows may find alternatives to rest. It can be by different postures at the cubicles such as lying diagonal or perching, or locations in the barn such as lying in the alleys (Cook and Nordlund, 2004). Furthermore, hygiene at calving, sanitation and poor management practices as poor estrous detection has been related with herd breeding problems before than a nutritional cause (Chase et al., 1979).

Cleanliness of the feed bunk and water also contributes to maintain a good health. Fermentation of feed left from day prior or accumulate in corners, may induce to disease including generalized deterioration typical of protein deficiency, malnutrition, diarrhea, irritability, respiratory disease, abnormal behavior, mycotic abortions, and occasional death (Pier et al., 1980).

4.1.2. Facility-based measurements and management practices

Traditionally, the spacing of animals was influenced by environmental factors: weather, risk of predation, and the distribution of resources. However, for domesticated animals housed in intensive farming systems, social factors have a greater impact on spacing than environmental factors (Keeling and Duncan, 1991).

Hierarchies on a dairy herd used to be established by the length of the horns, however with the actual practices (dehorning), the cow size and temperament are the factors determining the hierarchies. A high correlation between social rank, body weight, and age has been described (Beilharz et al., 1966). Therefore, if new animals are not incorporated into a pen, hierarchies might be maintained over long time. Furthermore, competition and aggression were reported to increase when feeding space is reduced (Olofsson, 1999).

Cattle that are in socially stressful environments may be less productive, more susceptible to disease, and are more likely to experience reproductive difficulties (Friend and Polan, 1974; Dobson. et al., 2001). Therefore, appropriate and efficient design of stable facilities, equipment as well as inspection and handling routines are required to obtain and maintain good stockman ship in the herd (Rousing et al., 2000; Welfare Quality®, 2009). For this reason, measurements of the facilities may not be addressed by themselves because the design and conditions depends on the management practices carried by the farmer.

Dairy cows at approximately 100 percent stocking density in free-stall housing spend 3 to 5 hours per day feeding, consuming 9 to 14 meals per day. In addition, they ruminate 7 to 10 hours per day, spend approximately 30 minutes per day drinking, 2 to 3 hours per day outside the pen for milking and other management practices and require approximately 10 to 12 hours per day of lying time (Grant and Albright, 2001). Approximately 70 percent of the cow's day is spent eating and/or resting. Consequently, the cow only has, on average, 2.5 to 3.5 hours per day to spend outside the pen and away from the feed, water and stalls. Forcing the cow to spend more than this time outside the pen, she will need to give up something, typically feeding and/or resting.

For this reason, the Welfare Quality® comprises records of several resource- and management based measurements covering resting, walking, feeding, ventilation and milking. However, biosecurity might be also considered when external visits arrival or new animals are incorporated to the herd.

Resting area

Dairy cattle are highly motivated to lie down for approximately 12 hours per day (Munksgaard et al., 2005; Cook et al., 2005; Fregonesi et al., 2007; Gomez and Cook, 2010). The measured range in resting time for lactating Holstein cows of varying milk yield, days in milk (DIM), and BCS was 4.1 to 17.1 hours per day (Bewley et al., 2010). The range may reflect both cow and environmental factors.

Lying behavior takes precedence over eating and social behavior when opportunities to perform these behaviors are restricted

(Munksgaard et al., 2005). Physiological function, health and productivity are impaired when the resting requirement is not met. Cows with restricted lying time have greater serum cortisol and lower growth hormone concentrations, impaired hoof health and locomotion and sometimes lower milk yield (Calamari et al., 2009).

An additional 1.5 hours per day standing time was associated with a 45-minute reduction in feeding time (Metz, 1985). Similarly, when cows experience a stocking density of 130 percent of stalls and headlocks preferred lying in free-stalls rather than feeding post-milking and spent more time in the alley waiting to lie down rather than feeding (Batchelder, 2000). Therefore, stocking density may affect animal welfare regarding feeding, drinking and resting (Fregonesi et al., 2007; McCarthy et al., 2007; Roche et al., 2007; Macdonald et al., 2008). Previous studies have shown overcrowding did not affect milk production (Hill et al., 2007; Krawczel et al., 2008); however variation on milk quality was reported through a decrease in milk fat and an increase in SCC (Hill et al., 2007).

Furthermore, stalls dimensions have been previously discussed and different results were obtained through research due to the wide range of variation on measurements and cow's size as well as management practices (Cook, 2002; Tucker et al., 2004, 2005; Fulwider et al., 2007; Fregonesi et al., 2009). For this reason, recommendations for stall dimensions are of the cow's size and behavior (Anderson, 2008). Similarly, different bedding materials have been widely described and compared, however results also depends on management practices (Cook, 2003; Schreiner and Ruegg, 2003; Cook and Nordlund, 2004; Tucker et al., 2004, 2005; Fulwider et al., 2007; Fregonesi et al., 2009; Barrientos et. al., 2013; Chapinal et al., 2013). Therefore, those studies suggest well managed stalls may provide adequate comfort independent from the high variation on the design or quality of bedding materials and, the objectives may focus on avoid dirtiness and possible infections as well as pain or injuries.

Walking area

Cows may walk trough wide corridors with no abrasive or smooth surfaces in order to allow heat expression, reduce competences like in overstocking (previously mentioned) and, avoid injuries and stressful reactions like with blocked alleys. To avoid high steps on the crossovers might be desirable as it helps on cows flow through the barn, decrease the risk of slippery or lesion and improve cleanliness when automatic scrapers are used (Magnusson et al., 2008). It is similarly to the rear curb height of the stalls, smaller curbs may be more attractive to enter in the stall (Cook, 2002; Anderson, 2007).

Further, management practices may not disturb cows nor impede their natural behavior, e.g. cleaning practices that could worn surfaces. In addition, rubber flooring has been described to improve the comfort of the cow as claw health and lameness (Vanegas et al., 2006) and therefore cows are more willing to move on and spend more time standing in front of the feed bunk when provided with softer flooring (Fregonesi et al., 2004; Telezhenko et al., 2007).

Also, footbath, when present, it is commonly placed on the walking area of the milking parlor or alleys. The main objective of the footbath is the control of early (subclinical) and chronic lesions, avoiding the progression of these lesions into acute (ulcerative) stages. Footbaths are not a substitute for individual treatment of acute lesions (Gomez, 2013).

A desirable cow comfort element to place on the alleys may be brushes. As environmental enrichment it satisfy grooming behavior needs, entertaining, diesstressing and improve cow cleanliness (Wilson et al., 2002; DeVries et al., 2007).

Feeding area

Management practices at feed bunk, i.e. limited bunk space, limited feed access time, restricted feeding versus feeding for 5% to 10%

refusal, inconsistent feeding schedule, infrequent push up of the ration and bunk competition (Milton, 1998), may increase the incidence of ruminal acidosis and laminitis because it promote cows eating fewer and larger meals more quickly. Furthermore, facilities design may also affect feeding behavior such as feeding the ration in a drive-by bunk 10 cm above the cow alley rate may decrease salivary flow and increase sorting which may develop acidosis (Albright, 1993).

The combination of limited bunk space and feed access time is worse than either situation alone. When overcrowding of free stalls coincides with limited bunk space, as is often the case, the potential for laminitis is greater because cows may spend more time standing on concrete rather than lying in stalls (Colam-Ainsworth et al., 1989). Further, overcrowding at headlocks negatively affects pregnancy rates (Wiltbank et al., 2007).

Estimates of water intake for cows in loose housing are 11 to 19 liters per minute from troughs (McFarland, 1998). Cows only spend about 12 to 15 minutes per day drinking water. The highest water intake periods are immediately following milking and during feed consumption. Therefore, provide water after milking and distribute it along the pen with availability for all cows, might be determinant for milk production. There are several factors that influence the animal's water intake and the most important ones are feed consumption, dry matter (DM) content in the diet, dry matter intake (DMI), production status (body weight) and ambient temperature (Murphy et al., 1983). Furthermore, dairy cows prefer and drink more from larger and deeper troughs (Pinheiro Machado Filho et al., 2004) as well as between 10 and 20°C (Andersson, 1984), temperatures less than 10°C, the cows yield 0.8 kg less milk per day (Himmel, 1964).

Therefore, the design and maintenance of drinkers will affect the quality of the water. The water in the drinkers may become polluted with faeces, urine, feed remnants, detritus, algae and other organisms that will reduce water quality. Troughs should be designed so they can be easily emptied and cleaned on a regular basis.

Common signs of poor quality and quantity of water intake in lactating dairy cows include depressed immune function (elevated SCC), increased reproductive failure, i.e. conception failure and early embryonic death/abortions, increased off-feed events and erratic eating patterns (Murphy et al., 1983; Adams and Sharpe, 1995).

For all those reasons, facilities design are involved in the health of the cows and should be constructed to minimize the time cows are away from feed and water (Smith et. al, 2002). However, feeding management practices, e.g. method of feeding (restrictive or ad libitum), homogeneity of a ration (mixing time), number of deliveries, consistency on the distribution of the ration on the feed bunk (feeder skills and mixer characteristics), may be a key factor for providing the cow with the formulated requirements.

Feeding management practices

Feed is the most expensive cost on a dairy representing 61% of the total production cost (CDFA, 2013). When ration fed differs from the formulated one, cows will not achieve their maximum production potential and some nutrients (i.e. nitrogen) will be wasted in manure rather than converted to milk.

There are five types of rations on a farm where variation in nutrient content of the ration will increase and be affected by feed management through each stage of creating the final ration (Kertz, 1998). The formulated diet is the diet prepared by the nutritionist to meet the cow or pen requirements, the working diet is the modified diet because the ingredients used in the ration preparation may not have the same nutrient composition that from what was used in ration formulation, the prepared diet is the diet as modified by the feeder because of weighing errors, or inadequate mixing, the consumed diet is the diet modified by the cow sorting behavior and, digested diet is the diet modified by digestion, for example lack of processing of corn silage may result in corn grains passing through without being digested.

Total mixed rations (TMRs) are formulated to contain a combination of feedstuffs that provide the right balance of nutrients in every bite consumed therefore, poor management practices on the preparation and distribution of a ration (uniformity mixing and delivery) can lead in behavior changes, as sorting activity and, consequently negatively impact animal performance and health through metabolic issues, such as sub-acute ruminal acidosis (Stone, 2004; Devries et al., 2008).

Silva-del-Rio and Castillo (2012) found a difference of -2 to 4 percentage units of crude protein (CP) between the formulated and the analyzed CP in seven dairies in Merced County. Rossow and Aly (2013) showed lignin, fat, and ash as best indices of feed management to include effects of variability in nutrients on variability in milk yield, milk fat, and milk protein percentages in ration formulation models.

Monitoring cow rations may ensure that specific dietary ingredients are kept at safe levels (Hansen, 2007). Oelberg and Stone (2014) had reported variation on TMR composition and distribution along the feedbunk through a TMR Audit system developed by Diamond V. For this reason, precision and accuracy, as well as adequate mixing time for the load weight during ingredient loading is needed to improve the efficiency of production, decrease feed cost and decrease the nutrients with an environmental impact (James y Cox, 2008).

The ration formulated may vary on farm frequently because several changes as the number of ingredients, ingredient type, inclusion rate or ingredient DM. Several of those factors are related with the specific physical and chemical characteristics of the ingredients such as DM content, particle length, shape and density however they could not be adjusted or improved on farm. This variation is more dependent on market prices or environmental conditions which cannot be controlled from the inside farm. However, the ration preparation is a process which mainly depends on farm management practices because it involves feeder job and equipment availability such as feed wagon or loader weigh cells calibration and maintenance. In this regard, variables as deviation from the target weight, mixing times or over/under filling can be evaluated, controlled, trained and improved on farm (Weiss et al., 2013).

Several of the commercially available computerized feed management software systems (EZfeed, www.dhiprovo.com; Feed Supervisor, www.feedsupervisor.com; Feed Watch, www.vas.com; TMR Tracker, www.digi-star.com) can keep records of the ration preparation as actual weights and times (Bucholtz, 2002). The systems can improve a feeder's accuracy and efficiency both through making their responsibilities easier to accomplish, because feeder can be monitored. Dry matters and rations can be updated by the feeder in the bunk or by someone else at the dairy office. The change in ingredient dry matter is then updated automatically in all rations. The systems typically come with a highly visible scale display to place in the feed wagon and make the feeder job easier. The systems can also record the accuracy with which each ingredient was added to a load, the time between ingredients, the time needed to prepare the entire load, and the total mixing time. Provided that dry matters and cow numbers are correct, and that refusals at the end of the day are measured, an accurate assessment of DMI can be obtained. Additionally, the software systems help in inventory management and to reduce shrink.

However, not all actions can be traced by the software and observational monitoring programs are needed on farm. Incorrect and inconsistent TMR mixes can arise from mismanagement of the mixing process. Therefore, sampling the bunk mix and performing a nutrient and particle size analysis may help to avoid those issues.

Oelberg and Stone (2014) had observed through an audit process nine main factors in the TMR mixing process that can each create variation in the TMR, i.e. worn parts of the mixer such as augers, kicker plates, and knives, mixing time after the last added ingredient, unlevel mixers, loading position on the mixer box, load size commonly too small for the reduced group of close-up cows, hay quality and processing, loading sequence of ingredients into the mixer, liquid distribution and vertical mixer auger speed. One of the main goals to reduce variation comes from silages (corn silage, haylage, hay), which are the major ingredients included in the TMR. Management practices with silages may minimize dry matter (DM), nutrient variation and silage spoilage. Facing silage from bunkers and piles and premixing the defaced silage with a loader bucket or mixer wagon makes the silage more consistent in moisture and nutrients and it is a key to minimizing variation between formulated and prepared diets (Oelberg and Stone, 2014).

Feeder job should be focus on avoid variation in the loading process. Errors in accuracy and precision can be attributed to variability in feedstuffs and/or operator error. However, settings of tolerance level (TL), which allow a certain deviation under the target, may decrease the precision and accuracy because it depends on the ratio kg of TL/kg of target weight.

Further, software does not recognize ingredients type. Therefore, some cheating can be performed such as the replacement of an ingredient targeted for another one or jumping to next ingredient without loading the next one which can be done directly with the computer, pushing the front-end-loader in the mixer wall, or replacing the next ingredient for the leftovers of the previous one. Those actions can be only detected on the system through a short period of time between ingredients.

The total mixing time should allow the homogeneity of the final ration. Adequate mixing time is a function of mixer characteristics, i.e. horizontal or vertical auger, capacity, interior design, number of augers, kickers and knives and horse power, as well as recipe characteristic, i.e. ingredient type such as wet ingredients might steak to others or long particle forages need more time to allow homogeneity on the ration, order of ingredients into the recipe which may be by increasingly density from first to last, number of ingredients, and load weight.

Most manufactures recommended between 2 to 5 minutes after last ingredient load, however, there is no researcher basis to this statement. To monitor the homogeneity of the TMR the Penn State-Nasco shaker box could be use on farm (Oelberg and Stone, 2014). It is recommended that the TMR contain 8% to 10% (as-fed basis) coarse particles or particles on the top screen of the shaker box. In a survey of 49 commercial dairies, Possin et al. (1995) reported coarse particle fractions of 7.6% and 4.8% (as-fed basis) for TMR mixed for < 15 min or > 15 min, respectively. Furthermore, they reported TMR coarse particle fractions of 7.9% and 3.5% (as-fed basis) in low-and high-incidence herds for laminitis, respectively.

Day to day variation on the physical properties and nutrient composition of the ration fed is unavoidable; therefore, operating time of mixing equipment should be sufficient to prevent sorting of long particles because it can negatively impact animal performance and health i.e. displaced abomasums and fluctuations in average daily milk yield (Stone, 2004; DeVries et al., 2008; Sova et al., 2014; Rossow and Aly, 2014).

Variation in the amount loaded also affects the nutritional value of the ration. Compensations on weight could be made adding another ingredient instead of the targeted one, however nutritional values (NDF, ADF, CP, …) vary within and across ingredient type.

Monitoring ration delivery through Software may help achieve objectives measured as kg/cow but not necessary on nutritional components to meet the formulated ration.

Ventilation area

Cows must adapt to each environment thermal characteristic of a geographical area and maintain homeothermy (constant temperature) using the body thermoregulatory mechanisms.

Heat stress may occur when the body cannot remove heat actively in situations of high temperatures. This affects increasing energy expenditure for maintenance, reducing DMI, increasing losses of water and minerals, altering the acid-base balance, changing the blood flow to organs and changes in biochemical and hormonal modifications (West, 2003; Arias e col., 2008). Heat stressed cows eat less and this nutrition deficit results in prolonged postpartum anestrus and impaired embryonic development. In addition, this inadequate nutrient intake reduces BCS and causes cessation of estrus cycles. Symptoms induced by heat stress gradually pile on, and the ultimate result is that the success of gestation is severely compromised even after the weather has moderated (Jordan, 2003; West, 2004).

As any chronic forms of stress, cows can experience metabolic changes which can result in stress-related illnesses and depressed immunity. This can lead to a lowering of the cow's defense against mastitis-causing pathogens. And it could be enhanced by the humidity levels. Therefore, ventilation and humidity might constitute two main factors on the design of the barn, as well as barn orientation (Buxadé, 1998). Cows are at risk of heat stress when temperature humidity index of 72, which corresponds to 22°C at 100% humidity, 25°C at 50% humidity, or 28°C at 20% humidity (Ravagnolo et al., 2000; Jordan, 2003).

Signs of poor ventilation include condensation on the ceiling and walls, steamy conditions and ammonia odor. Improving the natural ventilation in old free stall barns can be accomplished by opening the ridge caps and eaves.

One of the best practices to reduce heat stress is to provide adequate fresh, cool, clean drinking water. Other methods of cooling include shade, commercial coolers, tunnel ventilation, shower/fanning stations, fans, cooling ponds and center pivots. Shade alone will reduce a cow's respiration rate by 30%, and adding sprinklers will reduce the respiration rate by 67% (Kendall et al., 2007). Sprinkling or soaking with water, along with supplemental airflow has been shown to reduce respiration rates by 18-41%, improve DMI by 7-9% and increase milk yield by 9-16% (Bucklin, 1991; West, 2003). Once the temperature goes above 25ºC cows will reduce feed intake. Providing fresh air in the feeding area during hot weather, above 20ºC, will help to decrease heat stress, gives the cow the opportunity to breathe easily, keeps cows eating and also helps to keep flies away from the feeding area (Flamenbaum and Galon, 2010).

Further, cleanliness and ventilation might be linked to control cow disease. Dirtiness on the coat can increase the risk of disease due to microbial growth. Issues may start with skin irritation and evolution will depend on cow's body zone and the exposure to manure. Well-ventilated facilities may help to avoid microorganism proliferation.

Milking area

Quality milk may start with quality management; therefore hygienic conditions as well as adjustments of the milking machines, both are the most important practices in this area of the barn to ensure animal well-being. Further, milking dirty cows will also affect milk quality but it will reduce milking speed in the parlour, i.e. 20% fewer cows per hour affected. The efficiency of the milking parlor is measured by the number of cows per hour which will depend on the entrance speed and that is of the parlor lenght, number of cows by place, number of operators by cow and liters milked by operator which varied with the operator walking distance, being higher in automated side opening parlors and lowest in rotary parlors (Smith et al., 1998).

To keep constant milk production, schedules and routines during milking should be considered as well (Smith et al., 1998; Armstrong et al., 2001).

Management practices and facilities design such as time standing in the holding pen, space available per cow in the holding pen, treatment of the cows when pushing into the holding pen and/or milking parlour may develop stress and therefore affect oxytocine release compromising the pre-milking.

Negative animals' handling experiences results with higher level of fear of man and negative effects on production, reproduction, welfare and increasing the risk of injuries for both, animal and human (Seabrook, 1972; Hemsworth and Coleman 2000; Waiblinger et al., 2002).

5. Benchmarking process

Jackson and Lund (2000) had provided a definition of benchmarking, as a framework for continuous improvement. They have it defined as, first and foremost, to be a learning process structured so as to enable those engaged in the process to compare their performance in order to identify their comparative strengths and weaknesses as a basis for self improvement and/or self –regulation.

A benchmark is a point of reference to make comparisons, usually implying that it is a good basic standard to achieve. It implies to identify what are the most useful indicators, rather than what is easiest to measure. A benchmark can highlight a problem area, potential for improvement, incentive to change and assist in setting targets. For this reason, the Animal Welfare Science Centre has reported effective monitoring scheme based on good scientific basis satisfy public, industry and political views of animal welfare and active involvement from and feedback to producers.

Benchmarking is being increasingly used to track changes within the same farm over time, i.e. monitoring, or more often, to compare farms, i.e. learn best management practices and benefit from others. When the same animal-based measure is compared between farms with similar housing systems and management practices, it facilitates the identification of those farms that are outside the normal range of variation and this information also becomes relevant to the assessment of dairy cow welfare (EFSA, 2012).

The reasons to benchmark the animal welfare are based on assess industry performance, demonstrate and instill trust in consumers that welfare standards are being met to protect international markets, to assist and demonstrate continuous improvement.

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OBJECTIVES

The general objective of this thesis is to identify ***opportunities for improve*** several measures of the cow, facilities and management practices involved on the well-being and comfort of the cow by benefitting from ***benchmarking.***

The specific objectives is to ***describe variation*** on several parameters related with the well-being and comfort of the cow in 73 Galician dairies, and parameters related with feeding management practices in 26 California dairies:

Cow well-being

1) Animal-based parameters in Galician dairies: body condition, hock injuries, lameness and dirtiness of the cow's coat.

Cow comfort

2) Facility-based parameters and management practices in Galician dairies addressed through five areas of the barn: resting, walking, feeding, ventilation and milking area.

Feeding management practices

3) Parameters related with the deviation from target weight during ration preparation in Californian dairies.

4) Parameters related with the time during ration preparation and delivery of the ration in Californian dairies.

1

Benchmarking welfare indicators in 73 free-stall dairy farms in Northwestern Spain

Adapted from:

Y Trillo, LA Quintela, M Barrio, JJ Becerra, M Vigo, AI Peña, J Caínzos, PG Herradón. Benchmarking welfare indicators in 73 free-stall dairy farms in Northwestern Spain.

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ABSTRACT

The objective of this paper was to describe the results of an on-farm benchmarking study focused on animal-based measures of welfare (including BCS, hock injuries, locomotion, and cleanliness), facility-based (including resting, walking, feeding, ventilation, and milking area) and management practices (including bedding maintenance, stocking density, frequency of cleaning, footbath protocols, settings of mechanical systems, and cow behaviour the milking time) measures of cow comfort. Feedback of those measurements was given to producers to better address management goals in 73 free-stall dairy farms in Northwestern Spain (Lugo, Galicia). A benchmarking process classified and rated farms by the number of animal-based welfare indicators felling into three categories (A, B, C), corresponding to low (25% of the top farms or percentile 25th), medium (50% of the farms or percentile 50th) and high prevalence (25% of the bottom farms or 75th percentile) for each indicator across farms respectively. Unsuitable BCS comprised [median (range)] 51.7% (13.3 to 89.5%) of the cows by herd. Hock injuries had a median prevalence [median (range)] of 40.0% (7.0 to 100%) while clinical lameness was 9.0% (0 to 60.0%) however, highlighted the median prevalence of locomotion score 2 comprising 28.0% (7.7 - 56.7%). Dirtiness of the cows coat had a high prevalence ranging from 37.5 to 100% with a median of 73.0%. Most of the farms (98.6%) did not perform consistently well or poorly across those indicators suggesting opportunities to improve by benefiting from benchmarking. Further, considerable variation was found on the facilities design and management practices. Critical points for the top and bottom farms, as well as from an overall perspective, were located at stocking density of the stall and headlocks (incidence of 31.5 and 26.0% respectively) and the small front lunge space (<90 cm; 90.4%). Poor natural ventilation was described by the observations of cobwebs or humidity on the roof and ammonia odder in 32.8% of the farms and 85.0% of the farms with barns totally closed or partially open for an open side which represents <50% of the wall height. The poor design of the milking parlour area suggested cow management issues [paths of the milking area were non-linear (two or more turns >90°) in 49.3% of cases, some farms (45.2%)

had a milking area design that did not allow cows to see the milking parlour before entering it and a total of 38 farms (52.0%) reported that >15% of the cows had to be forcefully taken into the milking parlour on a daily basis]. All those issues described of the facilities and management practices suggested to deprecate cow comfort and therefore indicators of the cow welfare. In conclusion, many factors may be involved in the cow welfare and it varies within and across facilities and management practices by farm.

Keywords: animal welfare, on-farm assessment, animal indicators, facilities, management practices.

INTRODUCTION

Welfare assessment systems, for use in farms, may differ according to both the definition of animal welfare, and the purpose of the welfare assessment (Johnsen et al., 2001). Thus choice of welfare indicators and methods of measurement reflects the basic considerations of how animal welfare is understood.

Although many different assessment systems have been developed in Europe (Johnsen et al., 2001), the recently developed Welfare Quality® (2009) protocol considers more animal-based parameters revealing the "direct" outcomes of the interaction between the animal and its environment. Animal welfare measurements may form the basis for the identification of causes of well-being problems. However, resource- and management-based parameters are also needed to highlight the potential risk of reduced welfare in the future and help to identify the reasons underlying current animal welfare problems (EFSA, 2012).

Further, a relevant welfare assessment system should describe the welfare of the animals in the herd and allow the farmer to continuously monitor welfare and respond to any challenges over time (von Borell et al., 2001).

Benchmarking is increasingly used to track changes within the same farm over time or, more often, to compare farms. When the same animal-based measure is compared between farms with similar housing systems and management practices, it facilitates the identification of those farms that are outside the normal range of variation and this information also becomes relevant to the assessment of farm cow welfare (Von Keyserlingk et al., 2012; EFSA, 2012). Additionally, looking for opportunities to improve from the beginning of the overall production process (the farm) has the potential to affect the final results of the food chain (the table). It is translated on quality products, as beef palatability – low stress (avoid pale, soft and exudative meat) (Ferguson et al., 2001). Therefore, using the animal welfare assessment on farm as a tool to describe potential hazards and to identify Critical Control Points (CCP) may help farmers in controlling and monitoring the production process (Grandin, 2000). The critical limits for each identified CCP must involve a measurable parameter (von Borell et al., 2001).

Body condition scoring (BCS) is a quantitative tool for determining if an animal is too thin, too fat or in ideal condition depending upon stage of lactation (Coleen and Heinrichs, 2004; Bewley and Schutz, 2008). The importance of the cow condition to production, reproduction, and health is enhanced by the number of measurements considered over the cow. BCS may be a valid indicator of animal welfare, but further research is required to determine the effect of BCS and BCS change on how a cow "feels" (Roche et al., 2009). Gillund et al. (2001) confirmed the importance of BCS monitoring because ketotic cows lost significantly more body condition over a prolonged period of time than sound cows.

Hocks injuries, on the tarsal joints, are defined as hairless patches and lesions/swellings in an area extremely exposed and sensitive to pressure when the cow is lying down on a hard and/or abrasive surface with poor hygiene (Zurbrigg et al., 2005; Huxley and Whay, 2006; Kielland et al., 2009). These lesions are painful and may force the animal to stand up or lie down for longer intervals (Haley et al., 2001).

Lameness is often described as one of the most important well-being problems and severe problems in farm production for reasons that include pain, changes in cow behavior and adverse effects on milk yield and reproduction (Galindo and Broom, 2002; Hernandez et al., 2005). The locomotion score of farm cattle evaluates certain walking behaviours and postures that are thought to be indicative of lameness (Sprecher et al., 1997; Flower and Weary, 2006; Thomsen et al., 2012; Hoffman et al., 2014). Use of locomotion score may help to identify cows at early stages of lameness and therefore it results in faster recovery and reduced treatment costs. Research to date has shown that facility design and management can affect lameness which in turn affects cow welfare and longevity (Whay et al., 2003; Bicalho et al., 2007). Furthermore, research indicates that producers tend to underestimate the prevalence of lameness in their herds (Wells et al., 1993). Despite of being a subjective assessment, monitoring locomotion scores and lameness prevalence over time might be a good tool to evaluate the functionality of the barn design.

Body hygiene is an indicator of the environmental cleanliness at herd level. Several methods of hygiene scoring have been documented for scoring different zones of the cows' coat but mainly focus on the rear limb, i.e. lower leg, udder and upper leg/flank (Schreiner and Ruegg, 2003; Reneau et al., 2005). Some of those systems have been used to prove that poor hygiene results in udder health problems, as manure may compromise the cow comfort increasing intramammary infections risk (Reneau et al., 2005).

The objectives of this paper were to describe the prevalence of unsuitable BCS, clinical lameness, hock injuries, and dirtiness of the cow's coat as measures of cow well-being among producing cows on free-stall farms. Furthermore, a description of the variation in facility design and management practices of facilities and herd thought to affect cow comfort and animal-based measures was provided in 73 free-stall farms in Northwestern Spain (Lugo, Galicia). Farmers were provided with feedback through an anonymous report which allows opportunities to improve by rating their herd through the benchmarking process of the 73 farms.

MATERIALS AND METHODS

Farms selection and description

A convenience sample of seventy-three free-stall Holstein dairies were selected to participate in the study. Enrolled dairies were recruited with the assistance of dairy veterinarian practitioners. One researcher (Y.T.) accompanied the farm veterinarian during their scheduled pregnancy check to perform all farm assessments in a single visit. Prior to the assessment, dairy producers were informed of the nature of the study and offered an aggregate data summary after study completion. Those agreeing to participate were visited between November 2011 and March 2012. Dairy farms were located in Lugo province (Galicia – Spain). Herd size ranged from 20 to 244 cows however, the median across farms was 43 cows. Most farms milked twice a day (97.3%) and only two farms (2.7%) milked three times a day. All farms were family owned and the age of the facilities (since the last restoration or as a new building) ranged between 5 and 20 years old, as reported by producers. During the assessment humidity levels ranged from 80 to 100% and temperatures from 0 to 14°C.

Data collection

The assessment for each farm was composed of three sections: 1) animal-based parameters, 2) facility-based parameters, and 3) dairy producer survey.

Measurements were collected only once on every farm around the time of the first milking (7 to 9 am) by the same assessor. Data records of herd milk production and reproductive performance were provided by reproduction veterinarians (software records of one year prior to the visit).

Animal-based parameters

In order to avoid biased results by the housing conditions of dry cows kept on pasture year round (50.7% of the farms) and inside the barn (e.g.

assessing locomotion on grass vs concrete floors), only lactating cows (n=3,426) were included on the study.

All and each lactating cow by farm was released from the headlock and scored by direct observation (direct indicators) from an average distance of 3 meters for locomotion and as close as necessary (60 to 120 cm) for BCS, hock injuries and hygiene status.

Body condition score: in each farm cows were evaluated on a 1 to 5 scale with 0.25 point increment (Edmonson, 1989). BCS within each herd was classified as suitable, high (overweight) or low (underweight) based on DIM. Coleen and Heinrichs (2004) spreadsheet were used to group cows within herd on the three levels which thresholds ranged between 3.5 to 2.5 of BCS from 0 to 30 DIM, 3.0 to 2.25 of BCS from 30 to 100 DIM, 2.25 to 3.0 of BCS from 100 to 180 DIM and 3.0 to 3.5 of BCS from 180 to 300 DIM respectively. Percentage of cows with unsuitable BCS across herds was considered for the overall benchmarking process.

Hock injuries: tarsal joints of each cow within the herd were evaluated. None hock scoring system was considered due to the time that cows would be locked (producer's consent). Only the prevalence of cows with any scratch, swelling, abrasion or trauma in one or both limbs either inside or outside leg was reported and included in the overall benchmarking process.

Locomotion score: cows were scored between 1 (sound) and 5 (severely lame) according to guidelines by Sprecher et al. (1997) assessment. For descriptive analysis, lameness was categorized as clinical lameness (prevalence of cows scored ≥3) and severe lameness (prevalence of cows scored ≥4). Only clinical lameness was considered for the overall benchmarking process across herds.

Hygiene score: lower leg (rear only), udder and upper leg/flank were scored on a 1 (free of dirt) to 4 (covered with caked on dirt) scale according to guidelines by Schreiner and Ruegg (2003) assessment. Hygiene score >2 was related to dirty cows within a herd. For the overall benchmarking process, dirtiness was involved in one parameter which considered the average prevalence of the three zones of the cow's coat with hygiene score >2 across herds.

Data records of *productive and reproductive performance* (indirect indicators) were described through several parameters across herds. Average total herd milk production was projected 305-d mature-equivalent (305ME, Kg), Milk Bulk Tank Somatic Cells Count (BTSCC) of the sampled month (cells/mL) and yearly average of DIM were included in the analysis. Ten farms had no DHI data registers, thus only 63 farms were included for production data. Six reproductive parameters were considered as the most relevant: days of calving to first service interval (CFSI), percentage of conception at first service (FSC %), days of calving to conception interval (CCI), percentage of heat detections (HD %), average of calving number (CN) and percentage of average conception (C %). Culled cows were not considered in the description for being an unreliable measure, dependent on producers data records.

Facility-based parameters

Measurements were taken in five different areas of the barn (resting, walking, feeding, ventilation and milking) either by observation or measuring (tape/laser). Parameters and method of data collection assessed in each area are described in Table 1.

Table 1. Description of facility-based parameters collected by direct observation or measured in five areas of the free-stalls in 73 dairy farms in Northwestern Spain.

Area	Parameters	Procedure (levels)
Resting	Stall stocking density	Number of cows/number of stalls*100 (continuous).
	Stall location	Against a side wall or head to head platform
	Stall dimensions	Described in Figure 1
	Brisket locator presence	Either concrete, board, tube or bedding material (yes/no)
	Slope of the platform	Slope towards the rear (yes/no)
	Dividers design	Italian, Michigan, "U" loop and wide-span type
	Bedding materials type	No materials, rubber mats, mattresses, straw/sawdust, sand
	Dryness of bedding materials	"knee test"- dry after 3 seconds kneeling on the bedding material (yes/no)
Walking	Surfaces characteristics	Concrete: Slatted/grooved/flat, slippery/rough - by the graze of the boots
	Dirty alleys	Manure evenly covered the floor at a depth of at least 2 cm (yes/no)
	Rubber on the floor	Feeding alley or milking parlor floor with rubber on the floor (yes/no)
	Alleys width	From the external side of the stall curb to another or to the wall - back alley, feeding alley and crossovers (continuous)
	Blocked alleys	Mobile fences and/or chains obstructing linear circulation (yes/no)
Feeding	Feed bunk characteristics	Materials and conditions (smooth/worn surface - by the graze of the boots)
	Feed bunk height	Difference between cow platform to feeding platform height (continuous)
	Feed bunk space/cow	Headlock's width (continuous)
	Feed bunk stocking density	Number of cows/number of headlocks*100 (continuous)
	Lighting on the feed bunk	Visual perception, feed bunk lighter than the rest of the barn (yes/no)
	Troughs characteristics	Materials (metal/concrete) and types (dumping/fixed)
	Linear watering space/cow	Total length from all accessible sides/number of cows (continuous)
	Covered feed bunk	Roof covering the feed bunk (yes/no)
Ventilation	Signs of poor ventilation	Humidity and/or cobwebs (>1m² roof) and ammonia smelling (yes/no)
	Roof insulation	Insulation materials (yes/no)
	Open sides and height	Gap on sidewall barn (yes/no) and measurement of the gap (continuous)
	Open ridge	Gap in the top of the roof (yes/no)
	Roof height	Measure from the floor to the middle of the roof (continuous)
Milking	Parlor design	Herringbone, parallel, tandem, rotary, swing
	Holding and release area	Presence (yes/no)
	Holding area space/cow	Width*width/number of cows fitting in the parlor (continuous)
	Floor characteristics in holding area	Slope (%): difference in height/length*100 (continuous)
		Grooved floor - parallel lines (yes/no)
	Milking area design	Entrance door width, direct to the parlor or by holding area (continuous)
		Straight design: cows can see the parlor from the holding area (yes/no)
		≥2 turns: turns ≥ 90° in the entrance and exit paths to the parlor (yes/no)

Three stalls located every five in a row by farm were sampled to calculate an average of the stall dimensions (bed width, bed length, brisket locator height, total stall length, low lateral bar, high lateral bar, neck rail height, neck rail position, front lunge space, and rear curb height) as shown in Figure 1. Bed length of the stalls without brisket locator was measured to the first barrier blocking the front. Space available in the stall was calculated by the formula: with*length (cm)/1000, to express it in m^2. Overstocking at stalls and headlocks was defined by the ratio (number of animals/number of spots*100) >100%. All farms had stalls on the resting area and headlocks on the feeding area.

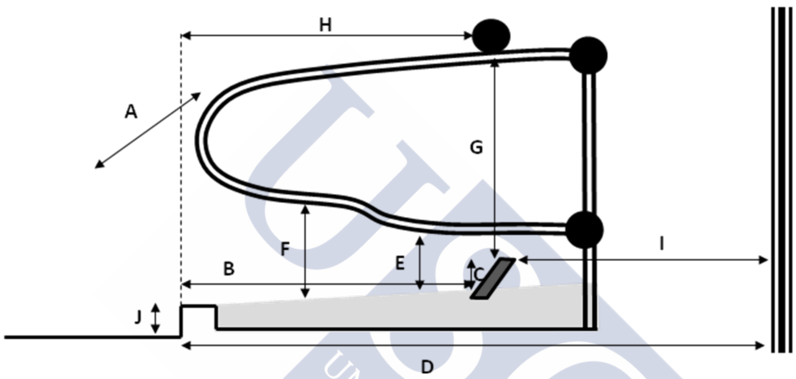

Figure 1. Stall dimensions measured in 73 dairies in Northwestern Spain. Bed width (A) from the middle of one side divider to another; bed length (B) from the external side of the rear curb to the internal side of the brisket locator if available (when brisket locator not present, measure was to the first barrier); brisket locator height (C) vertical line from the bottom to the top; total stall length (D) from the external side of the curb to the middle front with the other stall or to the wall; low lateral bar (E) and high lateral bar (F), from the bed to the bottom of the bar; neck rail height (G) from the bedding surface to the bottom of the rail; neck rail position (H) distance from the vertical plane above the rear curb to the internal side of the rail; front lunge space (I) distance from the middle of the brisket locator to the half way with another stall or to the wall; rear curb height (J) from the bottom of the alley to the top.

Management practices of facilities and herd

Producers were interviewed regarding the frequency and procedure of outdoor access for lactating cows, bed maintenance, cleaning practices (floor, feed bunk and water troughs), water analysis, environmental enrichment (brushes), footbath protocol, yearly hoof trimming/inspection routine, mechanical ventilation (when available) and settings, milking practices and, behaviour in the milking parlour (>15% of the cows per herd): refuse to enter parlour voluntarily (producer reported pushing cows in every milking) and/or show other signs of stress (defecation, urination, kicking, fast tail movements). To count for the number of cows with any of those behaviours in the first milking of the visit day, producers were warned (by phone) in advance. The frequency of practices was reported in number of times per day, or year, and "when producers considered it necessary" (not routinely).

Benchmarking animal-based parameters

The overall benchmarking process included four direct animal-based parameters based on the percentage of cows by herd as welfare indicators: unsuitable BCS, hock injuries, clinical lameness and dirtiness of the cow's coat. First, each indicator was sorted from low to high prevalence across farms and three groups were classified by percentiles 25th (Q_1), 50th (Q_2) and 75th (Q_3). Thus each group of farms felling within each percentile were assigned categories A, B and C respectively. Therefore, the 25% of the farms within A category had the lowest prevalence for each indicator while C category included the highest prevalence across the assessed farms. Second, each farm was sorted by the number of indicators in categories A and C. After data exploring, top farms were considered when at least two indicators fell in category A but cero in category C and, bottom farms were defined by two indicators felling at least in category C and any indicator in category A. Furthermore, a description of the facilities design characteristics and specific management practices carry out on the top and bottom farms (classified by the animal-based welfare indicators previously) was provided.

Productive and reproductive parameters were ranked by the same percentiles used for the animal-based direct indicators, but those parameters were not included on the overall benchmarking process for being indirect measures of the cow well-being.

Data analysis

Data analysis undertaken in this study was only for descriptive purposes. Results are presented as percentages, ranges and/or percentiles 25th (Q_1) 50th (Q_2 or median) and 75th (Q_3).

Descriptive statistics were conducted with the PROC MEANS and PROC UNIVARIATE procedure of SAS 9.4 (SAS Institute Inc., Cary, NC). Percentiles were computed using the PCTLDEF = 4 option in the output statement of the PROC UNIVARIATE.

Furthermore, a Pearson correlation was established between over- and underweight cows, severe and clinical lameness and, among hygiene scores of the three zones of cow's coat. Finally, a Pearson correlation was also established among the four animal-based welfare indicators used in the overall benchmarking process and among reproductive parameters.

RESULTS

Animal-based parameters

Animal-based parameters, including direct (BCS, hock injuries, clinical lameness and dirtiness of the cow's coat) and indirect (productive and reproductive performance) indicators of cows well-being and comfort is summarized for the 25, 50 and 75% of the times in Table 2.

Table 2. Percentiles 25th, 50th and 75th of the animal-based direct indicators including unsuitable body condition score (BCS) for stage of lactation [days in milk (DIM)], hock injuries, clinical lameness (locomotion score 3, 4, 5) and dirtiness of the cow's coat (average of the percentage of cows with hygiene score>2 in the three zones of the cow's coat), and indirect indicators including productive and reproductive parameters assessed in 73 dairy farms in Northwestern Spain.

Description of parameters based of the animal	Percentiles rank		
	25th	**50th**	**75th**
Animal-based welfare indicators (n=73)			
Body Condition Score unsuitable for cows DIM (%)	42	52	61
Hock injuries (%)	25	40	56
Clinical lameness - locomotion score 3, 4, 5 (%)	5	9	16
Dirtiness - average of three zones of cow's coat with hygiene score >2 (%)	63	73	83
Productive parameters (n=63)			
Milk Bulk Tank Somatic Cell Count monthly (cells/mL)	154	186	254
Days in Milk	157	184	202
Herd milk production (305ME, kg)	8434	9111	9734
Reproductive parameters (n=73)			
Calving to first service interval (days)	70	75	81
Conception at first service (%)	23	30	35
Calving to conception interval (days)	132	152	171
Heat detections (%)	49	53	60
Average of calving number (%)	2.3	2.4	2.8
Average conception (days)	30	34	37

Across dairies, cows within a herd had suitable BCS [median (range)] 48.3% (10.5 to 86.7%), above desirable BCS 27.8% (0 to 78.8%) or below desirable 18.4% (0 to 89.5%), which is represented in Figure 2.

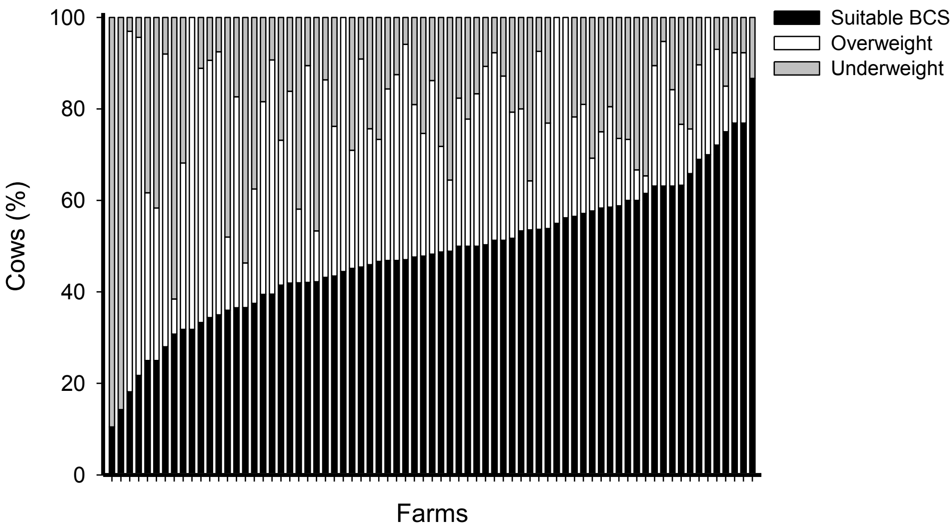

Figure 2. Distribution of the body condition score (BCS) by cows by herd as the percentage of cows with suitable, high or low BCS regarding their stage of lactation or DIM in 73 dairy farms in Northwestern Spain.

Only four (5.5%) and nine (12.3%) herds had <5% of overweight and underweight cows respectively at the assessment time. All herds had <3% of lactating cows with a BCS <2, however most herds (55%) had >3% of the cows with a BCS >4. Overweight cows were more frequent (r = 0.637; P<0.0001) than underweight cows within herds.

The hock injuries had a great variation ranging from 7.0 to 100%. Only eleven herds (15.1%) had <15% of cows with no lesions whereas 13 herds had > 60% of cow with lesions.

Locomotion score 1 was [median (range)] 61.3% (23.3 to 82.1%) while score 2 cows comprised 28.0% (7.7 to 56.7%). Score 3 was [median (range)] 6.25% (0.0 to 35.0%) and scores 4 and 5 were 0.8% (0 to 20.0%) and 0.0% (0 to 13.3%) respectively. Clinical lame cows ranged from 0 to 60.0% (Figure 3). Merely 31.5 and 42.5% of the herds had a prevalence of <5 and <10% clinical lame cows respectively. Most herds (76.7%) had <5% of the cows with an obvious limp or severe lameness while the remaining 12.3% of the farms had >10% of the cows severely lame. Severe lameness averaged 3.8% across farms and it was positively correlated with clinical lameness (r = 0.753; *P* < 0.0001). Farms (n=7) without lame cows (clinical or severe) had a prevalence of score 2 between 20 to 45%. Therefore, only 17.8% of the herds met at least 70% score 1, <20% score 2, <10% score 3 and 0% scores 4 and 5.

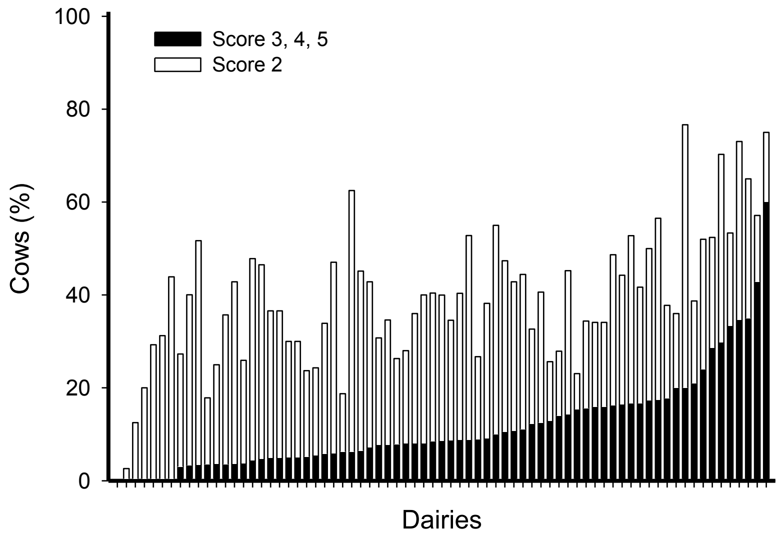

Figure 3. Percentage of cows by herd with locomotion score 2 and score 3, 4, 5 (lameness) in 73 dairies in Northwestern Spain. Dairies organized by the percentage of lame cows (small to large from left to right).

Dirty lower legs, udders and upper leg/flank had a median [median (range)] of 95.0% (50.0 - 100%), 62.5% (25.0 - 100%) and 62.5% (25.0 - 100%) of the cows by herd respectively. Overall dirtiness averaged from 37.5 to 100%. A significant correlation (r >0.814; *P* <0.0001) was found among scores of the three zones of cow's coat.

The total milk production (305ME) ranged from 6,321 to 11,951 kg and milk production by cow and day varied highly from 23 to 44 kg where 30.2% of the herds produced an average <30 kg. Cows DIM had also a wide range of variation (88 to 251 days) and it was <155 and >175 days in 26.9% and 61.9% of the herds respectively.

Regarding reproduction, the correlations established were not surprising, it was negative between HD % and CFSI ($r = -0.628$; $P < 0.0001$) and positive between FSC % and C % ($r = 0.659$; $P < 0.0001$). The CFSI ranged from 56 to 116 days and it was >80 days in 32.0% of the herds, while the CCI was between 103 to 243 days, where most of the farms (97.3%) were >115 days and there was severe issues (>145 days) in 58.9% of the herds. A high range of variation was also found on FSC, HD and C which was from 10.3 to 63.0%, 30.0 to 69.3% and 15.8 to 49.3% respectively. Poor HD (<50%) was found in 32.5% of the herds and also issues on FSC (<35.0%) were shown in most of the farms (72.6%). Furthermore, the CN ranged from 1.7 to 3.7 across farms.

Facility-based parameters

Facility design varied across farms as it is shown on Tables 3 and 4 for several categorical and continuous variables on the five areas assessed in the 73 barns.

Table 3. Distribution of the categorical variables for facility-based parameters in 73 dairy farms in Northwestern Spain.

Area	Categorical variables	Level	Frequency (%)
Resting	Stall location	Against a side wall	12.3
		Head to head platform	84.9
		Both combined	2.7
	Brisket locator	Yes	84.9
		No	15.1
	Dividers design	Italian	45.2
		Michigan	20.6
		"U" loop	17.8
		Wide-span	16.4
	Slope of the platform	Yes	64.4
		No	35.6
	Bedding materials type	Rubber mats	45.2
		Sand or straw	28.8
		No bedding (concrete/soil)	17.8
		Mattresses	8.2
	Dryness of bedding materials	Yes	52.0
		No	48.0
Walking	Crossovers	Yes	94.5
		No	5.5
	Crossovers curb	Yes	84.9
		No	15.1
	Back alley	Yes	95.9
		No	4.1

Table 4. Median (range) of the continuous variables for facility-based parameters in 73 dairy farms in Northwestern Spain.

Area	Continuous variables	Median	Min	Max
Resting	Bed width (cm)	120	90	135
	Bed length (cm)	185	60	230
	Brisket locator height (cm)	20	5	50
	Total stall length (cm)	240	200	325
	Low lateral bar (cm)	30	0	70
	High lateral bar (cm)	60	20	90
	Neck rail height (cm)	115	90	140
	Neck rail position (cm)	165	85	190
	Front lunge space (cm)	60	0	115
	Rear curb height (cm)	28	15	40
	Stall stocking density (%)	98	55	186
Walking	Crossovers width (cm)	160	90	350
	Crossovers curb (cm)	25	5	40
	Back alley width (cm)	300	0	620
	Feeding alley width (cm)	400	240	500
Feeding	Feed bunk stocking density (%)	96	50	178
	Feed bunk space/cow (cm)	65	50	70
	Feed bunk height (cm)	10	0	50
	Linear watering space/cow (cm)	8.4	2.6	32.0
Milking	Holding are space/cow (m^2)	1.2	0.7	7.7
	Slope of the holding area (%)	2.0	0.0	15.4
	Entrance door width (cm)	250	100	800
	Exit path width (cm)	110	90	300

Resting area

The incidence of overstocking was 31.5% (n=23) across farms. This situation was observed when dry and lactating cows were housed in the same pen (n=4) separated by chains and/or mobile fences (n=13) or there was a lack of space for the number of cows (n=6).

Most farms (74.0%) had stalls width between 115 to 122 cm, however it was >125 cm in some farms (13.7%). In contrast stall length was 178 - 182 cm or >185 cm in 31.5% and 39.7% of the farms respectively. Therefore, only 20.5% of the farms had a space available between 2.0 to 2.2 m^2. Furthermore, front lunge space was <90 cm in length in most farms (90.4%) and, it was >90 cm in few farms (9.6%). Some farms (58.9%) placed the neck rail <115 cm (height) and few of them (13.7%) >122 cm. Furthermore, curb height was >25 cm in 67.1% of the farms.

Divider design and bar position explained the range of variation in high and low lateral bars. In most farms (94.5%) the height of the high lateral bar was >35 cm and only in one farm it was <30 cm.

Walking area

Fifteen farms had slatted floors (20.6%) and thirteen of them were slippery (n=13). Sixteen had a flat concrete floor (21.9%), four were rough and eight were slippery. The most common floor type was grooved concrete (57.5%; n=42) and few of them resulted slippery (n=4). Moreover 2.7% of farms had rubber floors in the milking parlour and only one (1.4%) had also rubber floors in the feed alley. Surfaces were dirty in 16.4% of the farms at the assessment time.

Blocked alleys (interruption in linear circulation) were created by chains and/or mobile fences located in the pens to group cows (17.8%). Back alley, when present (95.9%), were <350 cm in 79.5% of the farms and most feeding alleys (64.4%) were <420 cm width.

Feeding area

Feed bunks were concrete metal or tile and classified as smooth (26.0%) or rough (worn) (74.0%). Feed bunk height was 10 – 15 cm in 50.7% of the farms and >15 cm in 13.7%.

Overstocking at feed bunk had 26.0% (n=19) incidence. Furthermore most farms overstocked at headlocks (n=15) were also overstocked at stalls. Feed bunk space (headlock width) was <60 cm in 24.7% of the farms. Low light at the feed bunk was observed in 50.7% of the farms at the assessment time.

Linear watering space per cow was <8 cm in 42.5% of the farms. Water troughs available at the farms were metallic with a draining system (53.4%), concrete troughs fixed with a drain (38.4%) or a combination of the previous two (8.2%).

Ventilation area

Signs of poor ventilation were observed in 32.8% of the farms. Only 12.3% had an insulated roof with sandwich plate. Farms were partially closed with small windows in the sidewall (20.5%) or partially open with small open sides (78.0%) which median (range) was 146 cm (20 - 300 cm) in height. Only one farm had 75% of the side wall open (400 cm). Therefore, the open side represented <50% of wall height in 47 out of the 58 farms. Any farm has an open ridge however roof height reached [median (range)] 700 cm (400 - 1,000 cm). Fans and sprinklers were available in few farms (13.7 and 1.4% respectively).

Milking area

The most frequent milking parlour design was the herringbone (75.3%) while parallel or tandem parlours were less common (11.0% respectively). Only one farm (1.4%) used a rotary milking system and another one (1.4%) a swing parlour.

Few farms (2.7%) had a walkway or release area (previous to the holding area) however most farms (74.0%; n=54) provided a holding area. Holding area space per cow was <1.3 m^2 in 27 out of the 54 were. The slope of the holding area was >4% in 13 out of the 54. Furthermore, 17 farms grooved floor of the holding area. The milking area communicated with the barn through a door in all cases either by the release/holding area (74.0%) or the milking parlour (26.0%). The entrance door was >300 cm in width with <100 cows and >500 cm in width with >100 cows in 41.7% of the farms respectively. Exit paths in the holding area were >160 cm in 9.7%. Paths of the milking area were non-linear (two or more turns >90°) in 49.3% of cases. Additionally, some farms (45.2%) had a milking area design that did not allow cows to see the milking parlour before entering it.

Management practices of facilities and herd

Cow and facility management varied widely across farms as it is shown in Table 5 for several categorical variables.

Table 5. Distribution of the categorical variables of the management practices in 73 dairy farms in Northwestern Spain.

Categorical variables	Level	Frequency (%)
Frequency of bed cleaning	"When necessary"	12.3
	1 daily	15.1
	≥2 daily	72.6
Hoof trimming routine	"When necessary"	49.3
	1 yearly	12.3
	≥2 yearly	38.4
Frequency of feed bunk cleaning	"when necessary"	2.7
	1 daily	87.7
	2 daily	9.6
Frequency of trough cleaning	"when necessary"	82.2
	1 daily	13.7
	2 daily	4.1

At least during a specific time of the year lactating cows had outdoor access to exercise areas (19.2%) or pasture (13.7%).

Daily bed maintenance mainly consisted of removing manure from the stall. As part of stall hygiene procedures, calcium carbonate was sprinkled on the concrete, rubber mats, mattresses and waterbed. Beds of sand, straw/sawdust and soil were groomed (racked) and replaced "when necessary". Most producers (86.3%) reported removing manure with an automatic scraper at least twice a day on a random schedule and the remained 13.7% had a fixed schedule up to 6 times a day.

Several farms (42.5%) had footbath facilities but did not have a footbath protocol (not effective product), most of them have reported to not change the product for more than a month (23 out of 31 farms) or they used it "when considered it necessary" (8 out of 31 farms). Some farms (27.4%) located at least one cow brush in the alleys. Producers reported turning fans/sprinklers (when present) on summer but not routinely. Further, all farmers cleaned the feed bunk before feeding delivery (in the morning) and they also performed a water analysis yearly.

A total of 38 farms (52.0%) reported that >15% of the cows had to be forcefully taken into the milking parlour on a daily basis. Observations in 15 of the 19 farms without a holding area revealed that the pathway to the milking parlour was not linear because it did not allow the cows to see into the milking parlour before arrival and, in the 15 cases producers were forced to lead the cows themselves. Stressful reactions at the milking time were also reported in 19.2% of the farms.

Benchmarking animal-based parameters

The cut-off point considered to assign the categories for each indicator across farms is presented in Table 2. Across overall farms, the number of indicators in A, B and C category ranged from 0 (n=22) to 3 (n=1), 0 (n=4) to 4 (n=7) and 0 (n=32) to 4 (n=1) respectively. There was not any correlation among the four animal-based welfare indicators and only one farm had all indicators in category C. Ten farms had the same number of indicators in A and C category and seven farms had the four indicators in category B. However, eleven farms had cero indicators on category C and other eleven in category A, thus the top and bottom farms respectively, which were presented in Table 6.

Table 6. Ranking of the top and bottom 15% of the farms sorted by the number of animal-based welfare indicators (% of cows by herd with unsuitable body condition score to stage of lactation, hock injuries, lameness and dirtiness of the cows coat as an average of the lower leg, udder and upper leg/flank) in A (25th percentile; white) > B (50th percentile; grey) > C (75th percentile; dark grey) categories in Northwestern Spain dairy farms.

Indicators - Percentage of cows by herd (%)	**Top 15% dairies**										
Body Condition Score unsuitable for cows DIM (%)	B	A	A	A	B	B	B	B	B	B	B
Hock injuries (%)	A	B	B	B	B	A	A	A	A	A	A
Lameness - locomotion score 3, 4, 5 (%)	A	A	A	B	A	B	B	A	A	A	A
Hygiene score >2 - average of three zones of cow's coat (%)	A	B	B	A	A	A	A	B	B	B	B

Indicators - Percentage of cows by herd (%)	**Bottom 15% dairies**										
Body Condition Score unsuitable for cows DIM (%)	C	C	C	B	C	C	B	B	C	C	C
Hock injuries (%)	B	B	C	C	B	B	C	C	C	C	C
Lameness - locomotion score 3, 4, 5 (%)	B	B	B	B	C	C	C	C	C	C	C
Hygiene score >2 - average of three zones of cow's coat (%)	C	C	B	C	B	C	C	C	B	B	C

The number of lactating cows was similar for top and bottom farms, increasing (median) by 8 linear units on the top farms. Also, herd milk production and DIM were similar, representing (median) 100 kg and -93 DIM of linear unit difference between top and bottom farms. The median of BTSCC was 264.000 and 310.000 cells/mL in the top and bottom farms respectively. All reproductive parameters had less than (median) 6 linear unit difference between both groups of farms.

The top farms presented a stall stocking density of [median (range)] 98% (74 to 117%) while bottom farms 100% (68 to 154%) and similar situation was of the headlocks with 94% (73 to 117%) and 103% (71 to 143%) in the top and bottom farms respectively. However, similar number of blocked alleys were observed in the top and bottom farms (six and seven respectively).

Frequency of bedding maintenance did not varied between both groups of farms and none of them used sand bedding materials. However, most of the top farms (n=7) had dry bedding materials while most of the bottom (n=7) did not. Front lunge space was 10 cm linear unit difference between top and bottom farms. Brushes were a complement on the alleys in four of the farms respectively. Dirty alleys were observed in two and three farms of the top and bottom groups respectively. Feeding alley width of the top farms had 50 cm linear unit difference of the bottom farms and crossovers curbs were -5 cm linear unit difference between top and bottom farms. Hoof trimming was performed up to producers decision in most of the bottom farms (n=9), while most of the top farms were following a protocol at least twice a year (n=7).

Light conditions over the feed bunk were the same in both groups (six farms had more visibility than in the rest of the barn) and feed bunk space per cow was also similar (averaging 60 cm). However, feed bunk was smooth in five of the top farms while in bottom farms were rough.

Signs of poor ventilation as well as close barns were observed in five of the bottom farms while none of the top registered any. Those findings result in poor natural ventilation.

Most of the bottom farms (n=9) did not have a holding area and seven of them had reported to push cows manually inside the parlour. However in most of the top farms (n=9) there was a holding area and only two farmers reported to help cows get inside the parlour. Furthermore, the holding area space per cow ranged from 0.7 to 7.7 m^2 in the top farms (n=9) and 1.0 to 2.1 m^2 in the bottom farms (n=2). Also, the slope of the holding area was between 2 to 4% in most of the top farms (7 out of 9 farms with holding area), while the two bottom farms had 4% and 15% of slope.

DISCUSSION

This study constitutes the largest independently observed assessment of the animal welfare status carried out in the region of Galicia, in which 52% of Spanish farm cattle is located with an estimated milk production comprising around 40% of Spanish milk production. This assessment only included a limited number of aspects of dairy cow wellbeing in a commercial setting. Animal rearing and management (treatment and care along the day or attitude at the milking parlour), animal health status, nutritional value of feed (quality and quantity) and feeding management practices (drops pushes mixing uniformity sorting etc.) equally affects the animal-based parameters measured during a welfare status assessment. However, these measurements could not be included due to several reasons, i.e. producer consent (time spent on the dairy, type of questions or copy of data records) and unavailability/unreliability of data records. Therefore, based on those limitations, Welfare Quality® Protocol could not be applied and only common variables available across all sampling farms were considered for description.

Animal-based parameters

Following Coleen and Heinrichs (2004) graph, more than a half of the cows by herd had an unsuitable BCS and those cows were mostly fat. Several management practices as unbalanced rations, prolonged dry periods, overfeeding during the dry period or poor reproduction management were reported to affect over-conditioning and therefore, the health i.e. fatty liver, ketosis, displaced abomasum, dystocia, retained placenta, uterine infections, and performance such as milk yield, and overall reproductive parameters (Bewley and Schultz, 2008). Similarly, under-conditioning or body condition score (BCS) losses post-calving are commonly associated with milk production, reproduction and health status - lameness (Espejo et al., 2006; Roche et al., 2009). However, in this study there was no records of nutrition values or feeding management practices which could directly affect BCS, but several management practices or facilities design such as overstocking, small front lunge space, feed bunk conditions or poor ventilation could be secondly affecting BCS by decreasing feed intake due to competitions, limited feed bunk space, low feed quality if fermentations are developed, decreased resting time and rumination, or heat stress conditions (Bewley and Schultz, 2008; Roche et al., 2009). Cows might be at an ideal BCS at dry off and might be fed to maintain this condition until calving. Although our results show considerable variation in the BCS status among lactating cows we assessed, it is encouraging that some farms had low rates of unsuitable BCS, showing that success is achievable.

Variation in the prevalence of hock injuries across farms is surprising because these lesions are relatively easy to recognize and prevent. For more than a decade, we have known that the use of poorly bedded mattresses greatly increases the risk of hock injuries (Weary and Taszkun, 2000; Fulwider et al., 2007). Stall features that restrict the normal rising and lying down movements (i.e., small stalls, presence of obstructions, hard lying surface, etc.) may aggravate the risk of lesion as cows try to adapt to restricted space (Zurbrigg et al., 2005). In addition, concrete stalls (or similarly hard surfaces) are known to cause swollen knees resulting from impact as cows lie down (Rushen et al., 2007). Furthermore, other risk factors, different from lying time, type of stall base, type of bedding materials or stall dimensions and also previously reported included parity, herd size, BCS, DIM, and milk production (Weary and Taszkun, 2000; Andreasen and Forkman, 2012; Barrientos el al., 2013). Therefore, it suggests the development of hock injuries involve several facilities design and management practices.

Prevalence of hock lesions in this study was less than in other studies (Weary and Taszkun, 2000; Kielland et al., 2009; Brenninkmeyer et al., 2013) which registered 73.0%, 60.5% and 50.0% respectively. However it was not as low as 16.3% (Rutherford et al., 2009). On farms where these lesions are common, dairy producers may come to believe that these are normal and thus fail to manage the problem. The comparative data provided by our benchmarking process may help address this issue.

The prevalence of lameness can provide valuable information about the functionality of the stall design, and several studies have shown a link between features of the free stall and the incidence of hoof problems (Leonard et al., 1994; Faull et al., 1996). However, this relationship is complex, and limitations exist in using lameness or hoof health to assess stall design per se. In free-stall systems, the link between stall design and lameness is most likely due to uncomfortable stalls resulting in cows spending more time standing (Cook and Nordlund, 2009), but the effect also depends on the nature of the surface that cows use for standing. Cows provided with free-stalls with no neck rail, where they could stand fully inside the stall on ample sand, had improved locomotion scores even though total standing time was unchanged (Bernardi et al., 2009). Therefore, several factors may contribute to lameness development including more than one factor at the time, i.e. management practices as breed, genetic selection, conformation characteristics, small herd size, nutrition and feeding practices, amount of milk production, stall designs, faecal contamination on bedding, type of bedding, the presence of damaged concrete in the yards, sharp turns near the parlour entrance or exit, automatic scrapers, presence or absence of certain types of infectious disease, and environment (Cook, 2003; Espejo and Endres, 2007; Bernardi et al., 2009; Barker et al., 2010; Chapinal et al., 2013). Further, lameness was related to reproduction failure and decrease milk production (Warnick et al., 2001; Morris et al., 2011).

Prevalence of lameness was less than previously reported in studies carried out in Wisconsin (23.9%; Cook, 2003), Minnesota (24.6%; Espejo et al., 2006) and the UK (36.8%; Barker et al., 2010) but, not as low as those reported in Sweden (5.1%; Manske et al., 2002).

Few studies (Espejo et al., 2006; Von Keyserlingk et al., 2012; Chapinal et al., 2013) have reported the prevalence of severe lameness (ranging from 6 to 10% prevalence) separately from clinical or overall lameness. Severe lameness was less in our study than in those studies but, similarly to those studies, it accounted for only a small portion of clinical lameness. Of interest is that the patterns of severe lameness across farms did not match those of clinical lameness; for example, some farms with a low prevalence of severe lameness had a high prevalence of clinical lameness, and vice versa. Causes of mild versus severe cases of lameness are likely different and may not always be progressive, but more research is required to further our understanding in this area.

Highlight the high prevalence of locomotion score 2, which is defined as an imperfect locomotion but the ability to move freely is not diminished (Flower and Weary, 2006), may predispose to lameness if specific management practices does not change to improve the comfort of the cow. It could be due to the lack of footbath protocols in most farms and, especially in this region, which humidity levels raised above 80% during the assessment period. The frequent used of the footbaths might be desirable to avoid microorganism proliferation and possible development in dermatitis. Furthermore, it may worsen with manure, which was revealed trough the prevalence of dirtiness cows and the lack of protocols to clean the floor on a routine basis in most farms (86.3%). Another practice that may contribute to alterations in locomotion could be explained by the lack of hoof trimming protocols. In this case, a monitoring process might be desirable to follow-up the locomotion scores over time and to find the causes of this prevalence by changing several management practices.

Facility cleanliness contributes to clean and dry hair coats and udders. Variation in the scoring can be associated with soiling of the animals' coat, manure (which is influenced by cow behaviour) and, facility cleaning factors including: direct transfer (lying down in manure), leg transfer (walking through the manure and splash transfer) or tail transfer (contamination while resting). For this reasons, stocking rate, maintenance and facility design, type of bedding materials have being previously reported to determine the hygiene of the herd (Reneau et al., 2005; Fulwider et al., 2007; Andreasen and Forkman, 2012). Further, Schreiner and Ruegg (2003) showed linear effects of hygiene score on somatic cell scores (cell score increased with dirty udder). From Schreiner and Ruegg (2003) study was extracted that <15% of cows should score 3 or 4 in the udder and performing an evaluation routinely may help to prevent milk quality issues. For this reason, the high prevalence of dirty udders could be considered a potential hazard in some of the farms evaluated in this study.

The high CCI or commonly named "open days" across herds may indicate fertility and/or estrous detection issues, which was the case in this study (low HD %). Factors affecting reproductive performance were associated to either to the management factors (such as methods of husbandry, feeding, estrus detection, semen handling and transition cow management) or to the cow factors (such as age, BCS, post-parturient problem, disease events, milk yield, and genetics) (Lucy 2001, Hudson et al 2012).

Facility-based parameters and management practices of facilities and herd

Management practices and facility dimensions appear to have opportunities for improvement in the assessed farms. Following the conclusions reached by several research (Murphy et al., 1983; Weary and Taszkun 2000; Cook, 2003; Reneau et al., 2005; Espejo et al., 2006; Fulwider et al., 2007; Bewley and Schultz, 2008; Roche et al., 2009; Bernardi et al., 2009; Morris et al., 2011; Andreasen and

Forkman, 2012; Barrientos el al., 2013; Chapinal et al., 2013) critical points could be found at the small front lunge space (developing social obstruction and diagonal positioning in the stall which may allow to defecate inside), big stall curb height (refusing to get inside the pen), discomfort at the stall for bedding type (limiting lying time as research to now have shown sand bedding materials of cow preference), narrow alleys (limiting space flow), slippery floors surfaces (avoiding expression of heats), rough or worn feed bunk surfaces (promoting the fermentation of the feed stuff), the lack of daily troughs cleaning routine (decreasing quality and feed intake and limiting milk production), small linear watering space per cow (<8 cm, limiting water intake), the lack of footbath protocols (promoting digital dermatitis), the lack of fixed schedules for running automatic scrapers (increasing dirtiness of the cows coat), poor natural ventilation (promoting heat stress), and poor design of the milking parlour and overall design of the holding area (slowing cow flow, increasing stress and hindering the letdown mechanism).

Benchmarking animal-based parameters

The prevalence of dirty cows was high across the 73 farms, similarly to analogous studies carried out in the UK (Whay et al., 2003) and Hungary (Gudaj et al., 2012), specially as regards lower leg hygiene.

Farms with equal number of indicators placed in the top and bottom categories, suggested a wide range of variation between management practices within those specific parameters. Most of the farms did not perform consistently well or poorly across animal-based welfare indicators and each farm had its own set of strong (indicators included in A category) and weak points (indicators included in C category). These results may explain the lack of correlations among animal-based welfare indicators and it may suggest that several factors are involved in the cow welfare and those farms can benefit from benchmarking to look for better management practices. However, specific management practices may have a major influence on particular animal-based parameters and more research would be needed for determine the potential of each factor to influence on cow welfare.

Most farms shared several issues of the facilities design and management practices (previously described overall farms) that may or may not affect the animal-based welfare indicators. However, from the description made of the benchmarked top and bottom farms, there were main critical points between both groups that could be found at the stocking density on the feed bunk and headlocks, dryness of bedding materials, front lunge space, hoof trimming routine protocols, poor natural ventilation and poor facilities design of the milking area. Therefore, a specific improvement plan should be designed for each farm to increase performance and promote animal welfare.

One outcome of this field study was to provide individual farms with their own data and with results from other farms in their region to allow benchmarking of their own performance. Each farm received a confidential report that was often used as a basis for discussion (involving, for example, the owner, producer, nutritionist, clinician and reproductive veterinarian, hoof trimmer etc.). Our intention was that the reports provided producers and their advisors with an opportunity to make better informed decisions and develop tailored strategies for improving the care and management of cows on their farm. Anecdotal feedback from participants has been positive, but research is required to assess how producers use these data and whether benchmarking results in changes to practices and sustained improvements on farms. Dairy producers in general are concerned about the health and welfare of their animals; for instance, a sense of pride in a healthy herd was identified as one of the most important motivators for lameness control (Leach et al., 2010). Benchmarking may provide information that is either reassuring (if herd performance was high) or that helps to motivate change (if a major opportunity for improvement was identified).

CONCLUSION

Considerable variation exists within and across animal-based welfare indicators of the assessed 73 farms in Lugo. Some farms had a low prevalence of over and underweight cows, hock injuries and lameness, suggesting opportunities for the other farms to benefit from benchmarking. Improving several management practices of facilities and herd may help to prevent and control some aspects of the animal-based welfare indicators.

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2

Deviation from the formulated target weight of ingredients loaded into high milk yield cow recipes on California dairies.

Adapted from:

Y Trillo T, A Lago A., N Silva-delRio. Deviation from the formulated target weight of ingredients loaded into high milk yield cow recipes on California dairies. 2016. J. Dairy Sci. 99:1-13

ABSTRACT

Nutrient composition of the feed and formulated ration often differ depending on uncertainties in DM content and nutrient composition of ingredients as well as from feeder errors during loading. The objective of this study was to describe the deviation from target weight for the high producing cow ration (HCR) and premix (HCP) on 26 California dairies ranging in size from 1,100 to 6,900 cows. Records from a consecutive 12 month period were extracted from FeedWatch 7, a feeding management software. Variables extracted and studied were: date, recipe type, recipe number, ingredient, loading sequence, target weight, weight and tolerance level (TL, deviation allowed per ingredient during loading). Based on the distribution of the deviation from target weight for the 8 most common ingredients, loading accuracy (Q_1; small: | < 10| kg; medium | 10 | to | 20 | kg; large | > 20| kg), loading precision (IQR = Q_3-Q_1; small: < 20 kg; medium: 20 to 40 kg; large > 40 kg) and extreme observations (Q_3: small:| < 25 | kg; medium | 25 | to | 40 | kg, large (Q_3: | > 40| kg) were described. Descriptive statistics were conducted with SAS 9.4. The median TL assigned to ingredients across dairies ranged from 0 to 90 kg. At the ingredient level, the TL allowed a deviation from the median ingredient target weight of 0 to 2% (53.9%), > 2 to 5% (25.5%), > 5 to 10% (11.6%) or > 10% (8.9%). A total of 2.5% of the loads did not reach the target weight set by the TL, ranging from 0.1 to 21.1% loads across dairies. Ingredient deviation from the formulated target weight across dairies was below target 49.1% of the time [< -10% (2.5%), -10 to < -5% (4.8%), -5 to < -2% (8.9%), -2 to < 0% (32.8%)] or at or above target 50.9% of the time [0% (3.9%), > 0 to 2% (36.7%), > 2 to 5% (8.9%), > 5 to 10% (1.2%), > 10% (0.2%)]. Five dairies loaded ingredients with adequate accuracy (small to medium Q_1) and adequate precision (small to medium IQR), but accuracy and precision were very poor on 3 dairies based on a large Q_1 and IQR. Rolled corn and almond hulls were loaded with adequate precision (small to medium IQR) on a minimum of 64% of the dairies and

adequate accuracy (small Q_1) on at least 68% of the dairies. In contrast, alfalfa hay, corn silage, and canola were loaded with poor precision (large IQR) on a minimum of 60% of the dairies. There was a large variation within and across dairies on the deviation from target weight. Readjusting the TL settings might reduce the deviation from target weight. On 5 dairies, feeders were able to load ingredients with minimal deviation from target weight, setting achievable goals for the industry. Based on loading errors, there are opportunities to improve feeder performance on California dairies.

Key words: feeding management software, loading deviations from target, tolerance level

INTRODUCTION

Feed is the highest expense on a dairy. From 2011 to 2014 feed cost represented 61 to 64% of the total production cost on South Valley California dairies (CDFA, 2014). Research advances in past decades has facilitated the development of advanced mathematical models for ration formulation that accurately predict the performance of dairy cows based on the nutrient composition of their ration feed. These tools enable dairy nutrition consultants to formulate rations that cost the least while maximizing the efficiency of feed to milk conversion. However, the nutrient composition of the fed ration often differs from the formulated ration as a result of errors associated with weighing ingredients into a mixer box, and uncertainties in DM content and nutrient composition of the ingredients (Buckmaster and Muller, 1994; St-Pierre and Weiss, 2015). On 7 California commercial dairies, the observed variation between the fed and formulated recipe was important (CV > 5%) on 29% to 79% of recipes studied for NDF, CP, fat, Ca and P (Silva-del-Río and Castillo, 2012). Similarly, James and Cox (2008) reported high variability in CP and P content between the fed and formulated recipe. It has been reported that day-to-day variability in nutrient composition was not as large as the variability observed between the fed and formulated recipe (Sova et al., 2014). The observed variability in TMR nutrient composition might have implications in regard to milk yield (Rossow and Aly, 2013; Sova et al., 2014). Due to these uncertainties associated with the feeding process, nutrition consultants often times add a "safety" margin by formulating rations that exceed requirements for critical nutrients such as crude protein. The downside of this practice is the potential for a higher feeding cost as well as an increase in nutrient excretion, especially those with environmental impact such as nitrogen.

Incorporating new technologies such as a feed management software (FMS) may help dairy producers minimize the variation in nutrient composition (James and Cox, 2008). A 2009 California feeding management survey indicated that 44% of the dairy producers had incorporated a FMS into their operations (Silva-del-Río et al., 2010). This technology assists with recipe preparation, inventory management and feeder performance monitoring. The mixer box has a scale indicator that displays the type and amount of ingredients that should be loaded per recipe, the final weight loaded per ingredient, and the start and end time of each loading action is transmitted through an antenna to the main computer. The time and amount of feed delivered per pen is recorded. This information can be used to generate reports based upon loading and delivery errors, mixing time, time between loads, and loading and delivery sequence of ingredients. Most FMS users reported to find value in the loading errors reports that could be utilized to evaluate the efficiency of feeders (James and Cox, 2008; Silva-del-Río et al., 2010). Control charts could also be used as a tool to monitor feed management on dairies (Stewart et al., 2011). However, there is not an industry standard for an acceptable loading error. To the best of our knowledge, only one study reported loading errors from 7 Virginia dairies (James and Cox, 2008). Thus, the objective of our study was to describe loading deviations from target within and across 26 California dairies throughout a 12 month period.

MATERIALS AND METHODS

Data Collection and Dairies

Twenty-six California dairy cattle farms using FeedWatch 7 [Valley Agricultural Software Inc. (VAS), Tulare, CA] as their feeding management software (FMS) for at least 1 year were enrolled in the study. A 12 month data backup was obtained from the FMS for each farm. The final data set included information from Jan 2012 to May 2014. California dairy nutrition consultants and VAS personnel assisted with dairy identification. Enrolled dairies were located in the San Joaquin Valley ranging in size (lactating and dry cows) from 1,100 to 6,900 cows. Each dairy was given a number according to its herd size, from largest (Dairy 1) to smallest (Dairy 26). Dairies 1 to 6 had over 4,000 cows, Dairies 7 to 20 had between 2,000 and 4,000 cows, and Dairies 21 to 26 had less than 2,000 cows. Records included information from 2 recipes, high cow ration (HCR, including 511,554 ingredient loads) and high cow premix (HCP, including 72,726 ingredient loads). A description of feeding variables among dairies in the study is presented in Table 1.

Table 1. Description of feeding variables for high cow ration and high cow premix based on median values per dairy during a twelve month period on 26 California dairies.

	High Cow Ration (n=26)			High Cow Premix (n=20)		
	Median	Min	Max	Median	Min	Max
Recipe loads/day (n)	6	2	14	2	1	4
Ingredients/recipe load (n)	8	4	10	7	4	11
Ingredient loads/day (n)	43	16	108	9	4	19
Recipe load weight (kg)	10,055	4,785	17,998	15,613	8,548	24,298
Feeders (n)	4	1	6	3	1	6

Assembly and Structure of the Data Set

The consultant version of FeedWatch 7 was used to extract records from the setup function and user reports. Data were transferred to an excel spreadsheet (Microsoft Office Excel; 2010) to create a database for analysis. The variables extracted included: date, recipe, recipe drop number, ingredient, loading sequence, target weight, weight, tolerance level (TL) and feeder ID. A description of some of the variables obtained from the FMS is shown below.

Target Ingredient Weight. The expected weight that should be loaded.

Ingredient Weight. The weight read by the mixer box scale after loading each ingredient.

Recipe Load Number. The number that identifies each recipe load.

Ingredient Type. Over 44 types of ingredients were used in HCR and HCP recipes across all dairies throughout the 12 month study. Fifteen ingredients were deemed most common; they were used in at least half of the dairies: premix (n =26 dairies), alfalfa hay (n =26), corn silage (n =26), rolled corn (n =25), almond hulls (n =25), liquids (molasses, water and whey; n =24), whole cottonseed (n =23), mineral-vitamins (n =21), canola (n =20), dry distillers grains (DDG; n =16), wet distillers grains (WDG; n =15), straw (n =14), corn gluten feed (n =14), wheat silage (n =14) and by-pass fat (n =14). These ingredients represented 77% of the total ingredient loads. Results presented by ingredient type only include information from the 15 most common ingredient types used in HCR and HCP recipes.

Tolerance Level Settings. To avoid overloading ingredients, the FMS assigns a tolerance level (TL) to each commodity. After reaching the TL, if there is a pause of 5 s or longer, the FMS will register the new weight as the next ingredient of the recipe.

Feeder ID. The unique ID given to each employee operating the FMS.

Calculations

Deviation from the Median Recipe Load Target Weight Allowed by the TL. It was calculated for each dairy as: a) kg: TL assigned to ingredients within a recipe load; and b) percentage: [(Σ ingredients TL within a recipe load / Σ ingredients target formulated weight with the same recipe load number) *100].

Deviation from the Median Ingredient Type Target Weight Allowed by the TL. It was calculated for each dairy and ingredient type as: a) kg: TL assigned to each ingredient type across dairies; and, b) percentage: [(TL per ingredient type / median formulated target weight by ingredient type)*100]

Deviation from TL for Ingredient Loads not Reaching the Target Weight Set by the TL. For loads not reaching the TL, the deviation from target weight set by the TL was calculated as: a) kg: [(formulated target weight – TL) – (weight loaded)]; and, b) percentage: [((formulated target weight – TL) – (weight loaded)) / (formulated target weight – TL)*100].

Deviation from Recipe Load Target Weight. It was calculated as the absolute value and real value for each dairy as: a) kg: (weight loaded per recipe load – target weight per recipe load); and, b) percentage: [(weight loaded per recipe load – target weight per recipe load) / target weight per recipe load*100].

Deviation from Ingredient Type Target Weight. The final deviation from target weight was calculated for the 15 most common ingredient types as: a) kg: (weight loaded per ingredient type – target weight per ingredient type); and, b) percentage: [(weight loaded per ingredient type – target weight per ingredient) / target weight per ingredient type*100].

Deviation from Target Weight by Day of the Week. The proportion of loads with a deviation from target greater than 2% for each day of the week was evaluated. Dairies with a CV > 10% were considered to have a dissimilar percentage by day of the week and were reported.

Deviation from Target Recipe Load Cost. For each dairy, the cost of ingredients included in HCR and HCP was obtained from the FMS records. Three dairies (Dairies 1, 4 and 5) had no records for ingredient cost, consequently only information from 17 HCP and 23 HCR were used to evaluate recipe load cost deviations. The cost per ton of the target recipe was calculated as: [(Σ ingredient target weight*ingredient cost) / total target weight per recipe load]. The cost per ton of the recipe loaded was calculated as [(Σ ingredient weight*ingredient cost) / total weight per recipe load].

Distribution of the Deviations from Target Weight across Dairies based on Q_1, Q_3 and IQR

Based on the distribution of the deviation from target weight across dairies for the 8 most common ingredients (alfalfa hay, almonds hulls, canola, corn silage, liquids, premix, rolled corn, and whole cottonseed) loading accuracy (based on Q_1), loading precision (based on IQR = Q_3-Q_1) and extreme observations (based on Q_3) were described. Each of these variables was classified based on their quartile distribution among dairies as small, medium, or large deviation from target rounded to the nearest figure in 5 units increments.

25^th^ Percentile or Q_1: It was classified as small (Q_1: | < 10| kg; 52.0%), medium (Q_1:|10| to | 20 | kg; 38.3%), or large (Q_1: | > 20| kg; 9.7%).

75^th^ Percentile or Q_3: It was classified as small (Q_3: | < 25 | kg; 42.4%), medium (Q_3: | 25 | to | 40 | kg; 34.7%), or large (Q_3: | > 40 | kg; 16.3%).

Interquartile Range (IQR = Q_3-Q_1): It was classified as small (IQR: < 20 kg; 49.0%), medium (IQR: 20 to 40 kg; 34.7%), or large (IQR: > 40 kg; 16.3%).

Data interpretation

To interpret study findings, additional information on feeding management practices was obtained for some dairies through interviews with dairy nutritionists, VAS personnel or by direct interaction with feeders on dairies.

Data Analysis

Descriptive statistics were calculated with the PROC MEANS and PROC UNIVARIATE procedures of SAS 9.4 (SAS Institute Inc., Cary, NC). Percentiles were computed using the PCTLDEF = 4 option in the output statement of the PROC UNIVARIATE.

The relationship between deviation from target in kg and percentage by dairy was evaluated using the PROC CORR procedure of SAS 9.4.

RESULTS AND DISCUSSION

Data Screening

There were no feeding records for 2 consecutive months and for 40 non-consecutive days on Dairy 2 and Dairy 11, respectively. This could be explained by equipment breakdown, communication problems between the software and mixer box, or unintentional deletion of statistical information. On Dairy 6, recipe loads prepared with the stationary mixer box (20,498 ingredient loads, 62% of Dairy 6 observations) had no recipe load number information. Therefore, all observations were used to evaluate ingredient loading deviations from target, but loads prepared with the stationary mixer were not evaluated at the recipe load level.

Five dairies (2, 6, 18, 20 and 23) did not prepare the HCP recipe on farm. Dairy 11 had only HCP recipe records for 90 non-consecutive days, so it was removed from the final HCP recipe analysis. Dairy 26 (herd size 1,100) did not prepare HCP recipe during the first 5 months of the study period, so HCP recipe records from 7 months were included in the final data set.

On Dairy 14, one ingredient load reached a 10 figure number. This observation was eliminated. The FMS automatically generates a 10 figure number when apparent total scale weights are exceeded. This could be due to cell weight errors or to the front-end-loader striking excessive weight on the mixer box.

There were ingredients not loaded into the HCR or HCP recipe. Those ingredients registered a load weight of "0 kg" (1,299 total observations). This could be explained if ingredients were listed in the recipe but were not available at the dairy. In this scenario, the feeder must advance manually or by clicker to the next ingredient. However, the movement of the feed inside the mixer box often causes the scale reading to bounce during mixing. If the magnitude of the scale bouncing is higher than the minimum scale detection, there would be an ingredient weight record even if no ingredient was loaded. In the present study, we also considered that ingredients were not weighed down when the amount loaded was < 60 kg, the target weight was > 100 kg, and the amount loaded represented < 10% of the expected target weight. Based on this criteria, a total of 675 ingredients were not loaded and over half of those ingredients (53.6%) were from Dairy 15.

The initial data set included information from 584,280 ingredient loads. After data screening, the final data set included a total of 488,359 ingredient loads for HCR [range: 5,900 Dairy 1 to 84,125 Dairy 2] and 72,422 for HCP [range: 4,190 Dairy 1 to 6,900 Dairy 2].

Tolerance Level Settings

All dairies used the TL settings function of the FMS (Figure 1). During the 12 month study period, the assigned TL was kept constant for all ingredients across dairies. The minimum TL assigned to an ingredient was 0 kg (n = 15) or 2.3 to 9.0 kg (n = 11) and the maximum TL level ranged from 14 to 36 kg (n = 14), 45 kg (n = 6), 90 kg (n = 2) or 135 kg (n = 4).

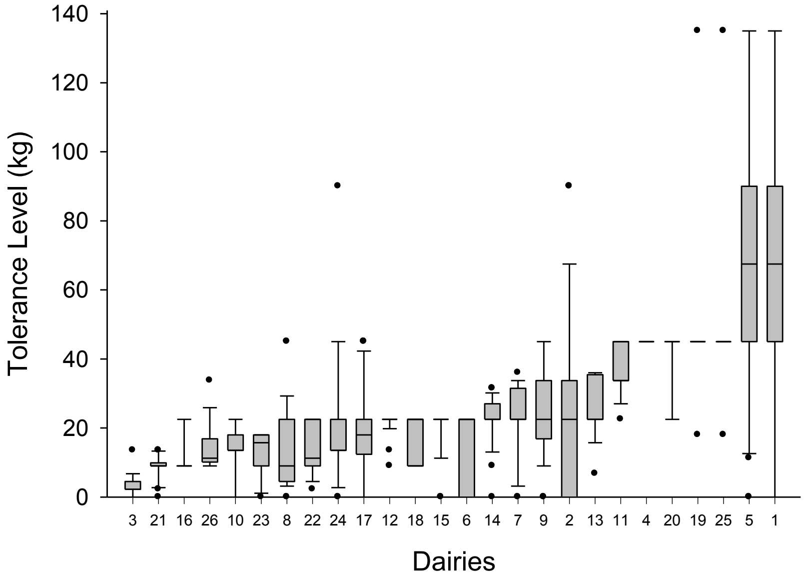


Figure 1. Boxplot of the tolerance level (kg) assigned to the various ingredients of the high cow ration and high cow premix recipe on 26 CA dairies. Data is presented sorted by 75th percentile (Q_3), and then by 50th percentile (Q_2). Each boxplot shows the 50th percentile (median, line within the box), 25th and 75th percentile (box), 10th and 90th percentiles (whiskers), and outliers (dots).

The major purpose of assigning commodities with a TL is to minimize the risk of overloading expensive ingredients. During software installation, information systems technicians educated clients on the TL settings of the FMS. It is at software installation time when most users decide the TL of ingredients [personal communication with Valley Agricultural Software Inc. (VAS), Tulare, CA]. Settings of 0 kg for TL could be explained due to dairy producers considering irrelevant to assign TL to some ingredients, or they did not know how to use the TL settings of the FMS for new ingredients. Ingredients with 0 kg of TL were feed additives (n = 12), forages (n = 10), by-products (n = 8), seasonal by-products (n = 4), premixes (n = 3) or grains (n = 1; Figure 2). Most of these ingredients (78.9%) were included in the recipe for less than 6 months. The most common TL assigned to an ingredient was 23 kg, used on 11.1 to 91.7% of the times on 18 of the dairies. However, it is unclear the criteria by which dairy producers assigned TL to various ingredient types. Most dairies selected TL values under 36 kg, but some dairies were more liberal with their TL settings. Six dairies assigned a similar TL to all ingredients (IQR: 0 kg), and 4 dairies chose various TL (IQR: 23 to 45 kg). One dairy assigned the same TL, 45 kg, to all ingredients.

Deviation from Target Weight Allowed by TL.

The TL added to < 200 kg (n = 14), 200 to 400 kg (n = 8) or > 400 kg (n = 4) for HCR representing 0.4 – 2.3%, 1.9 – 6.9%, and 3.3 – 4.6% of deviation from the median target weight respectively. Similarly, the TL added to < 200 kg (n = 15), 200 to 400 kg (n = 4) or > 400 kg (n = 1) for HCP, representing 0.2 – 1.2%, 1.5 – 4.2% and 2.8% of deviation from the median target weight respectively. The TL could potentially introduce at least a 4% deviation from target weight for HCR on 3 dairies [Dairy 5 (720 kg of TL), 19 (405 kg of TL), and 25 (315 kg of TL)] and on 1 dairy for HCP [Dairy 25 (360 kg of TL)].

At the ingredient level, the TL allowed a deviation of 0% (8.7%), > 0 to 2% (45.2%), > 2 to 5% (25.5%), > 5 to 10% (11.6%) or > 10% (8.9%) from the median ingredient target weight. Thus, the TL needs to be carefully considered, as it had the potential to introduce a deviation from target of > 5% in more than 20% of the ingredients. In most cases, the median formulated target weight for these ingredients was under 1,000 kg. However, there were some ingredients with a median formulated target weight of over 1,000 kg that had > 5% of deviation allowed by the TL [liquids (3/6), rolled corn (2/4), wheat silage (1/2), WDG (1/3), DDG (1/4), mineral-vitamins (1/6) and alfalfa hay (2/13)].

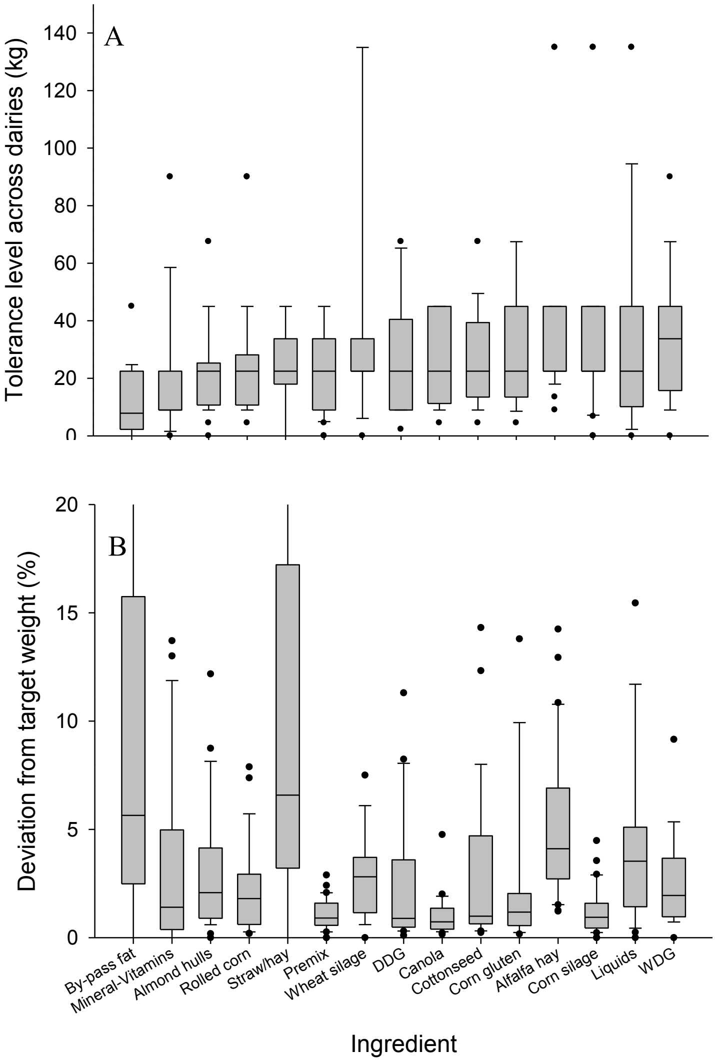


Figure 2. Boxplot of the tolerance level settings (A: kg) and of the median deviation allowed by the tolerance level (B: %) for ingredients included in the high cow ration and high cow premix recipes on 26 California dairies. Data is presented sorted by 75th percentile (Q_3), and then by 50th percentile (Q_2; A). The boxplot shows the 50th percentile (median, line within the box), 25th and 75th percentile (box), 10th and 90th percentiles (whiskers), and outliers (dots). **Notes:** Panel B whisker reaches 61.2% for by-pass fat and 36.1% for straw/hay. The deviation allowed by the TL was calculated per ingredient and dairy as follow ([Σ recipe ingredients' TL (kg) / Σ recipe ingredient's target (kg)]*100).

Five dairies had 1 ingredient (liquid, straw or by-pass fat) with an assigned TL that allowed > 30% of deviation from the median target weight. On 4 of these dairies, the deviation was explained by the low median target weight set by the recipe (23 to 483 kg) rather than by the TL assigned to those ingredients (18 to 23 kg). However, on 1 dairy the TL assigned to liquids was 90 kg whereas the median target weight was 300 kg. For ingredients added in small quantities, the most desirable loading method would be to weigh them prior to loading. Thus, assigning a TL would be irrelevant for those ingredients.

Loads not Reaching the Target Weight set by TL

A total of 12,439 times (2.5% of the total observations) ingredients were loaded under the target weight set by TL. This represented 0.1% to 21.1% loads of feed per dairy (Figure 3). The number of loads not reaching the TL by up to 50 kg [5 to 80 loads (n = 11 dairies), 128 to 500 loads (n = 10), 1,230 to 1,830 (n = 5)] or by more than 50 kg [2 to 36 (n = 12), 54 to 149 (n = 10) and 207 to 319 (n = 4)] ranged widely across the study dairies.

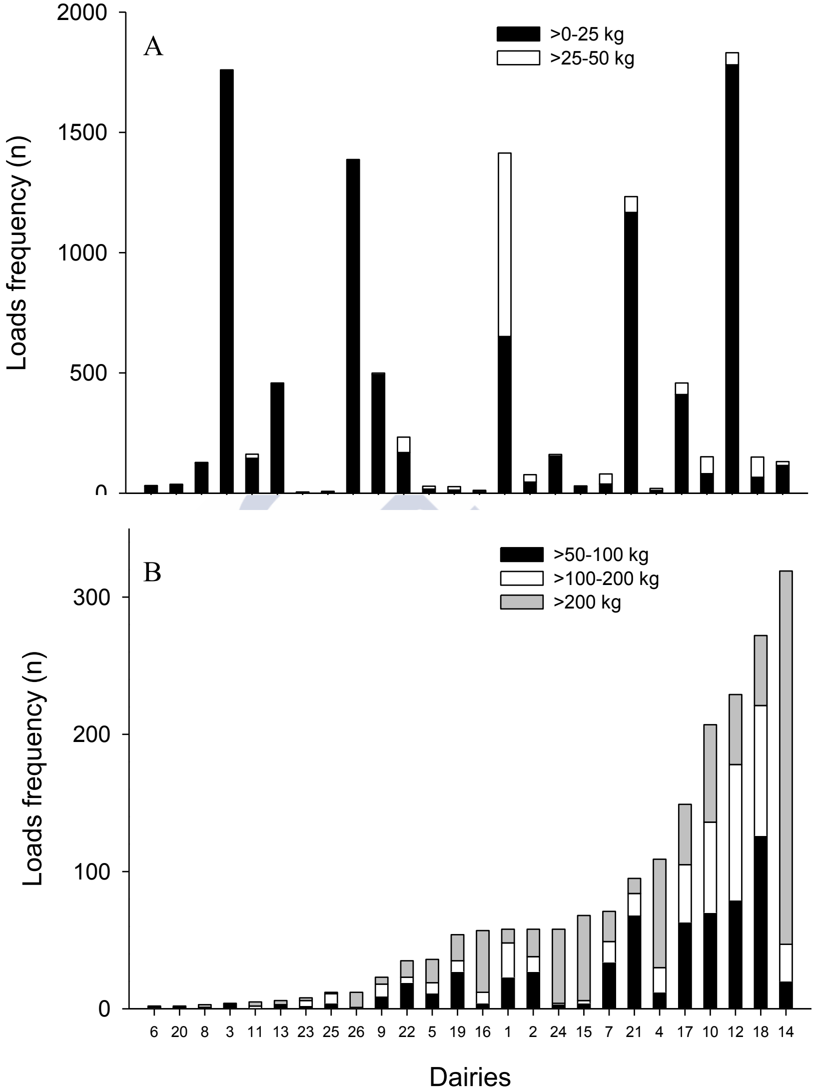


Figure 3. Frequency of loads that did not reach the target weight set by the tolerance level [by 0 to 50 kg (A) and by > 50 kg (B)] for ingredients loaded into the high cow ration and the high cow premix recipes on 26 California dairies. Data is presented sorted by the frequency of loads in B.

There were 4 dairies with over 1,000 ingredient loads not reaching the TL by up to 25 kg. The ingredients in most these cases were:

wheat silage (Dairy 3); corn silage, whole cottonseed and rice grain (Dairy 12); corn silage, canola, yeast, rolled corn and oat silage (Dairy 21); and, alfalfa hay, almond hulls, corn silage, premix and rolled corn (Dairy 26). On these dairies, feeders and owners potentially could have agreed it was an acceptable practice to manually advance to the next ingredient if less than 25 kg were left to reach the TL. However, this practice increased the deviation from the formulated target weight by 0.2 to 0.9 percentage units. Feeders and dairy owners should be informed about the implications of routinely not reaching the TL. Based on information from the FMS, we cannot determine if this practice saved the feeder an extra trip to the commodity barn or if simply the feeder did not want to pursue the task of reaching the target weight.

On Dairy 1, there were ingredient loads that did not reach the TL up to 25 kg (n = 651) or from > 25 up to 50 kg (n = 751). This increased the deviation from the median formulated target weight by 0.9 and 2.5 percentage units respectively. Sorghum represented 80% of the loads not reaching the TL. This was likely explained because sorghum had 0 kg of TL, whereas the mean TL for all the other ingredients on this dairy was 67.5 kg.

On 7 dairies, a total of 50 to 272 loads were below the TL by over 200 kg. The ingredients that were most commonly underloaded were citrus by-products, liquids and corn silage. For these ingredients, the deviation from the formulated target increased by 17.7 to 85.4 pertentage units.

Over the study period, all dairies but Dairy 20 had ingredients that were not loaded either 1 to 15 times (n = 11), 23 to 74 times (n = 12), 434 times (Dairy 14; mostly seasonal by-products and by-pass fat), or 641 times (Dairy 2; mostly liquids). We are unsure why ingredients were not loaded, but it is likely that occasionally some commodities were used up before a new truck load was delivered or one ingredient was removed from the recipe without updating the FMS. It is extremely important that dairy nutritionists and dairy managers maintain open lines of communication with feeders to understand why some ingredients are not being loaded. If adjustments need to be made to the FMS recipe, it would be recommended to introduce those as soon as possible, so feeding records can be accurately evaluated.

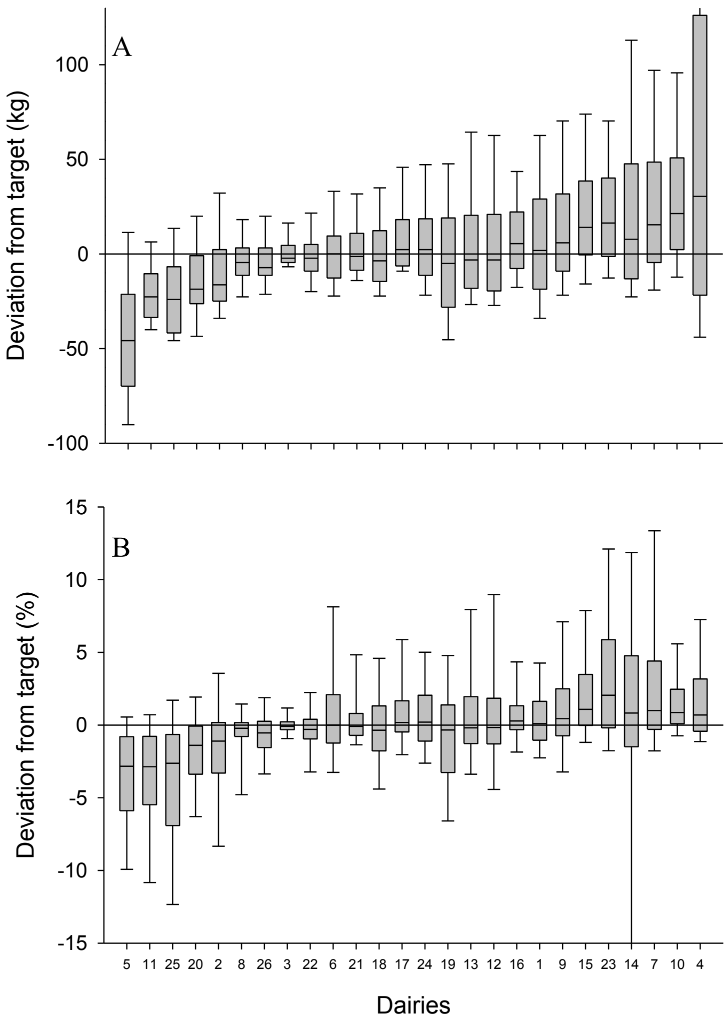


Figure 4. Boxplot distribution of the deviation from the target weight (A: kg; B: %) for ingredients loaded into the high cow ration and high cow premix recipes on 26 California dairies. Data is presented sorted by 75th and then by the 50th percentile (A). The boxplot shows the 50th percentile (median, line within the box), 25th and 75th percentile (box), and 10th and 90th percentiles (whiskers). **Notes**: whisker reaches: (A) 265 kg (Dairy 4); (B) -31% (Dairy 14).

Deviation from Target Weight by Dairy

The deviation from target weight, as kilograms and percentage, is represented in Figure 4. Across all ingredients loaded, the deviation from the formulated target weight was 49.1% of the time below target [< -10% (2.5%), -10 to < -5% (4.8%), -5 to < -2% (8.9%), -2 to < 0% (32.8%)] and 50.9% of the time at or above target [0% (3.9%), > 0 to 2% (36.7%), > 2 to 5% (8.9%), > 5 to 10% (1.2%), > 10% (0.2%)].

Deviation from target can be expressed in kg or percentage. When expressed in kg, at least 20% of the time ingredients were loaded with a deviation from target > 40 kg on 7 dairies (Dairy 4, 7, 9, 10, 14, 15 and 23) or < -40 kg on 2 dairies (Dairy 5 and 25). However as a percentage, at least 20% of the time ingredient deviations from the target was > 4% on 5 dairies (Dairy 4, 7, 14, 15 and 23) or < -4% on 6 dairies (Dairy 2, 5, 11, 19, 20, and 25). Although there was a significant association between deviation from target weight per ingredient load expressed as kg and as percentage, the correlation coefficient (r) was poor and only on 6 dairies it was > 0.5%. When small loads are prepared deviation from target weight expressed as percentage will be larger compared to big loads. This could explain why Dairy 9 and 10 (the 9th and 10th largest dairies), despite having a large deviation from target in kg, did not show the same extend of deviation as a percentage. Likewise, 6 dairies showed an important deviation below the target weight as a percentage, but only 2 dairies when deviation was expressed as kg. Dairy 4 showed the largest deviation above target weight in kg, but Dairy 23 (the 4th smallest dairy) had the largest deviation as a percentage. It is quite common that owners and nutritionists set feeder performance goals based on deviation from target as percentage rather than kg. Deviation from target weight expressed in percentage is a good tool to assess the extent of loading errors and their potential implications on the final nutrient composition of the recipe. However, deviation from target weight in kg is a better tool to monitor feeder performance. If feeder loading errors are mostly under the target weight, the assigned TL should be re-evaluated. Also, it is important to ensure that inaccuracies at loading are not due to equipment failure. The mixer box scale should be calibrated frequently and scale bouncing during mixing should be kept to a minimum. Based in our field experiences, we have observed mixer scales bouncing up to 40 kg. This situation makes it extremely difficult for the feeder to weigh ingredients accurately. On a 2010 feeding management survey, it was reported that dairy producers and managers neglected to check the mixer box scale enough (Silva-del-Río et al., 2010).

Deviation from Target Weight by Ingredient Type

The deviation from target weight, as kg, for the 8 most common ingredient types is represented as a box plot in Figure 5. Straw, wheat silage, by-pass fat, mineral-vitamins and canola were loaded in 10.0% to 14.3% of the dairies with a median deviation of > 2% from the target weight, however by-pass fat, straw, alfalfa hay, liquids, DDG, whole cottonseed, almond hulls, corn gluten feed, and mineral-vitamins were loaded in 13.2% to 42.8% of the dairies with a median deviation of < - 2% from the target weight. The most extreme deviation over the target weight was observed for by-pass fat on Dairy 7 (21.9%), with a median target weight of 76 kg. The most extreme deviations under the target weight were observed for by-pass fat [-24.3% (Dairy 17); -44.7% (Dairy 11); -78.7% (Dairy 14)] and mineral-vitamins [-62.5% (Dairy 17)]. This could be explained by the low median target weight loaded for by-pass fat [247 kg (Dairy 17); 23 kg (Dairy 11); 40 kg (Dairy 14)] and mineral-vitamins [135 kg (Dairy 17)]. It is possible that most ingredients with extreme deviation from target weight were loaded as whole bags or were weighted prior to being added into the mixer box. In situations where the mixer was running during loading, the large deviation from target weight could be simply explained by mixer scale errors such as a scale bouncing rather than a lack of feeder accuracy when loading minimal quantities.

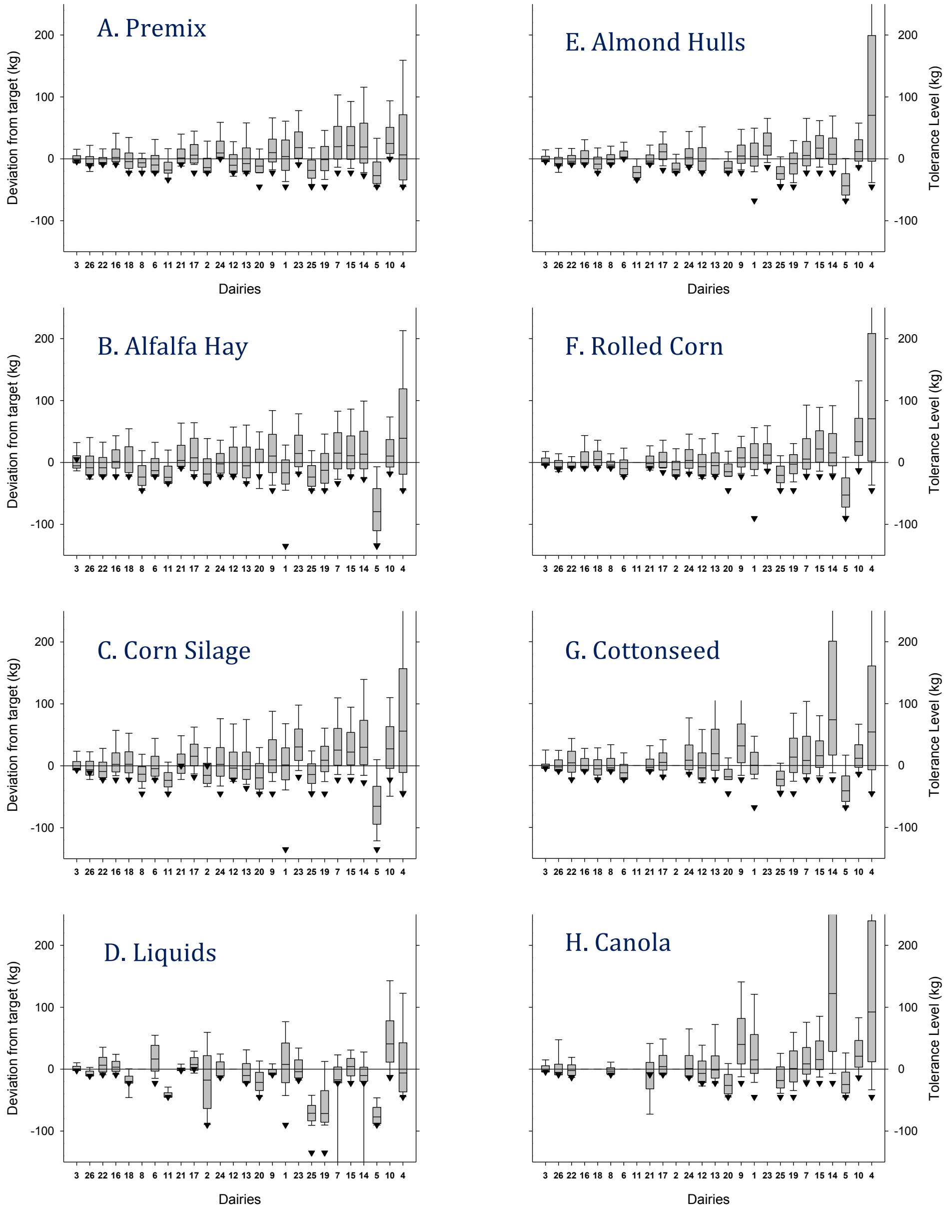


Figure 5. Boxplot distribution of the deviation from target weight for eight of the most common ingredients of the high cow ration and high cow premix recipes during a twelve month period on 26 California dairies. The tolerance level is represented in the secondary X-axis as ▼. Data is presented sorted by overall IQR (Q_3 - Q_1). The boxplot shows the 50th percentile (median, line within the box), 25th and 75th percentile (box), and 10th and 90th percentiles (whiskers). **Notes**: whisker reaches, **C**: 300 kg (Dairy 4); **D:** -640 kg (Dairy 7), -440 kg (Dairy 14); **E**: 450 kg (Dairy 4); **F**: 380 kg (Dairy 4), **G**: 400 kg (Dairy 14), 280 kg (Dairy 4), **H**: 500 kg (Dairy 14; Q_3: 300 kg), 350 kg (Dairy 4).

Deviation from Target Weight for HCR and HCP recipe

The box plot of the absolute deviation from target for HCR as a percentage is represented in Figure 6. The absolute deviation from target was more than 2% at least 50% of the time on 7 dairies. The real values of the median deviation for HCR recipe were either below the target weight on 10 dairies [< -2% (n = 2), -2 to < -1% (n = 2), -1 to 0% (n = 6)] or above the target weight on 16 dairies [> 0 to 1% (n = 11), > 1 to 2% (n = 3), > 2% (n = 2)].

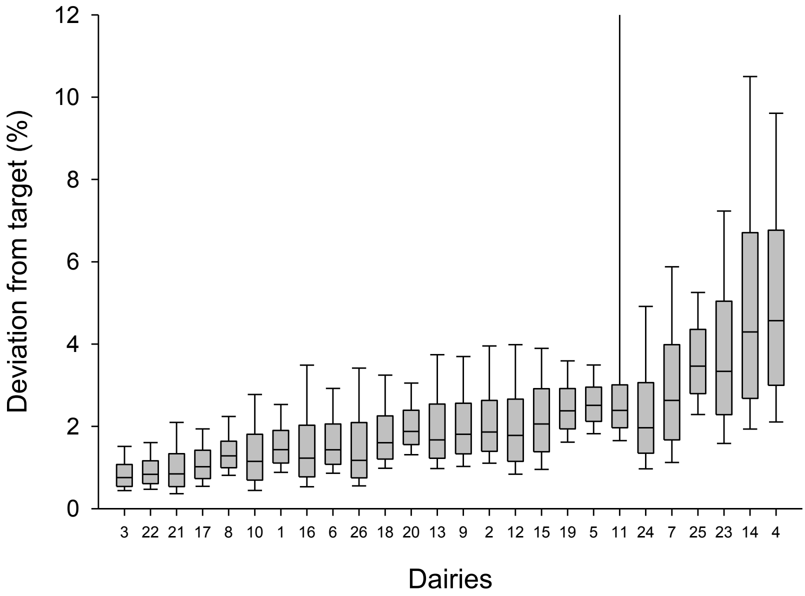


Figure 6. Boxplot distribution of the deviation from target weight (as an absolute value, %) for high cow ration on 26 California dairies. Data is presented sorted by 75th and then by the 50th percentile. Note: upper whisker of Dairy 11 reach 33 %.

The box plot of the absolute deviation from target for HCP as a percentage is represented in Figure 7. The absolute deviation from target was more than 2% at least 50% of the time on 3 dairies. The real values of the median deviation from target weight for HCR recipe were either below the target weight on 4 dairies [< -2% (n = 0), -2 to <-1% (n = 2; Dairy 5 and 25), -1 to 0% (n = 2)] or above the target weight on 17 dairies [> 0 to 1% (n = 13), > 1 to 2% (n = 2), > 2% (n = 2)].

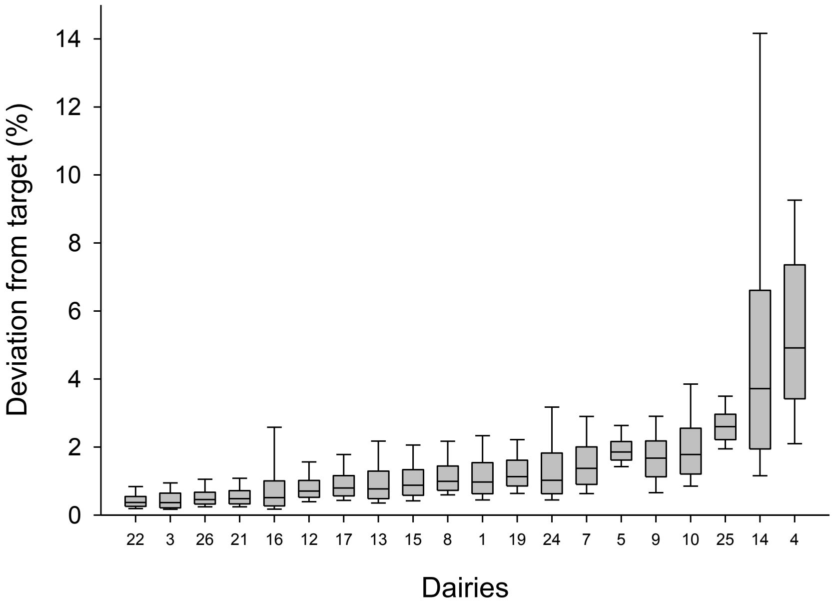


Figure 7. Boxplot distribution of the deviation from target weight (as an absolute value, %) for high cow premix on 26 California dairies. Data is presented sorted by 75th and then by the 50th percentile.

Our results indicated that on most dairies HCP was prepared within a reasonable absolute deviation from its target as percentage. However, there are opportunities to improve the absolute deviation from target for HCR. Although HCP is designed to mix ingredients that otherwise will be added in small quantities into the HCR, 17 dairies were adding at least 1 ingredient under 225 kg into the HCR, most commonly straw, by-pass fat or yeast. Only 6 dairies included at least one ingredient under 225 kg into the HCP. Thus, dairy producers and nutritionist should evaluate if ingredients added into the HCR should rather be included into the HCP. Furthermore, it should be taken into consideration that ingredients added in small quantities often times come in bags. Feeders prefer to load whole bags as the first ingredient to avoid getting in and out of the loader during recipe preparation. This practice can compromise mixing uniformity. It is likely that feeders would be more compliant with the ingredient order at loading if they had to do it twice (median HCP recipe loads/d) versus 6 (median HCR recipe loads/d; Table 1) times per day.

Deviation from Target Weight by Day of the Week

The percentage of ingredients loaded into the HCR and HCP with a deviation from target greater than 2% by day of the week was similar (CV < 10%) in 12 dairies. However, other dairies showed an important deviation (CV ranging from 10.8 to 54.8%, n = 14), that in most cases (n = 12), was explained by an extreme observation on a single day of the week.

On 5 dairies, there was an increase in the deviation from target weight on Wed [Dairy 24 (extreme day value vs. six days average): 27.7 vs 12.3%)], Thu (Dairy 25: 9.7 vs 5.4%) and Sun (Dairy 1: 22.5 vs 16.4%; Dairy 18: 20.8 vs 15.7%; Dairy 23: 52.8 vs 36.8%). Nevertheless, on 7 dairies a reduction of deviation from target weight was observed on Mon (Dairy 10: 28.7 vs 37.6%), Wed (Dairy 9: 27.8 vs 36.0%; Dairy 17: 17.6 vs 23%), Sat (Dairy 8: 9.0 vs 24.9%; Dairy 13: 22.8 vs 36.1%; Dairy 26: 9.3 vs11.9%), and Sun (Dairy 16: 21.2 vs 29.7%).

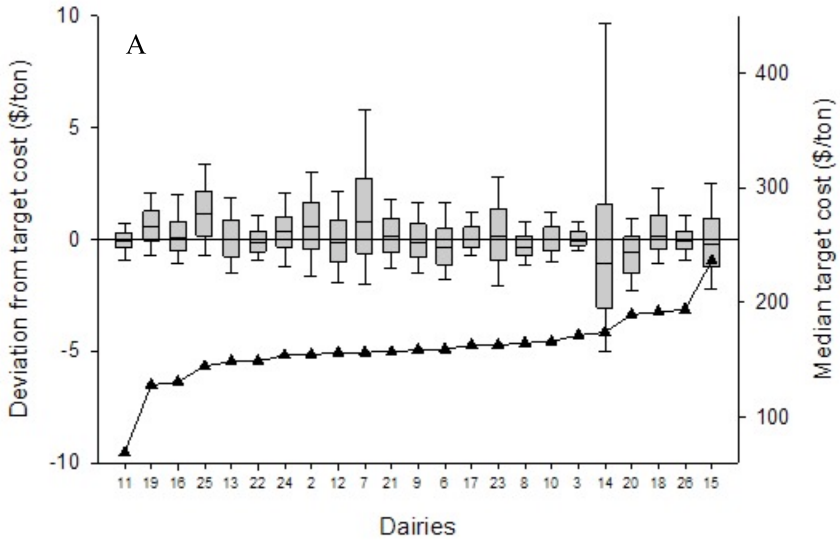
Variation in deviation from target in relation to the day of the week could be related to differences in loading accuracy between the primary and secondary feeder.

In our study, we did not use the FMS information on feeder ID as we observed that the primary user logged at least 85% of the days on 6 dairies, and between 82% to 85% of the days on 8 dairies. Taking into account that most feeders get at a minimum one day off a week and at least two weeks of vacation, others than the primary feeder were likely logged in under the same feeder ID. On Virginia dairies, there was no significant difference in deviation from target between the primary (1.57%) and secondary (1.26%) feeder (James and Cox, 2008). Contrary to their initial hypothesis, secondary feeders had a numerically inferior deviation from target. James and Cox (2008) speculated that bad working habits acquired by the main feeder might have played a role in feeding errors. Information on feeders performance may be used to establish goals and rewards among operators within a dairy, however based on our field experience dairy nutritionists and dairy managers are paying little attention to FMS records to evaluate feeders. Thus, dairy managers are giving minimal attention to ensure feeders are logged in with their unique ID each time.

Deviation from Target Recipe Cost

The deviation from target cost for HCR and HCP recipe is represented in Figure 8. As a result of deviations from the target weight, the HCR recipe cost increased by at least $3 per ton < 5% (n = 15), 5 – 20% (n = 6) or > 20% (Dairies 7 and 14) of the times. It also decreased by $3 per ton < 5% (n = 18), 5 – 20% (n = 4) or > 20 % (Dairy 14) of the times. Some dairies were consistent in the final recipe cost relative to the target cost (IQR: $0.3/ton, Dairy 3), but other dairies fluctuated largely (IQR: $4.6/ton, Dairy 14).

The HCP recipe cost increased by at least $3 per ton < 5% (n = 13) or 5 – 20% (n = 4; Dairies 10, 14, 15 and 17) of the times or decreased by $3 per ton < 5% (n = 14), 5 – 20% (n = 2; Dairies 14 and 15) and > 20% (Dairy 17) of the time. The within dairy variation, based on IQR ranged between $0.3/ton (Dairy 22) to $5.3/ton (Dairy 17).



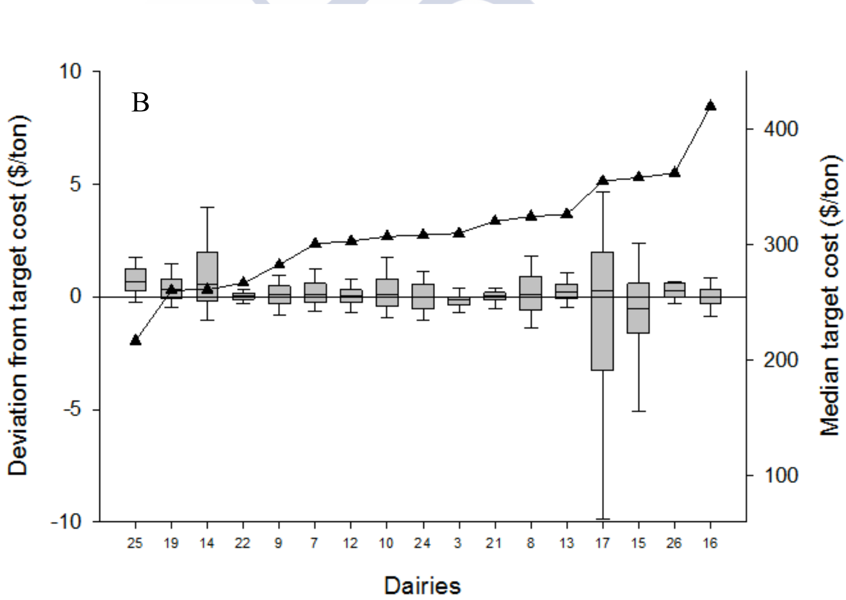


Figure 8. Boxplot distribution of the deviation from target cost by high cow ration (A, n = 23) and high cow premix (B, n = 17) recipes on California dairies. Median target cost is represented in the secondary X-axis as ▲. Data is presented sorted by the smallest to the largest median target cost. The boxplot shows the 50th percentile (median, line within the box), 25th and 75th percentile (box), and 10th and 90th percentiles (whiskers).

It is accepted that by overloading ingredients recipe cost will increase. On Dairy 14, HCR recipes were mostly prepared under the target cost by at least $1 per ton, even though the feeder frequently overloaded ingredients (Figure 4). It is likely the feeder was paying attention to detail when loading costly ingredients but not when loading relatively inexpensive ingredients. Conversely, on Dairy 25, HCR and HCP recipes were prepared generally over the target cost per ton, but very few ingredients on this dairy were loaded over the target weight as the TL was very restrictive (Figure 1). Expensive ingredients may have been loaded closer to the target than inexpensive ingredients.

Our results reflect the changes in recipe cost per ton associated with deviations from the target weight. To estimate the true economical implications of loading actions, the impact on production associated with changes in nutrient composition as well as the final amount of feed per pen should have been taken into consideration. On most dairies, nutritionists formulate least cost rations, thus any modification to the formulated recipe will most likely have a detrimental impact on income over feed cost.

Distribution of the Deviations from the Target Weight based on Q_1, Q_3 and IQR

By Dairy. The deviation from target weight across dairies for the 8 most common ingredients based on Q_1, Q_3 and IQR is represented in Table 2. These results provide guidelines for producers and the allied industry on achievable goals at loading. There were 5 dairies (Dairy 3, 16, 18, 22 and 26) that loaded almost all ingredients with adequate accuracy (small Q_1) and precision (small to moderate IQR). However, there were 4 dairies where feeders showed inadequate accuracy (moderate to large Q_1) by either overloading (Dairy 4 and 14) or under loading ingredients (Dairy 5 and 11). Loading precision was poor on Dairy 4, 5 and 14 (large IQR), but good on Dairy 11 (small IQR). It is likely that by reducing or eliminating TL on Dairy 11 the feeder could have been accurate. Six dairies (Dairy

4, 5, 7, 10, 14 and 15) loaded at least 50% of the ingredients with a large deviation from target (Q_3: | > 40| kg), that represented up to a 14.5% of deviation. Dairy nutritionists and managers should actively engage with the feeder to improve loading performance on dairies with poor precision and accuracy.

Table 2. Distribution of the deviation from the expected target weight (in absolute values, kg) based on the interquartile range (IQR), 25th percentile (Q_1) and 75th percentile for the eight most common ingredients (premix, alfalfa hay, corn silage, rolled corn, almond hulls, liquids, cottonseed, and canola) included into high cow ration and high cow premix recipes on 26 California dairies.

Ingredient type		Dairies																									
		3	26	22	16	18	8	6	11	21	17	2	24	12	13	20	9	1	23	25	19	7	15	14	5	10	4
IQR (Q_3 - Q_1)	Premix	2	11	4	12	15	12	14	14	14	16	12	28	15	19	14	24	29	36	23	24	42	41	45	24	42	49
	Alfalfa hay	6	17	14	15	15	24	11	18	23	29	19	14	20	21	41	32	27	33	25	28	35	31	39	66	29	90
	Corn silage	0	14	14	15	15	19	14	20	19	26	21	30	20	22	30	31	29	45	23	27	48	41	61	54	60	128
	Rolled corn	3	6	4	13	13	5	14	–	11	9	14	14	18	14	12	16	20	23	21	19	29	40	36	41	63	175
	Almond hulls	0	11	4	8	13	5	12	16	4	17	11	10	16	–	13	16	16	31	18	22	22	28	24	31	23	171
	Liquids	2	6	17	9	9	–	29	7	1	13	57	8	–	12	24	4	31	10	24	43	9	14	15	26	73	34
	Cottonseed	0	8	14	7	14	5	14	–	7	14	–	25	21	44	11	52	14	–	20	33	36	31	182	34	26	131
	Canola	1	4	9	–	–	6	–	–	47	16	–	15	17	17	25	64	44	–	21	28	27	37	283	24	35	208
25th percentile (Q_1)	Premix	4	6	4	3	6	4	8	12	4	6	10	0	9	10	7	7	11	7	11	9	10	10	12	19	9	22
	Alfalfa hay	7	9	8	6	9	14	11	15	5	9	14	7	9	12	0	13	11	10	14	13	12	10	11	44	8	28
	Corn silage	5	6	7	6	7	9	8	14	7	8	11	9	10	10	11	10	12	13	9	9	12	12	13	41	19	29
	Rolled corn	3	5	4	4	4	3	8	–	4	6	8	6	8	9	10	7	9	7	12	7	8	10	9	32	15	32
	Almond hulls	3	5	4	4	6	3	0	13	4	6	10	5	9	–	9	6	8	9	15	9	9	9	8	28	8	31
	Liquids	1	4	5	3	13	–	9	38	1	4	19	5	9	–	12	4	14	7	58	42	13	6	9	61	18	18
	Cottonseed	4	4	8	4	6	6	8	–	4	5	–	7	9	13	10	14	8	–	13	12	11	9	22	25	7	29
	Canola	3	5	4	–	–	2	–	–	7	6	–	6	9	8	15	17	11	–	12	10	8	8	33	18	10	32
75th percentile (Q_3)	Premix	6	18	9	15	22	16	22	27	18	23	22	29	24	29	22	31	41	43	34	33	52	52	57	43	51	71
	Alfalfa hay	13	26	22	22	25	39	22	34	29	39	34	22	30	34	41	45	39	43	40	41	48	42	51	111	37	118
	Corn silage	6	20	21	22	22	29	22	35	27	34	32	40	30	33	42	42	42	59	33	36	60	53	74	96	79	157
	Rolled corn	7	12	9	18	18	9	22	–	15	16	22	20	26	23	22	24	30	30	33	27	38	51	46	73	78	208
	Almond hulls	4	17	9	13	19	9	12	30	9	24	22	16	26	–	22	22	25	41	33	31	31	38	33	59	31	202
	Liquids	4	11	23	13	22	–	38	45	3	18	76	13	22	–	36	9	46	18	83	85	22	21	24	87	92	52
	Cottonseed	4	13	23	11	21	11	22	–	12	20	–	33	31	58	22	67	22	–	34	45	47	40	205	60	33	160
	Canola	5	10	13	–	–	9	–	–	54	23	–	21	27	26	41	82	56	–	34	39	35	45	316	42	46	240

[1] IQR: white (|<20| kg), grey (|20| to |40| kg), dark (|>40| kg).

[2] Q_1: white (|<10| kg), grey (|10| to |20| kg), dark (|>20| kg).

[3] Q_3: white (|<25| kg), grey (|25| to |40| kg), dark (|>40| kg).

The two dairies with the more liberal TL (0 to 135 kg, Dairy 1 and 5) were owned by the same dairyman, shared the same manager and dairy nutritionist. However, on Dairy 5 deviation from target based on Q_1 was large (|18| to |44| kg) with most ingredients loaded under the target weight, whereas Dairy 1 was relatively accurate (Q_1 : |8| to |14| kg). On these 2 dairies feeders interpreted differently what the loading target was, either the one set by the TL (Dairy 5) or the true target (Dairy 1).

On Dairy 3, the feeder showed remarkable skills with quality precision (IQR: 0 to 6 kg), and accuracy (Q_1: |1| to |7| kg) with minor deviations from target (Q_3: |4| to |13| kg). Conversely, the feeder on Dairy 4 lacked desirable loading skills. On this dairy, precision was poor (IQR: 34 to 208 kg), accuracy was moderate to poor (Q_1: |18| to |32| kg) and there were extreme deviations from target (Q_3: |52| to |240| kg). On Dairy 3, the feeder was directly supervised by a feed manager that tracked inventory and frequently supervised feeder errors. It was likely that this close supervision influenced feeder performance. Moreover, on this dairy, minerals and feed additives were automatically added into the recipe with a micronutrient liquid dispenser, minimizing loading errors. The good accuracy and precision observed for alfalfa hay could be explained by hay processing prior to loading; however, it is unknown if the dairy was actually doing this. One frequent concern with increasing loading accuracy is the potential detrimental impact on feeder efficiency. Based on a companion paper evaluating recipe preparation times, Dairy 3 had a loading time within average. Thus, neglecting accuracy and precision in favor of time efficiency might be a misconception.

By Ingredient. Rolled corn and almond hulls were easy to load. On at least 64% to 80% of the dairies, these ingredients were loaded precisely (IQR: < 20 kg) and accurately (Q_1 | < 10| kg). However, a total of 56.0% of the dairies loaded almond hulls with a deviation from target that ranged from 2.6 %to 14.5% based Q_3. Of those dairies, median inclusion rate of almond hulls ranged between 207 to 5,117 kg, representing 2.4% to 29.6% of the as-fed weight of the recipe.

Overall, 60.0% to 61.5% of the dairies had poor precision (IQR: > 20 kg) when loading alfalfa hay, corn silage and canola. Alfalfa hay, corn silage and canola were loaded with a large deviation from target (Q_3: | > 40| kg) on 34.6%, 38.5% and 45.0% of the dairies. This represented a deviation from target weight of 2.1% to 12.9% (alfalfa hay), 2.2% to 5.5% (corn silage) and 2.3% to 7.3% (canola). As expected, alfalfa hay was one of the most challenging ingredients to load accurately and precisely. Alfalfa hay particles are prone to attach to one another forming flakes that fall together during loading. Alfalfa hay represented 5.4% (Q_1) to 9.9% (Q_3) of the as-fed HCR recipe. Likewise, canola is an ingredient that flows rapidly from the bucket of the loader requiring excellent skill to load accurately. Canola represented 12.5% (Q_1) to 33.0% (Q_3) of the as-fed HCP recipe.

Corn silage was not expected to be difficult to load as it flows easily during unloading. Corn silage is a relatively inexpensive ingredient and primary component of HCR representing 26.5% (Q_1) to 38.9% (Q_3) of the as-fed ration. Feeders may not be as careful when loading corn silage compared to more expensive ingredients. Also, the distance between the mixer and the corn silage structure may play a role in the feeder accuracy. Often times the corn silage structure is placed far from the mixer, and the feeder will have to make an extra trip to acquire more silage or return leftovers to the structure. It may be easier for the feeder to dispose of the extra feed in the mixer and move to the next ingredient or manually advance if the target was not reached.

Five dairies (Dairy 2, 5, 10, 19, 25) loaded liquids with an extreme deviation from target weight (Q_3: | > 75| kg). On those dairies, liquids had a deviation from target that ranged from 6.2 to 25.1%. Liquids are added last to the recipe. Often times, the feeder has to get out of the loading equipment and manually open the faucet. The time to load the formulated liquid depends on the pipe design and viscosity of the liquid, especially for molasses in winter. Our results indicate that on these dairies the feeder might often forget to close the faucet in time.

CONCLUSION

Opportunities to improve feeder performance were observed based on loading errors. The TL settings introduced an important deviation from target weight for some ingredients. Dairy producers should evaluate if readjusting the TL settings for some ingredients could reduce the deviation from target. Deviation from target may be influenced by ingredient type. Some ingredients (rolled corn and almond hulls) were loaded with mostly adequate accuracy and precision, whereas others (alfalfa hay, corn silage and canola) were mostly loaded with poor accuracy and precision. Our results indicated that some dairies were able to load ingredients with minimal deviation from target weight suggesting that some poor performing dairies could set higher goals for loading accuracy and precision on their operations.

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3

Total mix ration preparation and feeding times for high producing cows on 26 California dairies.

Adapted from:

Y Trillo, A Lago, N Silva-del-Rio. Total mix ration preparation and feeding times for high producing cows on 26 California dairies.

Sent for publication

ABSTRACT

Mixing time plays a critical role in feed bunk nutrient uniformity and proper particle length of total mix dairy rations. The objective of this study was to describe within and across dairies the variability of high producing cow ration (HCR) preparation and feeding time. Twenty-six California dairies were enrolled, ranging in size from 1,100 to 6,900 cows. Consecutive records from a 12-month period were extracted from the feeding management software FeedWatch 7 (50,909 HCR loads; 487,218 ingredients loads). Descriptive statistics were conducted with SAS 9.4. The interquartile range (IQR: Q_3-Q_1) was used as a measurement of variability. The median HCR preparation time across dairies ranged from 9 min 18 s to 27 min 0 s. Four dairies were relatively consistent on their HCR preparation time (IQR < 3 min) whereas 3 dairies were not (IQR > 6 min). The median elapsed time from last ingredient loaded to feeding ranged from 1 min 54 s to 9 min 0 s. After HCR was prepared feeding started in < 3 min at least 70% of the time (n = 6) or > 10 min at least 20% of the time (n = 6). Six dairies were relatively consistent on HCR feeding time (IQR < 1 min) whereas 2 dairies were inconsistent (IQR > 5 min). Feeding took < 2 min at least 20% of the time (n = 4) or > 10 min at least 45% of the time (n = 3). On 8 dairies time elapsed between ingredient loads was under 30 s at least 15% of the time, suggesting that the feeder may have improperly loaded the leftovers from these ingredients as the next ingredient. Extremely long, short, or inconsistent times were observed on some dairies, warranting further evaluation of the implications of these feeding management practices on California dairies.

Keywords: dairy cows, feed management software, mixing time, total mix ration

INTRODUCTION

Over the past decades, great progress has been made in understanding nutrient requirements of cattle, and in creating ration formulation models. However, there are opportunities to improve feed efficiency on dairies through management (Sova et al., 2014; Rossow and Aly, 2013). Dairies incorporating a feed management software (FMS) on their operations can track the weight and time of ingredients loaded and generate reports (i.e. sequence of ingredient loading, loading errors, feeding times, mixing time, and time between individual ingredient loads). Mixing time plays a critical role in feed bunk uniformity as well as in total mix ration (TMR) particle length (Zinn, 2004; Biermann, 2009; Buckmaster et al., 2014). Feed bunk mixing uniformity is a function of multiple factors related to recipe type (physical properties of ingredients, order of ingredients, load size), mixer box characteristics (type, brand, horsepower, presence of build-up, worn parts), and mixing time. Thus, the most appropriate mixing time will be a function of both recipe type and characteristics of the mixing equipment. If mixing time is too short, hay could end up being improperly processed. That could promote sorting behavior (Leonardi and Armentano, 2003; Devries et al., 2008) and affect milk yield and milk components (Oelberg and Stone, 2014). Nevertheless, over-mixing may end up favoring segregation of some ingredients and reducing excessively the particle length of forages (Kammel, 1999).

On most dairies, mixing starts as soon as the first ingredient is added. Thus, if recipe load preparation time varies widely within a dairy, physical properties of the TMR might be different across recipe loads. Evaluation of times during loading and feeding can provide insight into management practices implemented on dairies. Moreover, time elapsed between loads of ingredients can be used to monitor feeders. If it is too short it could indicate feeders are not taking time to return commodities leftover in the front-end-loader and they are loading those as the new ingredient. Thus, the objective of this study was to describe the variability within and across 26 California dairies of high producing cow recipe (HCR) preparation and feeding times.

MATERIALS AND METHODS

Data Collection and Dairies

Twenty-six California dairy cattle farms using FeedWatch 7 (Valley Agricultural Software Inc. [VAS], Tulare, CA) as their feeding management software (FMS) for at least 1 year were enrolled in the study. A 12-month data backup was obtained from the FMS for each farm. The final data set included information from Jan 2012 to May 2014. California dairy nutrition consultants and VAS personnel assisted with identifying dairies to participate in the study. Enrolled dairies were located in the San Joaquin Valley, ranging in size (lactating and dry cows) from 1,100 to 6,900 cows. Each dairy was given a number according to its herd size, from largest (Dairy 1) to smallest (Dairy 26). Dairies 1 to 6 had more than 4,000 cows, Dairies 7 to 20 had between 2,000 and 4,000 cows, and Dairies 21 to 26 had less than 2,000 cows. Records were extracted only from the HCR to standardize data interpretation across dairies. The number of recipe loads prepared per day (median [range]) was 6 (2 – 14), the number of ingredients per recipe was 8 (4 – 10), the recipe load weight was 10,000 kg (4,800 – 18,000 kg), the number of feeders registered in the FMS was 4 (1 – 6), the number of pens fed HCR was 8 (3 – 32), and the number of cows per pen was 206 (69 – 395).

Assembly and Structure of the Data Set

The consultant version of FeedWatch 7 was used to extract records from the setup function and user reports. The following records were obtained: date, recipe load number, feeding sequence, start loading time, end loading time, start feeding time, feeding tolerance level, end feeding time, and ingredient type. Time records were extracted from the FMS in military format (hh:min:ss AM/PM) and imported into a Microsoft Excel file for conversion into a 24 h configuration. A description of the variables obtained from the FMS is shown below.

Recipe Load Number. The number that identifies each recipe load.

Start Loading Time. The FMS registers the start loading time of an ingredient only after the minimum scale detection weight is reached. The minimum scale detection weight is set so the scale does not read small weight changes associated with mixing or driving.

Loading Tolerance Level. To avoid overloading ingredients, the FMS assigns a tolerance level (TL) to each commodity. When the amount of feed left to reach the formulated target is equal to or less than the assigned TL, the FMS asks for the next ingredient to be loaded. After reaching the TL, if there is a pause of 5 s or longer, the FMS will register the new weight as the next ingredient of the recipe.

End Loading Time. The FMS registers the end of loading time for an ingredient when the scale does not read any new weight for at least 5 s once the target weight set by the loading TL has been reached.

Start Feeding Time. The FMS registers the start of feeding when the mixer box doors are opened and feed is pushed out into the feed bunk.

Feeding Tolerance Level. To avoid delivering too much feed to a pen, the FMS assigns a tolerance level (FTL) per pen. When the amount delivered to a pen is equal to or less than the assigned FTL, the FMS asks to deliver feed to a different pen.

End Feeding Time. The FMS registers the end of a recipe load feeding by pen when the scale does not read any new weight for at least 5 s once the target weight set by the FTL has been reached.

Ingredient Type. There were 33 different types of ingredients used in HCR recipes across all dairies. However, the most common ingredients used in HCR were 8, representing 63.1% of the total observations and fed on at least half of the dairies: premix (n = 26), alfalfa hay (n = 26), corn silage (n = 26), liquids (n = 20), rolled corn (n = 19), almond hulls (n = 15), wet distiller grains (WDG; n = 14), and wheat silage (n = 14). Data presented by ingredient type only included information from the 8 most common ingredients used.

Calculations

Recipe Load Preparation Time. It is the time elapsed from the start loading time of the first recipe load ingredient to the end loading time of the last recipe load ingredient.

Time from Last Ingredient Loaded to Feeding. It is the time elapsed from the end of recipe load preparation to the start of feeding. During this time, the feeder could be mixing a recipe load, driving to reach the feed bunk, or both.

Feeding Time. It is the time elapsed from the start feeding time of the first pen to the end feeding time of the last pen fed for the same recipe load.

Time from Start of Recipe Preparation to End of Feeding. It is the sum of recipe load preparation time, time from last ingredient loaded to feeding, and feeding time. If the mixer box is working from the start of recipe preparation to the end of feeding, this variable will represent the total recipe mixing time.

Loading Time per Ingredient Type. It is the time that it takes to load each ingredient from start to end loading time. It was calculated for the 8 most common ingredients of the HCR recipe (premix, alfalfa hay, corn silage, liquids, rolled corn, almond hulls, WDG, and wheat silage).

Alfalfa Hay Loading Time. It was calculated as the time elapsed from the start loading time for alfalfa hay to the start loading time for the next ingredient. Thus, it included alfalfa hay loading time and the time elapsed until the next ingredient was added.

Time Elapsed between Ingredient Loads. It is the time elapsed between the end loading time of one ingredient and the start loading time for the next ingredient.

Data Analysis

Descriptive statistics were conducted with the PROC MEANS and PROC UNIVARIATE procedure of SAS 9.4 (SAS Institute Inc., Cary, NC). The 25th percentile (Q_1), the 75th percentile (Q_3), and interquartile range (IQR: Q_3 - Q_1) were computed using the PCTLDEF = 4 option in the output statement of the PROC UNIVARIATE. The IQR was used as a measure of variability within dairy.

RESULTS AND DISCUSSION

Data Screening

There were no feeding records on Dairy 2 for 2 consecutive months or on Dairy 11 for 40 non-consecutive days. This could likely be explained by equipment breakdown, communication problems between the software and the mixer box, or unintended deletion of historical information. On Dairy 6, recipes prepared with the stationary mixer box (20,498 ingredient loads, 62% of Dairy 6 observations) were assigned a recipe load number, but this number was discontinued when the TMR was transferred to a truck for feed delivery. Therefore, all Dairy 6 observations were used to evaluate recipe load preparation time, but loads prepared with the stationary mixer were not evaluated for time from last ingredient loaded to feeding and feeding time.

The same end and start time was registered for 2,697 (0.5%) ingredient loads on 4 dairies. All these observations were removed. They represented between 1.1 and 3.8% of the ingredient loads. For some ingredient loads, a value of 0 s corresponded to 0 kg loaded (n = 1,078), indicating that the feeder likely advanced manually to the next ingredient without loading it. But, for some loads, a value of 0 s corresponded to > 0 to < 60 kg (n = 675; representing < 10% of the target weight) or from 500 to 5,000 kg (n = 944; representing 10 to 30% of the target weight). The final data set at the recipe level did not include any of the recipe loads with one or more ingredients with a loading time of 0 s.

The same end and start feeding times were recorded from 2,411 (1.7%) feedings. Although some loads with the same start and end feeding time corresponded with 0 kg fed (n = 320), records indicated that on most loads (n = 2,091), there were less than 1,500 kg fed, representing < 10% of the target weight. All these observations were not included when feeding time was evaluated.

The final data set for loading times included 50,909 HCR recipe loads and 487,218 ingredient loads. The final data set for feeding times included information from 51,195 HCR recipe loads and 128,477 individual pen feedings.

Recipe Load Preparation Time

The median HCR recipe load preparation time across dairies ranged from 9 min 18 s to 27 min 0 s (Fig. 1 - A). Based on IQR, 4 dairies were consistent in their HCR recipe preparation time (IQR < 3 min), whereas 3 dairies were not (IQR > 6 min). On 4 dairies at least 10% of the time recipe preparation time was over 25 min. Recipe preparation could take longer if commodities are located far away from the feeding center, if there is a large number of ingredients included in the recipe, if the feeder gets interrupted during recipe preparation (i.e., signing for commodities just delivered), or if there are equipment problems. Based on the field experience of researchers, other factors may explain a lengthy recipe preparation time. For example, when knives are worn, some feeders try to improve hay processing by extending the loading process and increasing mixing time. Moreover, the payroll system implemented on dairies could influence time efficiency, with feeders slowing down when paid by the hour. On Dairy 20, the one with the lengthiest recipe preparation time, feeders were paid on a hourly base.

Feeders have raised the concern that loading ingredients accurately may require more time. However, the four dairies (Dairy 3, 26, 22 and 16) with the highest loading accuracy (Trillo et al., 2016) had a median recipe loading time within the IQR (Fig. 1-A).

At least 20% of the time, recipe preparation was under 10 min on 5 dairies. On these 5 dairies alfalfa hay was included in the HCR, with a median as-fed inclusion rate ranging from 4.4 to 12.1%. One important concern when recipes are prepared in a short span of time is the adequacy of ingredient mixing and hay processing, especially if not enough mixing time is allowed after the last ingredient is added before feeding. Insufficient mixing could have implications on health and production (Oelberg and Stone, 2014), especially if particle length of forages are long enough to be sorted.

Time from Last Ingredient Loaded to Feeding

The median elapsed time from last ingredient loaded to feeding ranged from 1 min 54 s to 9 min 0 s (Fig. 1 - B). Based on IQR, within-dairy variation ranged from 50 s to 10 min 50 s. The time from last ingredient loaded to feeding can be explained by the extra-mixing time allowed by the feeder, the driving distance from the feeding center to the high cow pens, or by the feeder performing other tasks in between (i.e., lunch break). Dairies with a large IQR should evaluate the possible sources of variation that explain the disparity of time from last ingredient loaded to feeding, and the possible implications of TMR physical properties.

On 6 dairies, at least 70% of the time there were < 3 min elapsed from last ingredient loaded to feeding. Most likely, on these dairies pens receiving HCR recipes were near the feeding center and feeders allowed minimal extra-mixing. However, there were 6 dairies that at least 20% of the time had > 10 min elapsed from recipe load preparation to feeding. On Dairy 6, at least 20% of the time the time from recipe preparation to feeding was 30 min to 1 h 30 min. Those recipe loads were always fed to the same 2 pens at around 11:00 AM. This observation could be explained by the feeder taking a break at the end of recipe load preparation but before feeding.

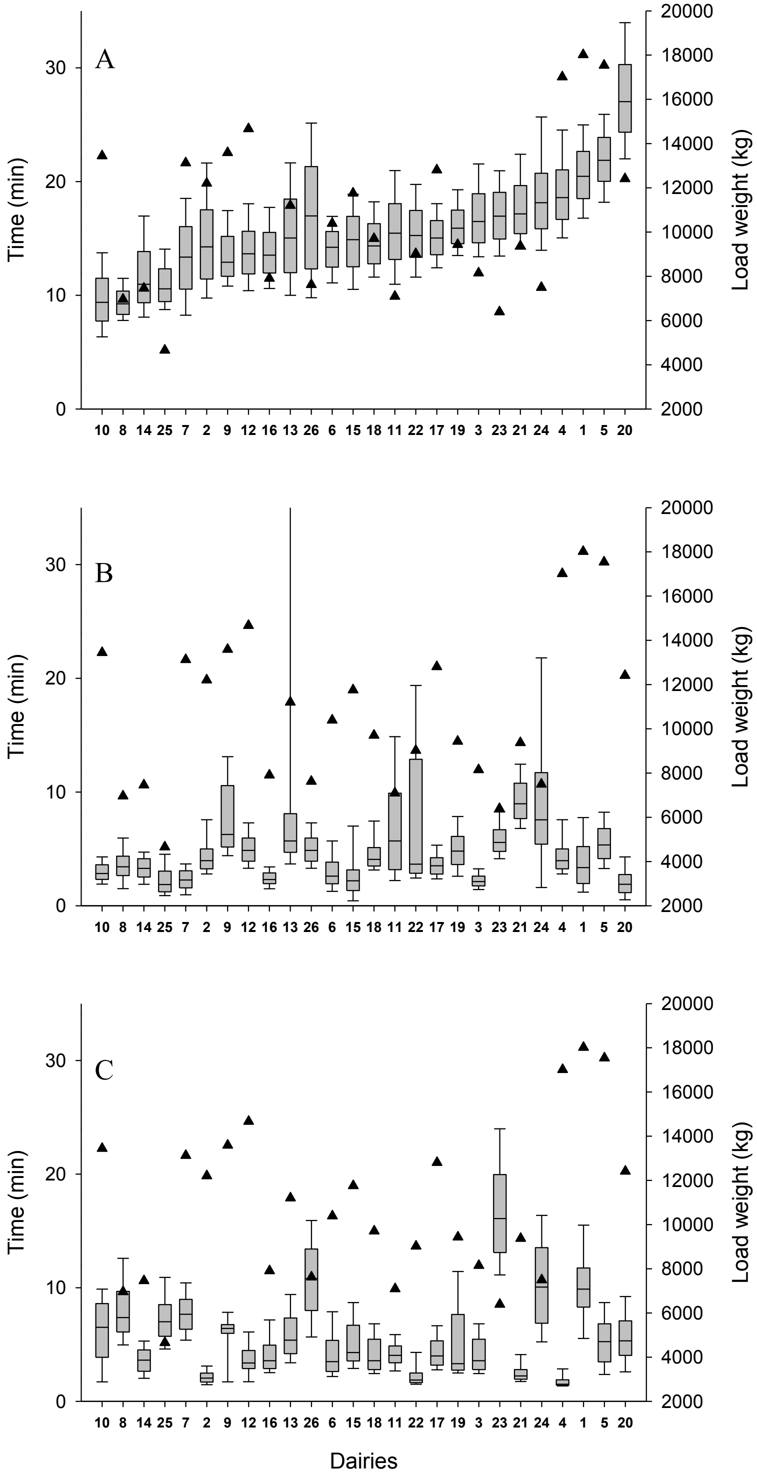
Twenty dairies added liquids as the last ingredient. In order for liquids to be uniformly incorporated into TMR, mixing time is critical. The time elapsed from last ingredient loaded (liquids) to feeding was < 3 min (n=8), 3 to 5 min (n=8) or > 5 min (n=4) on these 20 dairies.

Unfortunately, FMS are not designed to capture information on the mixing activity of the mixer box. Thus, it is not known if recipe loads with an extended time from recipe preparation to feeding were mixing for a long time, or if the mixing equipment was standing still whereas the feeder was performing other tasks.

Feeding Time

The median recipe load feeding time ranged from 1 min 30 s to 10 min 48 s (Fig. 1 - C). Six dairies were consistent on their feeding time (IQR < 1 min) whereas 2 dairies were inconsistent (IQR > 5 min). The time that it takes to feed a recipe load might be explained by a combination of the number of pens fed the same load of feed, the proximity of the pens fed the same recipe load, the final recipe load size, and the feeder driving skills.

On 4 dairies, at least 20% of the time feeding took < 2 min, with most loads (> 75%) fed to a single pen. However, on 3 dairies feeding took > 10 min at least 45% of the time. Most loads were fed to 2 to 4 pens. Some dairies might choose to offer fresh feed multiple times a day by splitting each load among multiple pens throughout the day. However, this practice may increase overall feeding time per day. On these 3 dairies that offered fresh feed multiple times a day, feeding took up to 3 h/day.



A
B
C
Time (min)
Load weight (kg)
0
10
20
30
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
10 8 14 25 7 2 9 12 16 13 26 6 15 18 11 22 17 19 3 23 21 24 4 1 5 20
Dairies

Figure 1. Boxplot distribution of the preparation time (A), time between the last ingredient load to the first feeding (B) and feeding time (C) for the high cow ration recipe during a 12 month period in 26 dairy cattle farms in CA. The median recipe load weight is represented in the secondary Y-axis as ▲. Data is presented sorted by 25th percentile (Q_3), and then by the interquartile range (IQR) for panel A. The boxplot shows the 50th percentile (median, line within the box), 25th and 75th percentile (box), and 10th and 90th percentiles (whiskers). **Notes**: whisker reaches: (**B**) 50 min (Dairy 13).

Time from Start of Recipe Preparation to End Feeding

The time elapsed from the start of recipe load preparation to the end of feeding is shown in Fig. 2 for the first quartile (Q_1; Fig. 2 - A) and third quartile (Q_3; Fig. 2 - B). The median time from the start of recipe load preparation to the end of feeding was 25 min and ranged from 14 to 42 min. Based on IQR, within-dairy variation ranged from 5 to 50 min. If the mixer box was operating from loading to feeding, this time will correspond with mixing and hay processing time per recipe. The most desirable mixing and hay processing time is a function of multiple variables such as ingredient type, ingredient loading order, type of mixing equipment, and rpm of mixing equipment. Data from FMS can provide information on some factors affecting time from recipe preparation to feeding (i.e., number of ingredients, recipe load size, and number of pens being fed). However, if FMS data indicates important variability within a dairy, the most desirable approach would be to evaluate the TMR physical properties and feed bunk mixing uniformity as well as to understand the feeder work organization. In our study, 15% of the time Dairy 20 spent > 50 min from the start of recipe preparation to the end of feeding, whereas 16% of the time it took < 11 min. The large within-dairy variation observed on Dairy 20 warrants further investigation to identify potential management issues and their implications.

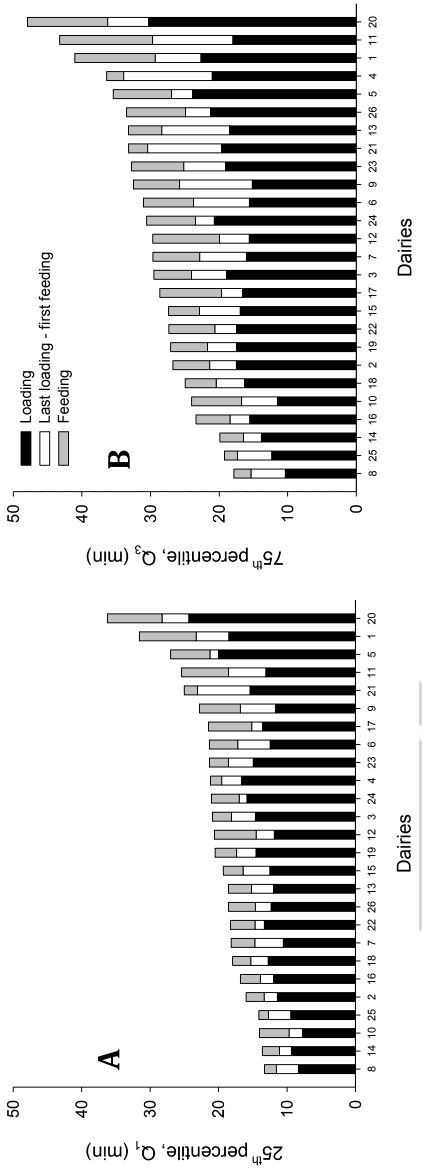


Figure 2. Time from high cow ration recipe preparation (loading), elapsed time from the last ingredient loaded to start feeding (last loading - first feeding), and feeding time (feeding) for the first quartile (Q_1: 25th; A) and the third quartile (Q_3: 75th; B) on 26 dairy cattle farms in CA. Dairies are presented sorted from the smallest to the largest time.

Loading Time per Ingredient Type

The median loading time per ingredient type ranged from 14 s (almond hulls) to 1 min 25 s (corn silage; Fig. 3 - A). On at least half of the dairies, the median loading time was under 30 s for almond hulls, rolled corn, and wheat silage, whereas it was over 1 min for liquids, alfalfa hay, and corn silage.

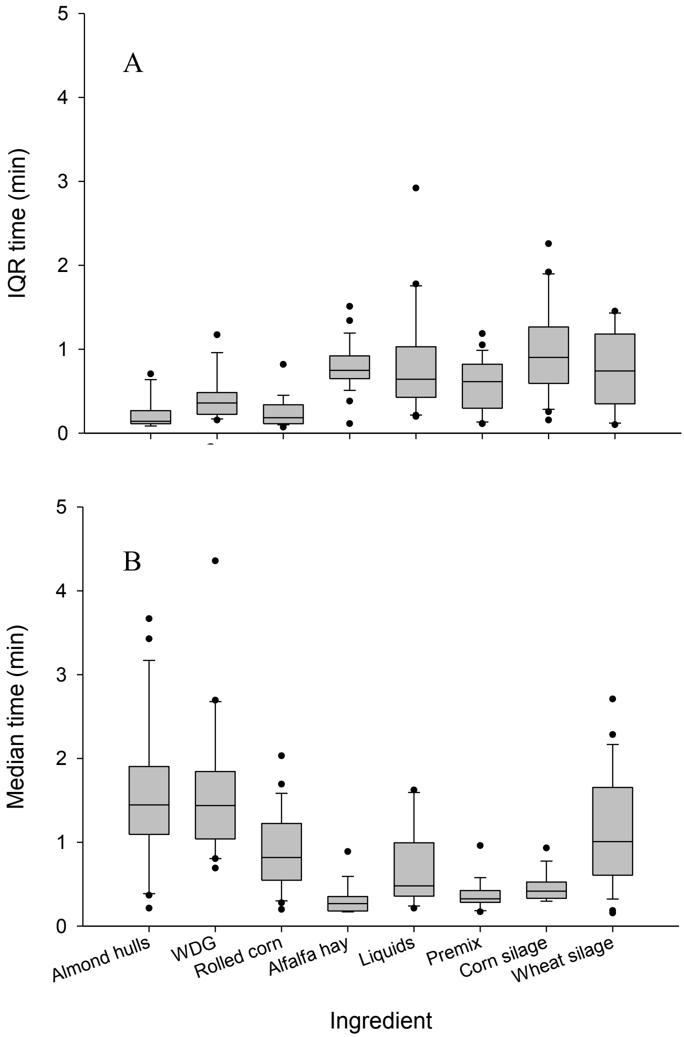


Figure 3. Boxplots of the median (A) and interquartile range (IQR = $Q_3 - Q_1$; B) of the loading time by ingredient among loads of the high cow ration recipe on 26 California dairies. Data is presented sorted by IQR (B). The boxplot shows the 50th percentile (median, line within the box), the 25th and 75th percentile (box), the 10th and 90th percentiles (whiskers), and outliers (dots).

On most dairies, the within-dairy variation for loading time was large (IQR > 40 s) for alfalfa hay, corn silage, and wheat silage (Fig. 3 – B). Possible explanations for this observation could be changes in silage DM that result in different number of trips to the silage pit or changes in the forage inclusion rate throughout the year to adjust for silage inventory. Liquid feeds were expected to show a large within-dairy variation, as the cold weather could make them more viscous and difficult to load, especially for molasses. However, in our study we failed to see that, most likely because of the mild winters in the Central Valley of California. It is likely that in regions with extreme cold winters the within-dairy variation would be more obvious.

Alfalfa Hay Loading Time

The time elapsed between the start loading of alfalfa hay to the next ingredient is represented in Fig. 4. The median time ranged from < 1 min (n = 1; alfalfa hay median load size of 315 kg), 1 to 3 min (n = 20; 330 to 1,500 kg), and > 3 min (n = 4; 900 to 2,000 kg). On most dairies (n = 19), alfalfa hay was loaded consistently (IQR < 1 min). To provide a good mixing of the TMR and prevent cattle from sorting against long particles, it has been recommended to process alfalfa hay before loading it into the TMR (Oelberg and Stone, 2014). Alternatively, alfalfa hay could be added slowly into the mixer box to allow for extra processing before loading the next ingredient (Kammel et al., 1999). Most California dairies prefer to process hay at the time of TMR preparation. On 20 dairies, alfalfa hay was loaded within 1 to 3 min; however, it is uncertain if this will allow proper hay processing before the next ingredient is added.

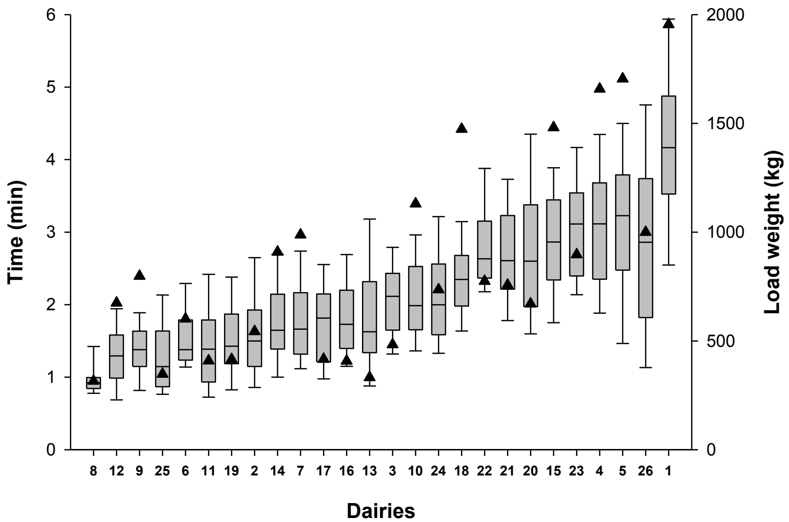


Figure 4. Boxplot of the time elapsed from start loading alfalfa hay to start loading the next ingredient for the high cow ration recipe on 26 California dairies. The median alfalfa hay load weight is represented in the secondary Y-axis as ▲. Data is presented sorted by 75th percentile (Q_3), and then by the interquartile range (IQR = $Q_3 - Q_1$). The boxplot shows the 50th percentile (median, line within the box), the 25th and 75th percentile (box), and the 10th and 90th percentiles (whiskers).

Time Elapsed Between Ingredient Loads

The median time elapsed between ingredient loads ranged across dairies from 40 s to 1 min 24 s (Fig. 5). Based on IQR, 5 dairies were consistent on the time elapsed between ingredient loads (IQR < 30 s), whereas 5 dairies were not (IQR > 1 min). The frequency that 0 to 15 s, > 15 to 30 s, and > 30 to 45 s elapsed between ingredient loads is represented in Fig. 6. On 8 dairies, at least 15% of the time (up to 49%) there were < 30 s elapsed between ingredient loads. However, on 3 dairies rarely (< 1%) time between ingredient loads was < 30 s.

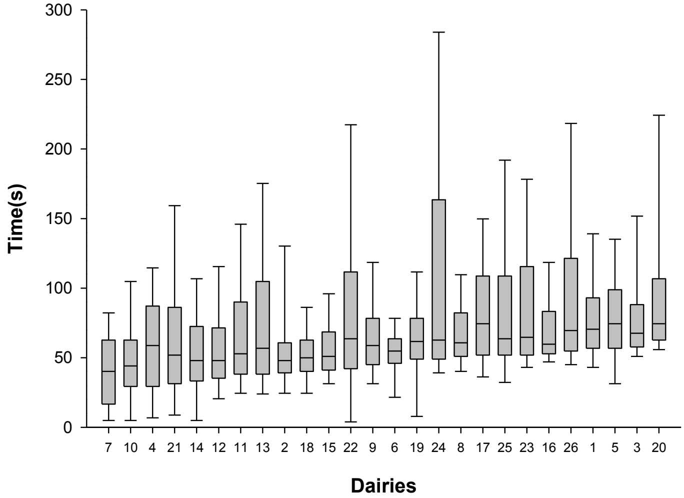


Figure 5. Boxplot of the time (s) elapsed between ingredients loaded in the high cow ration recipe on 26 California dairies. Data is presented sorted by 25th percentile and then by the interquartile range (IQR = $Q_3 - Q_1$). The boxplot shows the 50th percentile (median, line within the box), the 25th and 75th percentile (box), and the 10th and 90th percentiles (whiskers).

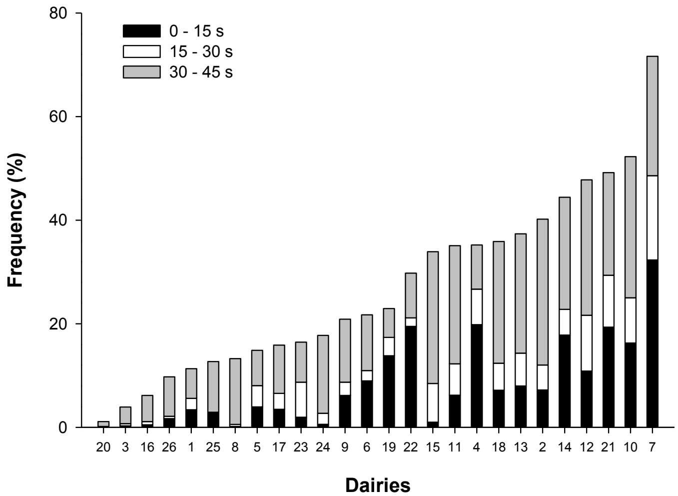


Figure 6. Distribution of the time elapsed between ingredient loads [0 to 15 s (black), > 15 to 30 s (white) and > 30 to 45 s (grey)] for the high cow ration recipe on 26 California dairies.

Once one ingredient is loaded, the feeder should take the leftovers back to the commodity barn before loading the next ingredient. If the time between loading ingredients is too short (i.e., <15 s), it is likely that the feeder is unloading the leftovers from the previous ingredient as the new ingredient. Based on our field experience, some feeders load a new ingredient without taking back leftovers from the previous ingredient. However, a short time lapse between ingredients might not always indicate poor feeder performance. It should be taken into account that the FMS can be used to set a fixed loading time per ingredient. The purpose of this feature is to allow extra mixing time, especially for hay. In this case, the feeder may have time to load the next commodity and be waiting with a full front-end loader for the FMS to ask for the next ingredient.

On 3 dairies, time elapsed between ingredient loads was < 15 s at least 15% of the time after loading premix, alfalfa hay, and corn silage. These results suggest that the feeder may have improperly loaded the leftovers from these ingredients as the next ingredient. The impact of these actions cannot be determined. However, some dairy producers and nutritionists are using this information as a quality control variable to assess the performance of feeders. Based on our field experience, there are dairies where the feeder and dairy producer have reached an agreement and accepted, to some degree, these practices with the expectancy to improve time efficiency. However, this practices might not be recommended.

At least 15% of the time, 10 dairies loaded ingredients after more than 2 min elapsed from the previous ingredient, most often corn silage (n = 6), premix (n = 3), or wheat silage (n = 3). Time between ingredient loads of more than 10 min represented 0.1 to 3.0% of the loads across dairies. On some dairies, commodities and silage structures could be stored far from the feeding area, increasing the time elapsed between ingredient loads. Also, we have observed that some feeders performed additional tasks during loading such as defacing silages. When a long span of time is observed between ingredient loads, it is important to talk to the feeder and evaluate if his work organization is as efficient as it could be.

CONCLUSION

Feed management software data can provide valuable insights on management practices implemented on dairies. There was wide variation within and across dairies on time from start of recipe load preparation to feeding based on FMS records. Dairy producers and consultants are likely underutilizing FMS to evaluate feed management practices. The present information on time from recipe loading to feeding could be used to compare a dairy operation with their peers and re-evaluate current practices. Records of time between ingredient loads could be a useful tool to evaluate if feeders are returning leftovers to the commodity barn or if they are loading them as a new ingredient.

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Conclusions / Conclusiones

From this thesis we have concluded that the big variation on management practices across dairies may allow other dairies to find opportunities to improve by benefitting from benchmarking.

Galicia farms

The prevalence of over- and underweight cows, lameness and hock injuries had a big range for improvement on several farms, while cleanliness of the cow coat had huge opportunities to improve in all assessed farms. Those indicators may vary with facilities design and management practices which critical points were found at high stocking density of the stall and headlocks, small front lunge space, poor natural ventilation and poor design of the milking parlour area.

California farms

Feed management software (FMS) data showed a wide variation within and across dairies on management practices such as ingredients inclusion and, preparation and delivery times of the high cow recipe. The deviation from ingredient target weight help to assess ration composition while mixing time indicate hay processing and ration homogeneity and, feeding time measures job routine and schedules. Feeders with low precission while loading ingredients also speeded preparing the ration. Several dairy producers may consider readjusting the TL settings of some ingredients to improve feeder load accuraccy however it may be also influenced by ingredient type. FMS can be a great tool to monitor ration preparation and delivery. However some data such as type of ingredient load, extra mixing time or pen fed cannot be detected by the FMS and additional observation on the field is required to confirm cheating actions.

De esta tesis se ha concluido que la gran variación que existe en las prácticas de manejo entre ganaderías permite usar estos valores de referencia para encontrar oportunidades de mejora.

Ganaderías de Galicia

La prevalencia de vacas con sobrepeso o muy delgadas, cojas y con lesiones en el tarso tuvieron un amplio margen de mejora en varias ganaderías, habiendo muchas oportunidades de mejora en la higiene de los flancos. Estos indicadores pueden variar con el diseño de las instalaciones y las prácticas de manejo cuyos puntos críticos se encontraron en la densidad de vacas tanto en cubículos como en colleras, escaso espacio frontal libre, escasa ventilación natural e inadecuado diseño de las sala de ordeño.

Ganaderías de California

Los datos del software de manejo alimentario mostaron una amplia variación intra e inter ganaderías en prácticas de manejo tales como inclusión de ingredientes y, tiempos de preparación y descarga de la ración de alta producción. La desviación del peso objetivo del ingrediente ayuda a evaluar la composición de la racion mientras que el tiempo de mezclado indica el procesado del heno y homogeneidad de la ración y, el tiempo de descarga permite conocer la rutina de trabajo y los horarios. Los alimentadores con poca precisión en la carga de ingredientes también fueron muy rápidos preparando la ración. Varios productores deben considerar el ajuste de los niveles de tolerancia de algunos ingredientes para mejorar la exactitud de carga del alimentador, sin embargo, esto puede variar también con el tipo de ingrediente. Los programas de manejo alimentario pueden ser una herramienta muy útil para monitorizar la preparación y descarga de raciones. Sin embargo, algunos datos, como el tipo de ingrediente cargado, tiempo de mezclado extra o número de corral alimentado, no son detectados por el programa y se requiere de observación adicional en el campo para confirmar posibles acciones erróneas.

SUMMARY/RESUMEN

The objective of this thesis is to describe animal-based, facility design and management practices measures of cow comfort. Observations were made once in 73 Galician farms while specific parameters of the feeding management practices were collected from one year software records in 26 California dairies.

In Galician farms, animal-based indicators had a prevalence [median (range)] of 52% (13-90%) for inadequate BCS to the stage of lactation, 40% (7-100%) for hock injuries, 9% (0-60%) for clinical lameness, and 73% (38-100%) for dirtiness of cows' coat. Those results may be a reflection of the variation in facilities design and management practices, which critical points were located at stocking density of the stalls and headlocks, the small front lunge space of the stalls, poor natural ventilation, and poor design of the milking area.

In California farms, loading accuracy and precision was adequate on 5 farms; however, it was poor on 4 farms. Rolled corn and almond hulls were loaded with good precision and accuracy, whereas alfalfa hay, corn silage and canola were not. On eleven farms at least 50% of the ingredients had a deviation allowed by the tolerance level above 2%. Across dairies recipe load preparation time ranged from 9 min 18 s to 27 min 0 s. Four dairies were relatively consistent on their recipe preparation time (IQR < 3 min) whereas 3 dairies were not (IQR > 6 min). On 8 dairies time elapsed between ingredient loads was under 30 s at least 15% of the time, suggesting that the feeder may have improperly loaded the leftovers from these ingredients as the next ingredient.

A wide range of variation was described in all management practices parameters. Most of the farms did not perform consistently well or poorly across parameters suggesting opportunities to improve by benefiting from benchmarking.

Key words: dairy cattle, welfare assessment, animal-based measures, facility-based measures, management practices, feeding management software.

El medio que rodea a los animales de producción varía entre explotaciones. De modo que, cuando se pretenden mejorar las condiciones en las que se encuentran los animales, parámetros como el diseño de instalaciones o las prácticas de manejo deben ser consideradas dentro de la evaluación del confort animal. El ***objetivo*** de esta tesis es describir indicadores de bienestar sobre los animales así como otras variables implicadas en el manejo de ganaderías de vacuno de leche. Para ello, se llevaron a cabo dos estudios en que los datos fueron tratados en un único análisis descriptivo usando frecuencias, medianas (percentil 50^{th} o segundo cuartil, Q_2) y los percentiles 25^{th} (primer cuartil, Q_1) y 75^{th} (tercer cuartil, Q_3). Para describir la variación se usaron rangos (min – max) o rangos intercuartílicos (RIC = Q3 – Q1).

El ***objetivo*** del Estudio 1 es describir el bienestar de los animales a través de parámetros observables en las vacas así como describir el tipo de intalaciones y prácticas de manejo en 73 ganaderías de la provincia de Lugo, Galicia - España.

Se realizó una auditoría en cada uno de los rebaños y en todos los animales, oscilando entre 20 y 244 vacas. Los parámetros recogidos sobre el animal incluyeron la condición corporal, lesiones del tarso, cojeras e higiene corporal, las medidas sobre las instalaciones se realizaron en las distintas áreas del establo: descanso, circulación, ventilación, alimentación y ordeño y, se cuestionó a los productores en diversas prácticas de manejo como el mantenimiento de las camas, sobrepoblación en los cubículos y trabadizas, frecuencia de limpieza, protocolos del baño de pezuñas, ajustes de los sistemas mecánicos de ventilación, y el comportamiento de las vacas en el área de ordeño.

Los resultados obtenidos permitieron clasificar a las ganaderías en base a las prevalencias de cada uno de los indicadores de bienestar recogidos sobre los animales:

- Estado de condición corporal en base a la fase de lactación en el momento de la evaluación. La puntuación se realizó en una escala de 1 a 5 con un incremento de 0.25 puntos. Dentro de cada ganadería las vacas se clasificaron en tres grupos: alta, baja y adecuada condición corporal.

- Lesiones en uno o ambos tarsos, tanto en la parte interna como en la externa de la pierna. Para cada ganadería se calculó el porcentaje de vacas con una o más lesiones.

- Cojeras. Se usó una escala de 1 a 5 basado en la metodología de Sprecher. Para cada ganadería se calculó el porcentaje de vacas con cojera clínica (puntuaciones 3, 4, 5).

- Suciedad en los cuartos traseros incluyendo la parte inferior de la extremidad trasera, ubre y flancos. Las vacas se clasificaron usando una escala de 1 a 4 para cada zona. Dentro de cada ganadería se calculó el porcentaje de vacas con una puntuación > 2 para cada zona y se obtuvo la media de dicho porcentaje como el total de vacas sucias en el rebaño.

Cada indicador se agrupó en tres categorías: A, B, C. De forma que, el 25% de las ganaderías con las prevalencias más bajas para un indicador determinado se incluyeron en la categoría A, el 25% con las prevalencias más altas entraron en una categoría C, y las restantes 50% se agruparon en una categoría B. Finalmente, las ganaderías se clasificaron por número de indicadores en las categorías asignadas y, tras realizar una exploración de los datos, se consideraron como las mejores ganaderías aquellas con al menos dos indicadores en la categoría A y ninguna en categoría C (n=11), por el contrario, las peores ganaderías tenían al menos dos indicadores en categoría C y ninguno en categoría A (n=11). Lo que sugirió una gran variación en las prácticas de manejo de una misma ganadería y entre ganaderías.

La prevalencia de los indicadores de bienestar animal en el 25, 50 y 75% de las ganaderías fue respectivamente: condición corporal inadecuada al estado de lactación de los animales (42, 52, 61%), lesiones del tarso (25, 40, 56%), cojeras clínicas (5, 9, 16%) y la suciedad del cuarto trasero de las vacas (63, 73, 83%).

Destaca especialmente la prevalencia de vacas por ganadería con una locomoción 2 del [mediana (rango)] 28.0% (7.7 a 56.7%), lo que podría derivar en cojera si no se corrigen prácticas de manejo específicas que mejoren el confort de los animales. Una de las sospechas podría radicar en la ausencia de protocolos para el baño de pezuñas, ya que los ganaderos informaron de no utilizarlo (57.5%) o hacerlo de forma inadecuada, tal como ausencia de renovación del producto por más de un mes (31.5%) o usarlo exclusivamente cuando ellos lo consideraban necesario (10.9%). Lugo es una región especialmente húmeda (Humedad Relativa: 80 a 100%) por lo que el uso frecuente del baño de pezuñas podría ser una práctica recomendable. Otra práctica que puede contribuir con alteraciones de la locomoción es el recorte funcional de cascos, que no se realizó en base a protocolos fijos en el 49.3% de las ganaderías. En esta situación, sería conveniente una monitorización del rebaño para conocer la evolución en el tiempo y encontrar la causa de dicha prevalencia cambiando las prácticas de manejo.

Por otro lado, también destacó la prevalencia de vacas sucias, sobretodo en la extremidad inferior del cuarto trasero con un [mediana (rango)] 95% (50.0 – 100%) de los animales, lo que puede relacionarse con la ausencia de protocolos de limpieza, ya que la mayoría de los ganaderos (86.3%) informaron de pasar la arrobadera al menos dos veces al día pero sin una rutina establecida. De modo que, la falta de limpieza que se refleja sobre los animales en combinación con la humedad del ambiente, podría estar favoreciendo la proliferación de microorganismos y por tanto constituir otro factor en el desarrollo de la locomoción 2 (e.g., la dermatitis, sin embargo los datos de dicha incidencia de enfermedad no estaban disponibles en ninguna ganadería).

Además, se encontró una variación considerable en el diseño de las instalaciones y otras prácticas de manejo, siendo los puntos críticos: la incidencia de la carga ganadera en los cubículos y en las trabadizas (31.5% y 26.0% respectivamente), el corto espacio frontal (<90 cm en el 90.4% de las ganaderías), la escasa ventilación de los establos (presencia de telarañas y áreas de humedad en el techo así como olor a amoníaco en el 32.8% de las ganaderías, y establos totalmente cerrados o parcialmente abiertos con una apertura que representa <50% de la pared lateral, en el 98.6% de los establos), y un diseño inadecuado del área de ordeño (los pasillos del área de ordeño no tenían un diseño lineal, sino que hacían dos o más giros de >90° en el 49.3% de los casos y el 45.2% de las salas no permitieron una visualización previa de la misma antes de la entrada de las vacas), lo cual puede explicar que el 52.0% de las ganaderos salieran a buscar al menos el 15% de las vacas para entrar en la sala de ordeño.

El manejo alimentario tiene importantes implicaciones en la salud del ganado lechero. Por ejemplo raciones mal mezcladas pueden llevar a que las vacas escojan de la ración las partículas finas derivando en problemas de acidosis o desplazamiento de abomaso. Además si hay errores al cargar y mezclar ingredientes críticos (e.g. sales anicónicas, minerales) se puede limitar la disponibilidad de ciertos nutrientes en el comedero. De modo que, se realizó un segundo estudio para completar parte de las prácticas de manejo en el área de alimentación.

El ***objetivo*** del Estudio 2 es describir la variación en los procesos de elaboración y descarga de las raciones de alta producción en 26 ganaderías de California.

Se extrageron datos de 12 meses almacenados en un software de manejo alimentario en cada una de las ganaderías, con un tamaño de rebaño que osciló entre 1,100 y 6,900 vacas. Todas las ganaderías incluidas en el estudio preparaban la ración con carros mezcladores verticales. Se prepararon una mediana de 6 raciones de alta producción al día incluyendo una mediana de 8 ingredientes en cada ración.

Este estudio se dividió a su vez en dos estudios.

El Estudio 2.1 describe los parámetros relacionados con los errores de pesada: nivel de tolerancia (margen de error permitido en las pesadas, kg), desviaciones del peso objetivo permitido por el nivel de tolerancia, desviaciones del peso objetivo calculado en kilos (peso cargado – peso objetivo) y en porcentaje (peso cargado-peso objetivo/peso objetivo*100), exactitud con la que se cargan los ingredientes (el percentil 25^{th} ó Q_1 se usó como medida para determinar el 25% de las cargas más exactas en cada granja), la precisión de carga de los ingredientes (el rango intercuartílico o $RIC=Q_3-Q_1$ se usó como medida para evaluar la variación dentro de una misma granja) y oportunidades de mejora en la carga de ingredientes (el percentil 75^{th} ó Q_3 se usó para determinar la desviación del peso objetivo para el 25% de las observaciones más extremas).

El Estudio 2.2 describe los parámetros del tiempo de preparación y descarga de la ración en el pesebre: tiempo total de preparación de la ración desde la carga del primer ingrediente hasta el último, tiempo entre el fin de carga de los ingredientes de la ración en el carro y el inicio de descarga de la ración en el pesebre, tiempo total de descarga de la ración en el pesebre que transcurre desde el inicio de la descarga en el primer corral hasta el fin de descarga en el último corral, tiempo de carga por tipo de ingrediente y tiempo que transcurre entre cada uno de los ingredientes cargados (desde el fin de carga del ingrediente anterior al inicio de carga del siguiente).

La mediana del nivel de tolerancia asignado a los ingredientes de todas las ganaderías estuvo entre 9 y 90 kg. Cinco ganaderías tuvieron menos del 20% de los ingredientes con una desviación de la mediana del peso objetivo permitido por el nivel de tolerancia por encima del 2%. Sin embargo, el 20.5% de los ingredientes cuyo objetivo de carga fue inferior a 1,000 kg, tenían un nivel de tolerancia asignado que permitía una desviación del peso objetivo superior al 5%, lo cual indica que el nivel de tolerancia de algunos ingredientes fue asignado aleatoriamente. Y, en once ganaderías, al menos el 50% de los ingredientes tuvieron una desviación permitida por el nivel de tolerancia mayor del 2%. Con lo cual, los niveles de tolerancia fijados para algunos ingredientes introdujeron una importante desviación del peso objetivo.

Un total de 12,439 ingredientes cargados (2.5% del total de las observaciones) no alcanzaron el peso objetivo marcado por el nivel de tolerancia, y esto representó desde 0.1 al 21.1% de todas las cargas por ganadería. Estas observaciones pueden tener origen en varias causas: un ingrediente que se terminó y fue reemplazado por otro o escasez de ese producto en el mercado sin existir modificación de la ración formulada. Esto toma importancia cuando los productos de temporada dejan de añadirse en la ración y/o se decide no alimentar productos caros como aditivos. Todo ello también podría explicarse por una falta de comunicación entre alimentador y/o nutricionista y/o gerente.

Al cargar los ingredientes el peso final se desvió al menos 2% bien por encima (10.3%) o por debajo (16.2%) del peso objetivo. En base al RIC ($|<20|$ kg), siete ganaderías cargaron de forma precisa todos o la mayoría de los ingredientes, mientras que nueve ganaderías cargaron la mayoría o todos los ingredientes con una precisión de escasa a moderada (RIC: $|\geq 20|$ kg). En base a el Q_1 ($|<10|$ kg), siete ganaderías cargaron todos o la mayoría de los ingredientes de forma muy exacta. Sin embargo, cuatro ganaderías cargaron de forma exacta solo mitad de los ingredientes. Seis ganaderías cargaron todos o la mayoría de los ingredientes con Q_3 $|<25|$ kg, mientras que en seis ganaderías esto fue $|\geq 25|$ kg.

Exactitud (Q_1) y precisión (RIC) tuvieron una asociación positiva, pero el coeficiente de correlación fue escaso (r=0.537; P <0.0001). Se observó una fuerte correlación entre la precisión (RIC) y las desviaciones extremas del peso objetivo basadas en Q_3 ($r=0.982$, $P <0.0001$). Algunos alimentadores demostraron buenas habilidades cargando los ingredientes, así como ser conocedores de la existencia del nivel de tolerancia, de tal forma que, en la mayoría de los ingredientes cargados eran capaces de superar el peso objetivo marcado por el nivel de tolerancia. La desviación del peso objetivo expresada en porcentaje ayuda a entender las implicaciones en la composición nutricional de la ración alimentada. Sin embargo, al evaluar el trabajo de los alimentadores, se obtiene mayor información con la desviación del peso objetivo en kilos.

El maíz extrusionado y la cáscara de almendra se cargaron con gran precisión (RIC: |<20| kg) en el 68% de las ganaderías. Además, la mayoría de las ganaderías (n=19) cargaron la cáscara de almendra con exactitud (Q_1: |<10| kg) y una desviación moderada del peso objetivo (Q_3: |<40| kg). Entre el 60 y el 61.5% de las ganaderías tuvo un RIC (>20 kg) grande o muy grande para el heno de alfalfa, ensilado de maíz y canola respectivamente. Y, en el 34.6%, 38.5% y 45.0% de las ganaderías hubo una gran oportunidad de reducir la desviación del peso objetivo (Q_3: |>40| kg) que representó entre 2.1 y 12.9% (heno de alfalfa), 2.2 y 5.5% (ensilado de maíz) y 2.3 a 7.3% (canola) del peso objetivo.

Según lo esperado, el heno de alfalfa resultó ser uno de los ingredientes más difíciles de cargar con precisión y exactitud, lo cual puede deberse a las partículas adheridas entre sí formando bolas que caen arrastradas una detrás de otra durante la carga. Por el contrario, no se esperaba que la canola y el ensilado de maíz resultaran difíciles de cargar. En el caso del ensilado de maíz esto podría explicarse por el coste, siendo los ingredientes más baratos los de mayor susceptibilidad a cargarse sin cuidado. Además, el ensilado de maíz fue un componente primario de la ración total mezclada (RTM), representando entre el 26.5% (Q_1) y el 38.9% (Q_3) de la ración alimentada, lo cual la cantidad de alimento disponible puede dar margen a una mayor libertad de derroche o escasa importancia sobre ese ingrediente.

El heno de alfalfa representó entre un 5.4% (Q_1) y un 9.9% (Q_3) de la ración alimentada, mientras que la canola supuso 12.5% (Q_1) y 33.0% (Q_3). Las implicaciones en la composición final de la ración radican en la combinación de diferentes porcentajes de inclusión y materia seca (MS) de los ingredientes, teniendo grandes repercusiones en los ingredientes de escasa humedad. Los errores de pesada de la canola tienen un gran impacto en la composición nutricional de la dieta debido al alto contenido en MS y en este caso también el porcentaje de inclusión en la dieta que fue mayor del 33.0% (Q_3).

El tiempo de preparación de la ración fue [mediana (rango)] 15 min 0 s (9 min 18 s a 27 min 0 s). Y, el RIC fue < 13 min 30 s (Q_1) y > 16 min 58 s (Q_3). Al menos el 20% (hasta el 68%) de las veces la preparación del carro fue <10 min en cinco ganaderías, y al menos el 10% (hasta el 70%) de las veces fue > 25 min en cuatro ganaderías. El tiempo requerido para preparar un carro depende de múltiples factores: la proximidad de los ingredientes al centro de alimentación donde se sitúa el carro, el número de ingredientes incluidos en el carro, el peso del carro final y las habilidades del alimentador durante la conducción y la carga de ingredientes así como las posibles interrupciones que le puedan surgir durante el proceso tales como llegada de camiones con ingredientes o problemas ocasionales del carro (el software no registra las paradas durante la carga de ingredientes). El tiempo de preparación del carro puede influir en el tiempo total de mezclado, y por tanto en un mezclado y procesado del heno adecuado.

El tiempo de carga entre ingredientes fue de [mediana (rango)] 60 s (40 s to 1 min 24 s). Y, el RIC por ganadería fue < 31 s (Q_1) y > 57 s (Q_3). Una vez que se carga el ingrediente, el alimentador debe dejar los restos de vuelta en el granero antes de descargar el siguiente ingrediente. Si el tiempo entre ingredientes es escaso o corto, puede deberse a que el alimentador está descargando los restos del ingrediente anterior como parte del siguiente o simplemente avanzando al siguiente ingrediente sin completar la carga anterior. En este caso, el alimentador debe tener la posibilidad de hacer un cambio manual al siguiente ingrediente, que fue el caso de las 26 ganaderías. De no saltar el ingrediente, este cambio sucedería de forma automática después de que la pesa detecta que el peso objetivo ha sido alcanzado, sin embargo existe una pausa de 15 s que marca la transición entre ingredientes, y en caso de existir una carga de ingrediente, bien no se registra en ese corto periodo de tiempo o una vez este transcurra, se contabiliza como carga del siguiente ingrediente. Con lo cual, cuando se contabiliza un tiempo entre ingredientes muy corto (< 45 s), existe una alta sospecha de engaño en el ingrediente cargado, ya que resulta imposible descargar los restos del ingrediente anterior y cargar el nuevo ingrediente en tan poco tiempo. El origen e impacto de estas acciones no se puede determinar exclusivamente a través del software y se precisa de observación a nivel de campo para confirmar la sospecha. Así es que, algunos nutricionistas pueden emplear esta medida para evaluar al alimentador. Por el contrario, largos tiempos entre la carga de ingredientes, puede deberse a la lejana localización de los ingredientes con respecto al carro u otras actividades como el sacar los ensilados desde la pared a una pila durante el proceso de carga de ingredientes.

El tiempo de fin de preparación del carro y el inicio de la descarga de la ración en el pesebre fue [mediana (rango)] 3 min 48 s (1 min 54 s a 9 min 0 s). Y, el RIC por ganadería fue < 2 min 30 s (Q_1) y > 5 min 10 s (Q_3). En seis ganaderías, el tiempo que transcurrió desde el fin de preparación del carro hasta el inicio de la descarga, fue < 3 min al menos el 70% (hasta el 80%) de las veces. Y, en otras seis ganaderías, al menos el 20% (hasta el 30%) de las veces esto fue > 10 min. Este tiempo contabiliza como el tiempo de conducción desde el centro de alimentación hasta el corral de descarga, el tiempo extra que el alimentador deja al carro mezclando después de añadir el último ingrediente (que a su vez depende del estado en que se encuentren las cuchillas) y otras actividades en medio del proceso de preparación y descarga (previstas, como el descanso para el almuerzo o, imprevistas). El software no contabiliza los tiempos reales de mezclado del carro ya que no identifica el tiempo en que los sinfines están en funcionamiento. Por tanto, los tiempos son una referencia de la operatividad del alimentador y/o el carro únicamente cuando está descargando la ración, ya que mientras carga los ingredientes, puede que no estén funcionando los sinfines.

El tiempo que llevó descargar la ración del carro en todos los corrales fue [mediana (rango)] 4 min 12 s (1 min 30 s á 10 min 48 s). Y, el RIC por ganadería fue < 3 min 20 s (Q_1) y > 6 min 30 s (Q_3). La descarga de la ración en todos los corrales de 4 ganaderías llevó < 2 min al menos el 20% (hasta el 75%) de las veces; y entre el 20 y 55% de las veces fue > 10 min en otras cuatro ganaderías. El tiempo que se tarda en descargar un carro depende del número de corrales a repartir, la distancia entre ellos, la cantidad descargada y las habilidades del alimentador, ya que si es cuidadoso en el reparto homogéneo a lo largo del pesebre, necesitará más tiempo.

El tiempo total transcurrido desde la preparación del carro hasta su descarga, el 25% de las veces (Q_1) fue < 15 min (n=10), entre 15 y 20 min (n=12) y > 20 min (n=4); y el 25% de las veces (Q_3) le llevó < 25 min (n=5), entre 25 y 35 min (n=16) y > 35 min (n=5). Si el carro está operativo durante todo el proceso, desde el inicio de la carga de ingredientes hasta el fin de descarga, esto corresponderá con el mínimo y el máximo tiempo de mezclado y picado del carro.

Finalmente, se construyeron gráficas de evaluación comparativa (benchmarking) para cada una de los parámetros descritos y se elaboró un informe de resultados personalizado para cada ganadería que participó en el estudio. De este modo, cada productor conoció la variación de resultados dentro de su ganadería y en las restantes ganaderías, valores que pudieron tomar como referencia para mejorar las prácticas manejo.

En ***conclusión***, se observó una gran variación entre todos los parámetros descritos debido a las diferentes prácticas de manejo y particularidades de cada ganadería.

La mayoría de las ganaderías gallegas no trabajaron de forma consistente, es decir, algunas ganaderías tuvieron prevalencias bajas en cuanto a las observaciones en los animales pero no necesariamente disponían de los mejores diseños de instalación o las mejores prácticas de manejo. En cuanto a las ganaderías de California, se observó que los alimentadores con escasa precisión durante la carga de ingredientes también fueron muy rápidos preparando la ración. Varios productores deben considerar el ajuste de los niveles de tolerancia de algunos ingredientes para mejorar la exactitud de carga del alimentador,

La variación descrita en las prácticas de manejo entre ganaderías y en ambos estudios sugiere que todas tienen oportunidades de mejora y pueden beneficiarse del proceso de benchmarking.

Palabras clave: ganado vacuno, evaluación del bienestar, medidas del animal, medidas de las instalaciones, prácticas de manejo, software de manejo alimentario.

ANNEXES

Benchmarking welfare indicators in 73 free-stall dairy farms in Northwestern Spain

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Introduction

Welfare assessment systems, for use in farms, may differ according to both the definition of animal welfare, and the purpose of the welfare assessment (Johnsen et al., 2001). Thus choice of welfare indicators and methods of measurement reflects the basic considerations of how animal welfare is understood.

Although many different assessment systems have been developed in Europe (Johnsen et al., 2001), the recently developed Welfare Quality® (2009) protocol considers more animal-based parameters revealing the “direct” outcomes of the interaction between the animal and its environment. Animal welfare measurements may form the basis for the identification of causes of well-being problems. However, resource- and management-based parameters are also needed to highlight the potential risk of reduced welfare in the future and help to identify the reasons underlying current animal welfare problems (EFSA, 2012).

Further, a relevant welfare assessment system should describe the welfare of the animals in the herd and allow the farmer to continuously monitor welfare and respond to any challenges over time (von Borell et al., 2001).

Benchmarking is increasingly used to track changes within the same farm over time or, more often, to compare farms. When the same animal-based measure is compared between farms with similar housing systems and management practices, it facilitates the identification of those farms that are outside the normal range of variation and this information also becomes relevant to the assessment of farm cow welfare (Von Keyserlingk et al., 2012; EFSA, 2012). Additionally, looking for opportunities to improve from the beginning of the overall production process (the farm) has the potential to affect the final results of the food chain (the table). It is translated on quality products, as beef palatability – low stress (avoid pale, soft and exudative meat) (Ferguson et al., 2001). Therefore, using the animal welfare assessment on farm as a tool to describe potential hazards and to identify Critical Control Points (CCP) may help farmers in controlling and monitoring the production process (Grandin, 2000). The critical limits for each identified CCP must involve a measurable parameter (von Borell et al., 2001).

Body condition scoring (BCS) is a quantitative tool for determining if an animal is too thin, too fat or in ideal condition depending upon stage of lactation (Coleen and Heinrichs, 2004; Bewley and Schutz, 2008). The importance of the cow condition to production, reproduction, and health is enhanced by the number of measurements considered over the cow. BCS may be a valid indicator of animal welfare, but further research is required to determine the effect of BCS and BCS change on how a cow "feels" (Roche et al., 2009). Gillund et al. (2001) confirmed the importance of BCS monitoring because ketotic cows lost significantly more body condition over a prolonged period of time than sound cows.

Hocks injuries, on the tarsal joints, are defined as hairless patches and lesions/swellings in an area extremely exposed and sensitive to pressure when the cow is lying down on a hard and/or abrasive surface with poor hygiene (Zurbrigg et al., 2005; Huxley and Whay, 2006; Kielland et al., 2009). These lesions are painful and may force the animal to stand up or lie down for longer intervals (Haley et al., 2001).

Lameness is often described as one of the most important well-being problems and severe problems in farm production for reasons that include pain, changes in cow behavior and adverse effects on milk yield and reproduction (Galindo and Broom, 2002; Hernandez et al., 2005). The locomotion score of farm cattle evaluates certain walking behaviours and postures that are thought to be indicative of lameness (Sprecher et al., 1997; Flower and Weary, 2006; Thomsen et al., 2012; Hoffman et al., 2014). Use of locomotion score may help to identify cows at early stages of lameness and therefore it results in faster recovery and reduced treatment costs. Research to date has shown that facility design and management can affect lameness which in turn affects cow welfare and longevity (Whay et al., 2003; Bicalho et al., 2007). Furthermore, research indicates that producers tend to underestimate the prevalence of lameness in their herds (Wells et al., 1993). Despite of being a subjective assessment, monitoring locomotion scores and lameness prevalence over time might be a good tool to evaluate the functionality of the barn design.

Body hygiene is an indicator of the environmental cleanliness at herd level. Several methods of hygiene scoring have been documented for scoring different zones of the cows' coat but mainly focus on the rear limb, i.e. lower leg, udder and upper leg/flank (Schreiner and Ruegg, 2003; Reneau et al., 2005). Some of those systems have been used to prove that poor hygiene results in udder health problems, as manure may compromise the cow comfort increasing intramammary infections risk (Reneau et al., 2005).

The objectives of this paper were to describe the prevalence of unsuitable BCS, clinical lameness, hock injuries, and dirtiness of the cow's coat as measures of cow well-being among producing cows on free-stall farms. Furthermore, a description of the variation in facility design and management practices of facilities and herd thought to affect cow comfort and animal-based measures was provided in 73 free-stall farms in Northwestern Spain (Lugo, Galicia). Farmers were provided with feedback through an anonymous report which allows opportunities to improve by rating their herd through the benchmarking process of the 73 farms.

Material and methods

Farms selection and description

A convenience sample of seventy-three free-stall Holstein dairies were selected to participate in the study. Enrolled dairies were recruited with the assistance of dairy veterinarian practitioners. One researcher (Y.T.) accompanied the farm veterinarian during their scheduled pregnancy check to perform all farm assessments in a single visit. Pior to the assessment, dairy producers were informed of the nature of the study and offered an aggregate data summary after study completion. Those agreeing to participate were visited between November 2011 and March 2012. Dairy farms were located in Lugo province (Galicia – Spain). Herd size ranged from 20 to 244 cows however, the median across farms was 43 cows. Most farms milked twice a day (97.3%) and only two farms (2.7%) milked three times a day. All farms were family owned and the age of the facilities (since the last restoration or as a new building) ranged between 5 and 20 years old, as reported by producers. During the assessment humidity levels ranged from 80 to 100% and temperatures from 0 to 14°C.

Data collection

The assessment for each farm was composed of three sections: 1) animal-based parameters, 2) facility-based parameters, and 3) dairy producer survey.

Measurements were collected only once on every farm around the time of the first milking (7 to 9 am) by the same assessor. Data records of herd milk production and reproductive performance were provided by reproduction veterinarians (software records of one year prior to the visit).

Animal-based parameters

In order to avoid biased results by the housing conditions of dry cows kept on pasture year round (50.7% of the farms) and inside the barn (e.g. assessing locomotion on grass vs concrete floors), only lactating cows (n=3,426) were included on the study.

All and each lactating cow by farm was released from the headlock and scored by direct observation (direct indicators) from an average distance of 3 meters for locomotion and as close as necessary (60 to 120 cm) for BCS, hock injuries and hygiene status.

Body condition score: in each farm cows were evaluated on a 1 to 5 scale with 0.25 point increment (Edmonson, 1989). BCS within each herd was classified as suitable, high (overweight) or low (underweight) based on DIM. Coleen and Heinrichs (2004) spreadsheet were used to group cows within herd on the three levels which thresholds ranged between 3.5 to 2.5 of BCS from 0 to 30 DIM, 3.0 to 2.25 of BCS from 30 to 100 DIM, 2.25 to 3.0 of BCS from 100 to 180 DIM and 3.0 to 3.5 of BCS from 180 to 300 DIM respectively. Percentage of cows with unsuitable BCS across herds was considered for the overall benchmarking process.

Hock injuries: tarsal joints of each cow within the herd were evaluated. None hock scoring system was considered due to the time that cows would be locked (producer's consent). Only the prevalence of cows with any scratch, swelling, abrasion or trauma in one or both limbs either inside or outside leg was reported and included in the overall benchmarking process.

Locomotion score: cows were scored between 1 (sound) and 5 (severely lame) according to guidelines by Sprecher et al. (1997) assessment. For descriptive analysis, lameness was categorized as clinical lameness (prevalence of cows scored ≥3) and severe lameness (prevalence of cows scored ≥4). Only clinical lameness was considered for the overall benchmarking process across herds.

Hygiene score: lower leg (rear only), udder and upper leg/flank were scored on a 1 (free of dirt) to 4 (covered with caked on dirt) scale according to guidelines by Schreiner and Ruegg (2003) assessment. Hygiene score >2 was related to dirty cows within a herd. For the overall benchmarking process, dirtiness was involved in one parameter which considered the average prevalence of the three zones of the cow's coat with hygiene score >2 across herds.

Data records of *productive and reproductive performance* (indirect indicators) were described through several parameters across herds. Average total herd milk production was projected 305-d mature-equivalent (305ME, Kg), Milk Bulk Tank Somatic Cells Count (BTSCC) of the sampled month (cells/mL) and yearly average of DIM were included in the analysis. Ten farms had no DHI data registers, thus only 63 farms were included for production data. Six reproductive parameters were considered as the most relevant: days of calving to first service interval (CFSI), percentage of conception at first service (FSC %), days of calving to conception interval (CCI), percentage of heat detections (HD %), average of calving number (CN) and percentage of average conception (C %). Culled cows were not considered in the description for being an unreliable measure, dependent on producers data records.

Facility-based parameters

Measurements were taken in five different areas of the barn (resting, walking, feeding, ventilation and milking) either by observation or measuring (tape/laser). Parameters and method of data collection assessed in each area are described in Table 1.

Three stalls located every five in a row by farm were sampled to calculate an average of the stall dimensions (bed width, bed length, brisket locator height, total stall length, low lateral bar, high lateral bar, neck rail height, neck rail position, front lunge space, and rear curb height) as shown in Figure 1. Bed length of the stalls without brisket locator was measured to the first barrier blocking the front. Space available in the stall was calculated by the formula: with*length (cm)/1000, to express it in m^2. Overstocking at stalls and headlocks was defined by the ratio (number of animals/number of spots*100) >100%. All farms had stalls on the resting area and headlocks on the feeding area.

Management practices of facilities and herd

Producers were interviewed regarding the frequency and procedure of outdoor access for lactating cows, bed maintenance, cleaning practices (floor, feed bunk and water troughs), water analysis, environmental enrichment (brushes), footbath protocol, yearly hoof trimming/inspection routine, mechanical ventilation (when available) and settings, milking practices and, behaviour in the milking parlour (>15% of the cows per herd): refuse to enter parlour voluntarily (producer reported pushing cows in every milking) and/or show other signs of stress (defecation, urination, kicking, fast tail movements). To count for the number of cows with any of those behaviours in the first milking of the visit day, producers were warned (by phone) in advance. The frequency of practices was reported in number of times per day, or year, and “when producers considered it necessary” (not routinely).

Benchmarking animal-based parameters

The overall benchmarking process included four direct animal-based parameters based on the percentage of cows by herd as welfare indicators: unsuitable BCS, hock injuries, clinical lameness and dirtiness of the cow’s coat. First, each indicator was sorted from low to high prevalence across farms and three groups were classified by percentiles 25th (Q_1), 50th (Q_2) and 75th (Q_3). Thus each group of farms felling within each percentile were assigned categories A, B and C respectively. Therefore, the 25% of the farms within A category had the lowest prevalence for each indicator while C category included the highest prevalence across the assessed farms. Second, each farm was sorted by the number of indicators in categories A and C. After data exploring, top farms were considered when at least two indicators fell in category A but cero in category C and, bottom farms were defined by two indicators felling at least in category C and any indicator in category A. Furthermore, a description of the facilities design characteristics and specific management practices carry out on the top and bottom farms (classified by the animal-based welfare indicators previously) was provided.

Productive and reproductive parameters were ranked by the same percentiles used for the animal-based direct indicators, but those parameters were not included on the overall benchmarking process for being indirect measures of the cow well-being.

Data analysis

Data analysis undertaken in this study was only for descriptive purposes. Results are presented as percentages, ranges and/or percentiles 25th (Q_1) 50th (Q_2 or median) and 75th (Q_3).

Descriptive statistics were conducted with the PROC MEANS and PROC UNIVARIATE procedure of SAS 9.4 (SAS Institute Inc., Cary, NC). Percentiles were computed using the PCTLDEF = 4 option in the output statement of the PROC UNIVARIATE.

Furthermore, a Pearson correlation was established between over- and underweight cows, severe and clinical lameness and, among hygiene scores of the three zones of cow's coat. Finally, a Pearson correlation was also established among the four animal-based welfare indicators used in the overall benchmarking process and among reproductive parameters.

Results

Animal-based parameters

Animal-based parameters, including direct (BCS, hock injuries, clinical lameness and dirtiness of the cow's coat) and indirect (productive and reproductive performance) indicators of cows well-being and comfort is summarized for the 25, 50 and 75% of the times in Table 2.

Across dairies, cows within a herd had suitable BCS [median (range)] 48.3% (10.5 to 86.7%), above desirable BCS 27.8% (0 to 78.8%) or below desirable 18.4% (0 to 89.5%) – represented in Figure 2.

Only four (5.5%) and nine (12.3%) herds had <5% of overweight and underweight cows respectively at the assessment time. All herds had <3% of lactating cows with a BCS <2, however most herds (55%) had >3% of the cows with a BCS >4.

Overweight cows were more frequent ($r = 0.637$; $P<0.0001$) than underweight cows within herds.

The hock injuries had a great variation ranging from 7.0 to 100%. Only eleven herds (15.1%) had <15% of cows with no lesions whereas 13 herds had > 60% of cow with lesions.

Locomotion score 1 was [median (range)] 61.3% (23.3 to 82.1%) while score 2 cows comprised 28.0% (7.7 to 56.7%). Score 3 was [median (range)] 6.25% (0.0 to 35.0%) and scores 4 and 5 were 0.8% (0 to 20.0%) and 0.0% (0 to 13.3%) respectively. Clinical lame cows ranged from 0 to 60.0%. Merely 31.5 and 42.5% of the herds had a prevalence of <5 and <10% clinical lame cows respectively. Most herds (76.7%) had <5% of the cows with an obvious limp or severe lameness while the remaining 12.3% of the farms had >10% of the cows severely lame. Severe lameness averaged 3.8% across farms and it was positively correlated with clinical lameness ($r = 0.753$; $P < 0.0001$). Farms (n=7) without lame cows (clinical or severe) had a prevalence of score 2 between 20 to 45%. Therefore, only 17.8% of the herds met at least 70% score 1, <20% score 2, <10% score 3 and 0% scores 4 and 5.

Dirty lower legs, udders and upper leg/flank had a median [median (range)] of 95.0% (50.0 - 100%), 62.5% (25.0 - 100%) and 62.5% (25.0 - 100%) of the cows by herd respectively. Overall dirtiness averaged from 37.5 to 100%. A significant correlation ($r > 0.814$; $P < 0.0001$) was found among scores of the three zones of cow's coat.

The total milk production (305ME) ranged from 6,321 to 11,951 kg and milk production by cow and day varied highly from 23 to 44 kg where 30.2% of the herds produced an average <30 kg. Cows DIM had also a wide range of variation (88 to 251 days) and it was <155 and >175 days in 26.9% and 61.9% of the herds respectively.

Regarding reproduction, the correlations established were not surprising, it was negative between HD % and CFSI ($r = -0.628$; $P < 0.0001$) and positive between FSC % and C % ($r = 0.659$; $P < 0.0001$). The CFSI ranged from 56 to 116 days and it was >80 days in 32.0% of the herds, while the CCI was between 103 to 243 days, where most of the farms (97.3%) were >115 days and there was severe issues (>145 days) in 58.9% of the herds. A high range of variation was also found on FSC, HD and C which was from 10.3 to 63.0%, 30.0 to 69.3% and 15.8 to 49.3% respectively. Poor HD (<50%) was found in 32.5% of the herds and also issues on FSC (<35.0%) were shown in most of the farms (72.6%). Furthermore, the CN ranged from 1.7 to 3.7 across farms.

Facility-based parameters

Facility design varied across farms as it is shown on Tables 3 and 4 for several categorical and continuous variables on the five areas assessed in the 73 barns.

Resting area

The incidence of overstocking was 31.5% (n=23) across farms. This situation was observed when dry and lactating cows were housed in the same pen (n=4) separated by chains and/or mobile fences (n=13) or there was a lack of space for the number of cows (n=6).

Most farms (74.0%) had stalls width between 115 to 122 cm, however it was >125 cm in some farms (13.7%). In contrast stall length was 178 - 182 cm or >185 cm in 31.5% and 39.7% of the farms respectively. Therefore, only 20.5% of the farms had a space available between 2.0 to 2.2 m^2. Furthermore, front lunge space was <90 cm in length in most farms (90.4%) and, it was >90 cm in few farms (9.6%). Some farms (58.9%) placed the neck rail <115 cm (height) and few of them (13.7%) >122 cm. Furthermore, curb height was >25 cm in 67.1% of the farms.

Divider design and bar position explained the range of variation in high and low lateral bars. In most farms (94.5%) the height of the high lateral bar was >35 cm and only in one farm it was <30 cm.

Walking area

Fifteen farms had slatted floors (20.6%) and thirteen of them were slippery (n=13). Sixteen had a flat concrete floor (21.9%), four were rough and eight were slippery. The most common floor type was grooved concrete (57.5%; n=42) and few of them resulted slippery (n=4). Moreover 2.7% of farms had rubber floors in the milking parlour and only one (1.4%) had also rubber floors in the feed alley. Surfaces were dirty in 16.4% of the farms at the assessment time.

Blocked alleys (interruption in linear circulation) were created by chains and/or mobile fences located in the pens to group cows (17.8%). Back alley, when present (95.9%), were <350 cm in 79.5% of the farms and most feeding alleys (64.4%) were <420 cm width.

Feeding area

Feed bunks were concrete metal or tile and classified as smooth (26.0%) or rough (worn) (74.0%). Feed bunk height was 10 – 15 cm in 50.7% of the farms and >15 cm in 13.7%.

Overstocking at feed bunk had 26.0% (n=19) incidence. Furthermore most farms overstocked at headlocks (n=15) were also overstocked at stalls. Feed bunk space (headlock width) was <60 cm in 24.7% of the farms. Low light at the feed bunk was observed in 50.7% of the farms at the assessment time.

Linear watering space per cow was <8 cm in 42.5% of the farms. Water troughs available at the farms were metallic with a draining system (53.4%), concrete troughs fixed with a drain (38.4%) or a combination of the previous two (8.2%).

Ventilation area

Signs of poor ventilation were observed in 32.8% of the farms. Only 12.3% had an insulated roof with sandwich plate. Farms were partially closed with small windows in the sidewall (20.5%) or partially open with small open sides (78.0%) which median (range) was 146 cm (20 - 300 cm) in height. Only one farm had 75% of the side wall open (400 cm). Therefore, the open side represented <50% of wall height in 47 out of the 58 farms. Any farm has an open ridge however roof height reached [median (range)] 700 cm (400 - 1,000 cm). Fans and sprinklers were available in few farms (13.7 and 1.4% respectively).

Milking area

The most frequent milking parlour design was the herringbone (75.3%) while parallel or tandem parlours were less common (11.0% respectively). Only one farm (1.4%) used a rotary milking system and another one (1.4%) a swing parlour.

Few farms (2.7%) had a walkway or release area (previous to the holding area) however most farms (74.0%; n=54) provided a holding area. Holding area space per cow was <1.3 m^2 in 27 out of the 54 were. The slope of the holding area was >4% in 13 out of the 54. Furthermore, 17 farms grooved floor of the holding area. The milking area communicated with the barn through a door in all cases either by the release/holding area (74.0%) or the milking parlour (26.0%). The entrance door was >300 cm in width with <100 cows and >500 cm in width with >100 cows in 41.7% of the farms respectively. Exit paths in the holding area were >160 cm in 9.7%. Paths of the milking area were non-linear (two or more turns >90°) in 49.3% of cases. Additionally, some farms (45.2%) had a milking area design that did not allow cows to see the milking parlour before entering it.

Management practices of facilities and herd

Cow and facility management varied widely across farms as it is shown in Table 5 for several categorical variables.

At least during a specific time of the year lactating cows had outdoor access to exercise areas (19.2%) or pasture (13.7%).

Daily bed maintenance mainly consisted of removing manure from the stall. As part of stall hygiene procedures, calcium carbonate was sprinkled on the concrete, rubber mats, mattresses and waterbed. Beds of sand, straw/sawdust and soil were groomed (racked) and replaced "when necessary". Most producers (86.3%) reported removing manure with an automatic scraper at least twice a day on a random schedule and the remained 13.7% had a fixed schedule up to 6 times a day.

Several farms (42.5%) had footbath facilities but did not have a footbath protocol (not effective product), most of them have reported to not change the product for more than a month (23 out of 31 farms) or they used it "when considered it necessary" (8 out of 31 farms). Some farms (27.4%) located at least one cow brush in the alleys. Producers reported turning fans/sprinklers (when present) on summer but not routinely. Further, all farmers cleaned the feed bunk before feeding delivery (in the morning) and they also performed a water analysis yearly.

A total of 38 farms (52.0%) reported that >15% of the cows had to be forcefully taken into the milking parlour on a daily basis. Observations in 15 of the 19 farms without a holding area revealed that the pathway to the milking parlour was not linear because it did not allow the cows to see into the milking parlour before arrival and, in the 15 cases producers were forced to lead the cows themselves. Stressful reactions at the milking time were also reported in 19.2% of the farms.

Benchmarking animal-based parameters

The cut-off point considered to assign the categories for each indicator across farms is presented in Table 2. Across overall farms, the number of indicators in A, B and C category ranged from 0 (n=22) to 3 (n=1), 0 (n=4) to 4 (n=7) and 0 (n=32) to 4 (n=1) respectively. There was not any correlation among the four animal-based welfare indicators and only one farm had all indicators in category C. Ten farms had the same number of indicators in A and C category and seven farms had the four indicators in category B. However, eleven farms had cero indicators on category C and other eleven in category A, thus the top and bottom farms respectively, which were presented in Table 6.

The number of lactating cows was similar for top and bottom farms, increasing (median) by 8 linear units on the top farms. Also, herd milk production and DIM were similar, representing (median) 100 kg and -93 DIM of linear unit difference between top and bottom farms. The median of BTSCC was 264.000 and 310.000 cells/mL in the top and bottom farms respectively. All reproductive parameters had less than (median) 6 linear unit difference between both groups of farms.

The top farms presented a stall stocking density of [median (range)] 98% (74 to 117%) while bottom farms 100% (68 to 154%) and similar situation was of the headlocks with 94%

(73 to 117%) and 103% (71 to 143%) in the top and bottom farms respectively. However, similar number of blocked alleys were observed in the top and bottom farms (six and seven respectively).

Frequency of bedding maintenance did not varied between both groups of farms and none of them used sand bedding materials. However, most of the top farms (n=7) had dry bedding materials while most of the bottom (n=7) did not. Front lunge space was 10 cm linear unit difference between top and bottom farms. Brushes were a complement on the alleys in four of the farms respectively. Dirty alleys were observed in two and three farms of the top and bottom groups respectively. Feeding alley width of the top farms had 50 cm linear unit difference of the bottom farms and crossovers curbs were -5 cm linear unit difference between top and bottom farms. Hoof trimming was performed up to producers decision in most of the bottom farms (n=9), while most of the top farms were following a protocol at least twice a year (n=7).

Light conditions over the feed bunk were the same in both groups (six farms had more visibility than in the rest of the barn) and feed bunk space per cow was also similar (averaging 60 cm). However, feed bunk was smooth in five of the top farms while in bottom farms were rough.

Signs of poor ventilation as well as close barns were observed in five of the bottom farms while none of the top registered any. Those findings result in poor natural ventilation.

Most of the bottom farms (n=9) did not have a holding area and seven of them had reported to push cows manually inside the parlour. However in most of the top farms (n=9) there was a holding area and only two farmers reported to help cows get inside the parlour. Furthermore, the holding area space per cow ranged from 0.7 to 7.7 m^2 in the top farms (n=9) and 1.0 to 2.1 m^2 in the bottom farms (n=2). Also, the slope of the holding area was between 2 to 4% in most of the top farms (7 out of 9 farms with holding area), while the two bottom farms had 4% and 15% of slope.

Discussion

This study constitutes the largest independently observed assessment of the animal welfare status carried out in the region of Galicia, in which 52% of Spanish farm cattle is located with an estimated milk production comprising around 40% of Spanish milk production. This assessment only included a limited number of aspects of dairy cow wellbeing in a commercial setting. Animal rearing and management (treatment and care along the day or attitude at the milking parlour), animal health status, nutritional value of feed (quality and quantity) and feeding management practices (drops pushes mixing uniformity sorting etc.) equally affects the animal-based parameters measured during a welfare status assessment. However, these measurements could not be included due to several reasons, i.e. producer consent (time spent on the dairy, type of questions or copy of data records) and unavailability/unreliability of data records. Therefore, based on those limitations, Welfare Quality® Protocol could not be applied and only common variables available across all sampling farms were considered for description.

Animal-based parameters

Following Coleen and Heinrichs (2004) graph, more than a half of the cows by herd had an unsuitable BCS and those cows were mostly fat. Several management practices as unbalanced rations, prolonged dry periods, overfeeding during the dry period or poor reproduction management were reported to affect over-conditioning and therefore, the health i.e. fatty liver, ketosis, displaced abomasum, dystocia, retained placenta, uterine infections, and performance such as milk yield, and overall reproductive parameters (Bewley and Schultz, 2008). Similarly, under-conditioning or body condition score (BCS) losses post-calving are commonly associated with milk production, reproduction and health status - lameness (Espejo et al., 2006; Roche et al., 2009). However, in this study there was no records of nutrition values or feeding management practices which could directly affect BCS, but several management practices or facilities design such as overstocking, small front lunge space, feed bunk conditions or poor ventilation could be secondly affecting BCS by decreasing feed intake due to competitions, limited feed bunk space, low feed quality if fermentations are developed, decreased resting time and rumination, or heat stress conditions (Bewley and Schultz, 2008; Roche et al., 2009). Cows might be at an ideal BCS at dry off and might be fed to maintain this condition until calving. Although our results show considerable variation in the BCS status among lactating cows we assessed, it is encouraging that some farms had low rates of unsuitable BCS, showing that success is achievable.

Variation in the prevalence of hock injuries across farms is surprising because these lesions are relatively easy to recognize and prevent. For more than a decade, we have known that the use of poorly bedded mattresses greatly increases the risk of hock injuries (Weary and Taszkun, 2000; Fulwider et al., 2007). Stall features that restrict the normal rising and lying down movements (i.e., small stalls, presence of obstructions, hard lying surface, etc.) may aggravate the risk of lesion as cows try to adapt to restricted space (Zurbrigg et al., 2005). In addition, concrete stalls (or similarly hard surfaces) are known to cause swollen knees resulting from impact as cows lie down (Rushen et al., 2007). Furthermore, other risk factors, different from lying time, type of stall base, type of bedding materials or stall dimensions and also previously reported included parity, herd size, BCS, DIM, and milk production (Weary and Taszkun, 2000; Andreasen and Forkman, 2012; Barrientos el al., 2013). Therefore, it suggests the development of hock injuries involve several facilities design and management practices.

Prevalence of hock lesions in this study was less than in other studies (Weary and Taszkun, 2000; Kielland et al., 2009; Brenninkmeyer et al., 2013) which registered 73.0%, 60.5% and 50.0% respectively. However it was not as low as 16.3% (Rutherford et al., 2009). On farms where these lesions are common, dairy producers may come to believe that these are normal and thus fail to manage the problem. The comparative data provided by our benchmarking process may help address this issue.

The prevalence of lameness can provide valuable information about the functionality of the stall design, and several studies have shown a link between features of the free stall and the incidence of hoof problems (Leonard et al., 1994; Faull et al., 1996). However, this relationship is complex, and limitations exist in using lameness or hoof health to assess stall design per se. In free-stall systems, the link between stall design and lameness is most likely due to uncomfortable stalls resulting in cows spending more time standing (Cook and Nordlund, 2009), but the effect also depends on the nature of the surface that cows use for standing. Cows provided with free-stalls with no neck rail, where they could stand fully inside the stall on ample sand, had improved locomotion scores even though total standing time was unchanged (Bernardi et al., 2009). Therefore, several factors may contribute to lameness development including more than one factor at the time, i.e. management practices as breed, genetic selection, conformation characteristics, small herd size, nutrition and feeding practices, amount of milk production, stall designs, faecal contamination on bedding, type of bedding, the presence of damaged concrete in the yards, sharp turns near the parlour entrance or exit, automatic scrapers, presence or absence of certain types of infectious disease, and environment (Cook, 2003; Espejo and Endres, 2007; Bernardi et al., 2009; Barker et al., 2010; Chapinal et al., 2013). Further, lameness was related to reproduction failure and decrease milk production (Warnick et al., 2001; Morris et al., 2011).

Prevalence of lameness was less than previously reported in studies carried out in Wisconsin (23.9%; Cook, 2003), Minnesota (24.6%; Espejo et al., 2006) and the UK (36.8%; Barker et al., 2010) but, not as low as those reported in Sweden (5.1%; Manske et al., 2002).

Few studies (Espejo et al., 2006; Von Keyserlingk et al., 2012; Chapinal et al., 2013) have reported the prevalence of severe lameness (ranging from 6 to 10% prevalence) separately from clinical or overall lameness. Severe lameness was less in our study than in those studies but, similarly to those studies, it accounted for only a small portion of clinical lameness. Of interest is that the patterns of severe lameness across farms did not match those of clinical lameness; for example, some farms with a low prevalence of severe lameness had a high prevalence of clinical lameness, and vice versa. Causes of mild versus severe cases of lameness are likely different and may not always be progressive, but more research is required to further our understanding in this area.

Highlight the high prevalence of locomotion score 2, which is defined as an imperfect locomotion but the ability to move freely is not diminished (Flower and Weary, 2006), may predispose to lameness if specific management practices does not change to improve the comfort of the cow. It could be due to the lack of footbath protocols in most farms and, especially in this region, which humidity levels raised above 80% during the assessment period. The frequent used of the footbaths might be desirable to avoid microorganism proliferation and possible development in dermatitis. Furthermore, it may worsen with manure, which was revealed trough the prevalence of dirtiness cows and the lack of protocols to clean the floor on a routine basis in most farms (86.3%). Another practice that may contribute to alterations in locomotion could be explained by the lack of hoof trimming protocols. In this case, a monitoring process might be desirable to follow-up the locomotion scores over time and to find the causes of this prevalence by changing several management practices.

Facility cleanliness contributes to clean and dry hair coats and udders. Variation in the scoring can be associated with soiling of the animals' coat, manure (which is influenced by cow behaviour) and, facility cleaning factors including: direct transfer (lying down in manure), leg transfer (walking through the manure and splash transfer) or tail transfer (contamination while resting). For this reasons, stocking rate, maintenance and facility design, type of bedding materials have being previously reported to determine the hygiene of the herd (Reneau et al., 2005; Fulwider et al., 2007; Andreasen and Forkman, 2012). Further, Schreiner and Ruegg (2003) showed linear effects of hygiene score on somatic cell scores (cell score increased with dirty udder). From Schreiner and Ruegg (2003) study was extracted that <15% of cows should score 3 or 4 in the udder and performing an evaluation routinely may help to prevent milk quality issues. For this reason, the high prevalence of dirty udders could be considered a potential hazard in some of the farms evaluated in this study.

The high CCI or commonly named “open days” across herds may indicate fertility and/or estrous detection issues, which was the case in this study (low HD %). Factors affecting reproductive performance were associated to either to the management factors (such as methods of husbandry, feeding, estrus detection, semen handling and transition cow management) or to the cow factors (such as age, BCS, post-parturient problem, disease events, milk yield, and genetics) (Lucy 2001, Hudson et al 2012).

Facility-based parameters and management practices of facilities and herd

Management practices and facility dimensions appear to have opportunities for improvement in the assessed farms. Following the conclusions reached by several research (Murphy et al., 1983; Weary and Taszkun 2000; Cook, 2003; Reneau et al., 2005; Espejo et al., 2006; Fulwider et al., 2007; Bewley and Schultz, 2008; Roche et al., 2009; Bernardi et al., 2009; Morris et al., 2011; Andreasen and Forkman, 2012; Barrientos el al., 2013; Chapinal et al., 2013) critical points could be found at the small front lunge space (developing social obstruction and diagonal positioning in the stall which may allow to defecate inside), big stall curb height (refusing to get inside the pen), discomfort at the stall for bedding type (limiting lying time as research to now have shown sand bedding materials of cow preference), narrow alleys (limiting space flow), slippery floors surfaces (avoiding expression of heats), rough or worn feed bunk surfaces (promoting the fermentation of the feed stuff), the lack of daily troughs cleaning routine (decreasing quality and feed intake and limiting milk production), small linear watering space per cow (<8 cm, limiting water intake), the lack of footbath protocols (promoting digital dermatitis), the lack of fixed schedules for running automatic scrapers (increasing dirtiness of the cows coat), poor natural ventilation (promoting heat stress), and poor design of the milking parlour and overall design of the holding area (slowing cow flow, increasing stress and hindering the letdown mechanism).

Benchmarking animal-based parameters

The prevalence of dirty cows was high across the 73 farms, similarly to analogous studies carried out in the UK (Whay et al., 2003) and Hungary (Gudaj et al., 2012), specially as regards lower leg hygiene.

Farms with equal number of indicators placed in the top and bottom categories, suggested a wide range of variation between management practices within those specific parameters. Most of the farms did not perform consistently well or poorly across animal-based welfare indicators and each farm had its own set of strong (indicators included in A category) and weak points (indicators included in C category). These results may explain the lack of correlations among animal-based welfare indicators and it may suggest that several factors are involved in the cow welfare and those farms can benefit from benchmarking to look for better management practices. However, specific management practices may have a major influence on particular animal-based parameters and more research would be needed for determine the potential of each factor to influence on cow welfare.

Most farms shared several issues of the facilities design and management practices (previously described overall farms) that may or may not affect the animal-based welfare indicators. However, from the description made of the benchmarked top and bottom farms, there were main critical points between both groups that could be found at the stocking density on the feed bunk and headlocks, dryness of bedding materials, front lunge space, hoof trimming routine protocols, poor natural ventilation and poor facilities design of the milking area. Therefore, a specific improvement plan should be designed for each farm to increase performance and promote animal welfare.

One outcome of this field study was to provide individual farms with their own data and with results from other farms in their region to allow benchmarking of their own performance. Each farm received a confidential report that was often used as a basis for discussion (involving, for example, the owner, producer, nutritionist, clinician and reproductive veterinarian, hoof trimmer etc.). Our intention was that the reports provided producers and their advisors with an opportunity to make better informed decisions and develop tailored strategies for improving the care and management of cows on their farm. Anecdotal feedback from participants has been positive, but research is required to assess how producers use these data and whether benchmarking results in changes to practices and sustained improvements on farms. Dairy producers in general are concerned about the health and welfare of their animals; for instance, a sense of pride in a healthy herd was identified as one of the most important motivators for lameness control (Leach et al., 2010). Benchmarking may provide information that is either reassuring (if herd performance was high) or that helps to motivate change (if a major opportunity for improvement was identified).

Conclusion

Considerable variation exists within and across animal-based welfare indicators of the assessed 73 farms in Lugo. Some farms had a low prevalence of over and underweight cows, hock injuries and lameness, suggesting opportunities for the other farms to benefit from benchmarking. Improving several management practices of facilities and herd may help to prevent and control some aspects of the animal-based welfare indicators.

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FIGURES AND TABLES

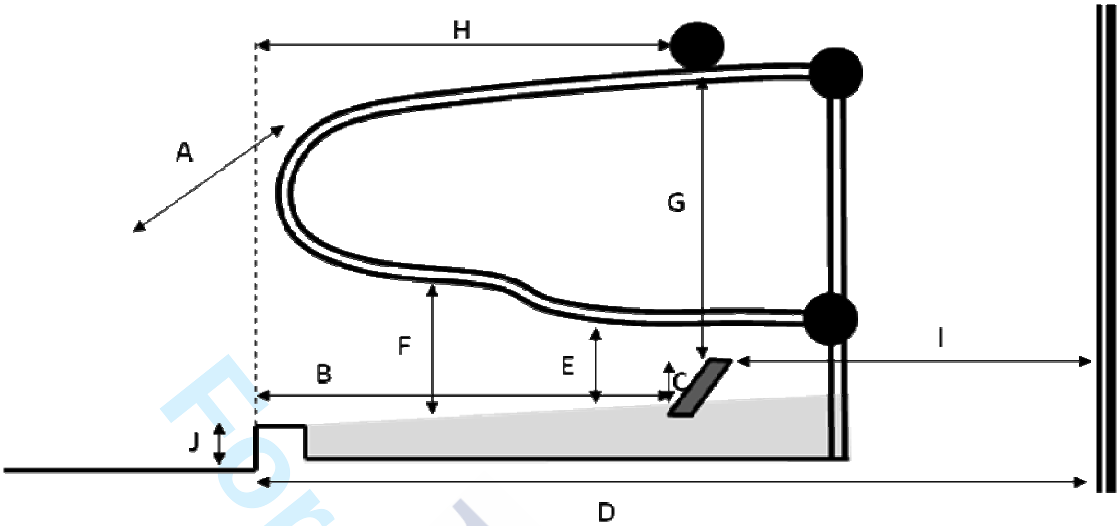

Figure 1. Stall dimensions (median, range) in 73 dairies in Northwestern Spain. Bed width (A) from the middle of one side divider to another; bed length (B) from the external side of the rear curb to the internal side of the brisket locator if available (when brisket locator not present, measure was to the first barrier); brisket locator height (C) vertical line from the bottom to the top; total stall length (D) from the external side of the curb to the middle front with the other stall or to the wall; low lateral bar (E) and high lateral bar (F), from the bed to the bottom of the bar; neck rail height (G) from the bedding surface to the bottom of the rail; neck rail position (H) distance from the vertical plane above the rear curb to the internal side of the rail; front lunge space (I) distance from the middle of the brisket locator to the half way with another stall or to the wall; rear curb height (J) from the bottom of the alley to the top.

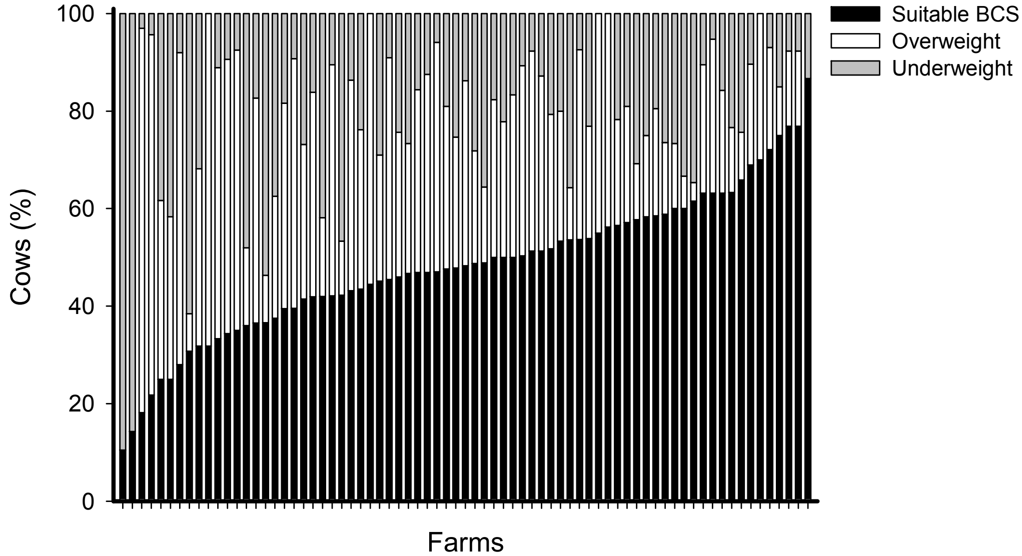

Figure 2. Distribution of the BCS by cows by herd as the percentage of cows with suitable, high or low BCS regarding their stage of lactation or DIM in 73 dairy farms in Northwestern Spain.

Table 1. Description of the facility-based parameters collected by direct observation or measured in five areas of the free-stalls in 73 dairy farms in Northwestern Spain.

Area	Parameters	Procedure (levels)
Resting	Stall stocking density	Number of cows/number of stalls*100 (continuous).
	Stall location	Against a side wall or head to head platform
	Stall dimensions	Described in Figure 1
	Brisket locator presence	Either concrete, board, tube or bedding material (yes/no)
	Slope of the platform	Slope towards the rear (yes/no)
	Dividers design	Italian, Michigan, “U” loop and wide-span type
	Bedding materials type	No materials, rubber mats, mattresses, straw/sawdust, sand
	Dryness of bedding materials	“knee test”- dry after 3 seconds kneeling on the bedding material (yes/no)
Walking	Surfaces characteristics	Concrete: Slatted/grooved/flat, slippery/rough - by the graze of the boots
	Dirty alleys	Manure evenly covered the floor at a depth of at least 2 cm (yes/no)
	Rubber on the floor	Feeding alley or milking parlor floor with rubber on the floor (yes/no)
	Alleys width	From the external side of the stall curb to another or to the wall - back alley, feeding alley and crossovers (continuous)
	Blocked alleys	Mobile fences and/or chains obstructing linear circulation (yes/no)
Feeding	Feed bunk characteristics	Materials and conditions (smooth/worn surface - by the graze of the boots)
	Feed bunk height	Difference between cow platform to feeding platform height (continuous)
	Feed bunk space/cow	Headlock’s width (continuous)
	Feed bunk stocking density	Number of cows/number of headlocks*100 (continuous)
	Lighting on the feed bunk	Visual perception, feed bunk lighter than the rest of the barn (yes/no)
	Troughs characteristics	Materials (metal/concrete) and types (dumping/fixed)
	Linear watering space/cow	Total length from all accessible sides/number of cows (continuous)
	Covered feed bunk	Roof covering the feed bunk (yes/no)
Ventilation	Signs of poor ventilation	Humidity and/or cobwebs (>1m^2 roof) and ammonia smelling (yes/no)
	Roof insulation	Insulation materials (yes/no)
	Open sides and height	Gap on sidewall barn (yes/no) and measurement of the gap (continuous)
	Open ridge	Gap in the top of the roof (yes/no)
	Roof height	Measure from the floor to the middle of the roof (continuous)
Milking	Parlor design	Herringbone, parallel, tandem, rotary, swing
	Holding and release area	Presence (yes/no)
	Holding area space/cow	Width*width/number of cows fitting in the parlor (continuous)
	Floor characteristics in holding area	Slope (%): difference in height/length*100 (continuous)
		Grooved floor - parallel lines (yes/no)
	Milking area design	Entrance door width, direct to the parlor or by holding area (continuous)
		Straight design: cows can see the parlor from the holding area (yes/no)

		≥2 turns: turns ≥ 90° in the entrance and exit paths to the parlor (yes/no)

Table 2. Percentiles 25th, 50th and 75th of the animal-based direct indicators including unsuitable body condition score (BCS) for the stage of lactation [days in milk (DIM)], hock injuries, clinical lameness (locomotion score 3, 4, 5) and dirtiness of the cow's coat (average of the percentage of cows with hygiene score>2 in the three zones of the cow's coat), and indirect indicators including productive [average total herd milk production was projected 305-d mature-equivalent (305ME, Kg), Milk Bulk Tank Somatic Cells Count (BTSCC) of the sampled month (cells/mL) and yearly average of DIM] and reproductive parameters [days of calving to first service interval (CFSI), percentage of conception at first service (FSC %), calving to conception interval (CCI), percentage of heat detections (HD %), average of calving number (CN) and percentage of average conception (C %)] assessed in 73 dairy farms in Northwestern Spain.

Description of parameters based of the animal	Percentiles rank		
	25th	50th	75th
Animal-based welfare indicators (n=73)			
Unsuitable BCS (%)	42	52	61
Hock injuries (%)	25	40	56
Clinical lameness (%)	5	9	16
Dirtiness of cow's coat (%)	63	73	83
Productive parameters (n=63)			
BTSCC (cells/mL)	154	186	254
DIM (days)	157	184	202
Herd milk production (305ME, kg)	8,434	9,111	9,734
Reproductive parameters (n=73)			
CFSI (days)	70	75	81
FSC (%)	23	30	35
CCI (days)	132	152	171
HD (%)	49	53	60
CN	2.3	2.4	2.8
C (%)	30	34	37

Table 3. Distribution of the categorical variables for the facility-based parameters in 73 dairy farms in Northwestern Spain.

Area	Categorical variables	Level	Frequency (%)
Resting	**Stall location**	**Against a side wall**	12.3
		Head to head platform	84.9
		Both combined	2.7
	Brisket locator	**Yes**	84.9
		No	15.1
	Dividers design	**Italian**	45.2
		Michigan	20.6
		"U" loop	17.8
		Wide-span	16.4
	Slope of the platform	**Yes**	64.4
		No	35.6
	Bedding materials type	**Rubber mats**	45.2
		Sand or straw	28.8
		No bedding (concrete/soil)	17.8
		Mattresses	8.2
	Dryness of bedding materials	**Yes**	52.0
		No	48.0
Walking	**Crossovers**	**Yes**	94.5
		No	5.5
	Crossovers curb	**Yes**	84.9
		No	15.1
	Back alley	**Yes**	95.9
		No	4.1

Table 4. Median (range) of the continuous variables for the facility-based parameters in 73 dairy farms in Northwestern Spain.

Area	Continuous variables	Median	Min	Max
Resting	Bed width (cm)	120	90	135
	Bed length (cm)	185	60	230
	Brisket locator height (cm)	20	5	50
	Total stall length (cm)	240	200	325
	Low lateral bar (cm)	30	0	70
	High lateral bar (cm)	60	20	90
	Neck rail height (cm)	115	90	140
	Neck rail position (cm)	165	85	190
	Front lunge space (cm)	60	0	115
	Rear curb height (cm)	28	15	40
	Stall stocking density (%)	98	55	186
Walking	Crossovers width (cm)	160	90	350
	Crossovers curb (cm)	25	5	40
	Back alley width (cm)	300	0	620
	Feeding alley width (cm)	400	240	500
Feeding	Feed bunk stocking density (%)	96	50	178
	Feed bunk space/cow (cm)	65	50	70
	Feed bunk height (cm)	10	0	50
	Linear watering space/cow (cm)	8.4	2.6	32.0
Milking	Holding are space/cow (m^2)	1.2	0.7	7.7
	Slope of the holding area (%)	2.0	0.0	15.4
	Entrance door width (cm)	250	100	800
	Exit path width (cm)	110	90	300

Table 5. Distribution of the categorical variables of the management practices in 73 dairy farms in Northwestern Spain.

Categorical variables	Level	Frequency (%)
Frequency of bed cleaning	"When necessary"	12.3
	1 daily	15.1
	≥2 daily	72.6
Hoof trimming routine	"When necessary"	49.3
	1 yearly	12.3
	≥2 yearly	38.4
Frequency of feed bunk cleaning	"when necessary"	2.7
	1 daily	87.7
	2 daily	9.6
Frequency of trough cleaning	"when necessary"	82.2
	1 daily	13.7
	2 daily	4.1

Table 6. Ranking of the top and bottom 15% of the farms sorted by the number of animal-based welfare indicators [unsuitable body condition score (BCS) for the stage of lactation [days in milk (DIM)], hock injuries, clinical lameness (locomotion score 3, 4, 5) and dirtiness of the cow's coat (average of the percentage of cows with hygiene score>2 in the three zones of the cow's coat)] in A (at least two indicators and cero in category C; white) > B (grey) > C (at least two indicators and cero in category A; dark grey) categories. Each indicator was previously sorted from low to high prevalence across farms and grouped into three categories were A represented the 25% of the farms with the lowest prevalence for each indicator, B the 50% of the farms and C the 25% of the farms with the highest prevalence in Northwestern Spain dairy farms.

Indicators - Percentage of cows by herd (%)	**Top 15% dairies**										
Unsuitable BCS (%)	B	A	A	A	B	B	B	B	B	B	B
Hock injuries (%)	A	B	B	B	B	A	A	A	A	A	A
Clinical lameness (%)	A	A	A	B	A	B	B	A	A	A	A
Dirtiness of cow's coat (%)	A	B	B	A	A	A	A	B	B	B	B

Indicators - Percentage of cows by herd (%)	**Bottom 15% dairies**										
Unsuitable BCS (%)	C	C	C	B	C	C	B	B	C	C	C
Hock injuries (%)	B	B	C	C	B	B	C	C	C	C	C
Clinical lameness (%)	B	B	B	B	C	C	C	C	C	C	C
Dirtiness of cow's coat (%)	C	C	B	C	B	C	C	C	B	B	C

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Deviation from the formulated target weight of ingredients loaded into high milk yield cow recipes on California dairies

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ABSTRACT

Nutrient composition of the feed and formulated ration often differ depending on uncertainties in DM content and nutrient composition of ingredients, as well as from feeder errors during loading. The objective of this study was to describe the deviation from target weight for the high-producing cow ration (HCR) and premix (HCP) on 26 California dairies ranging in size from 1,100 to 6,900 cows. Records from a consecutive 12-mo period were extracted from FeedWatch 7 (Valley Agricultural Software Inc., Tulare, CA), a feeding management software. Variables extracted and studied were date, recipe type, recipe number, ingredient, loading sequence, target weight, weight, and tolerance level (TL, deviation allowed per ingredient during loading). Based on the distribution of the deviation from target weight for the 8 most common ingredients, loading accuracy (quartile 1; small: |<10| kg; medium |10| to |20| kg; large |>20| kg), loading precision (interquartile range = quartile 3 to 1; small: <20 kg; medium: 20 to 40 kg; large >40 kg), and extreme observations (quartile 3; small: |<25| kg; medium: |25| to |40| kg; large: |>40| kg) were described. Descriptive statistics were conducted with SAS 9.4 (SAS Institute Inc., Cary, NC). The median TL assigned to ingredients across dairies ranged from 0 to 90 kg. At the ingredient level, the TL allowed a deviation from the median ingredient target weight of 0 to 2 (53.9%), >2 to 5 (25.5%), >5 to 10 (11.6%), or >10% (8.9%). A total of 2.5% of the loads did not reach the target weight set by the TL, ranging from 0.1 to 21.1% loads across dairies. Ingredient deviation from the formulated target weight across dairies was below target 49.1% of the time [<−10 (2.5%), −10 to <−5 (4.8%), −5 to <−2 (8.9%), −2 to <0% (32.8%)] or at or above target 50.9% of the time [0 (3.9%), >0 to 2 (36.7%), >2 to 5 (8.9%), >5 to 10 (1.2%), >10% (0.2%)]. Five dairies loaded ingredients with adequate accuracy (small to medium, quartile 1) and adequate precision (small to medium, interquartile range), but accuracy and precision were very poor on 3 dairies (large, quartile 1 and interquartile range). Rolled corn and almond hulls were loaded with adequate precision (small to medium, interquartile range) on a minimum of 64% of the dairies and adequate accuracy (small, quartile 1) on at least 68% of the dairies. In contrast, alfalfa hay, corn silage, and canola were loaded with poor precision (large, interquartile range) on a minimum of 60% of the dairies. There was a large variation within and across dairies on the deviation from target weight. Readjusting the TL settings might reduce the deviation from target weight. On 5 dairies, feeders were able to load ingredients with minimal deviation from target weight, setting achievable goals for the industry. Based on loading errors, opportunities exist to improve feeder performance on California dairies.

Key words: feeding management software, loading deviations from target, tolerance level

INTRODUCTION

Feed is the highest expense on a dairy. From 2011 to 2014, feed cost represented 61 to 64% of the total production cost on South Valley California dairies (CDFA, 2014). Research advances in past decades has facilitated the development of advanced mathematical models for ration formulation that accurately predict the performance of dairy cows based on the nutrient composition of their ration feed. These tools enable dairy nutrition consultants to formulate rations that cost the least while maximizing the efficiency of feed to milk conversion. However, the nutrient composition of the fed ration often differs from the formulated ration as a result of errors associated with weighing ingredients into a mixer box, as well as uncertainties in DM content and nutrient composition of the ingredients

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(Buckmaster and Muller, 1994; St-Pierre and Weiss, 2015). On 7 California commercial dairies, the observed variation between the fed and formulated recipe was important (CV >5%) on 29 to 79% of recipes studied for NDF, CP, fat, Ca, and P (Silva-del-Río and Castillo, 2012). Similarly, James and Cox (2008) reported high variability in CP and P content between the fed and formulated recipe. It has been reported that day-to-day variability in nutrient composition was not as large as the variability observed between the fed and formulated recipe (Sova et al., 2014). The observed variability in TMR nutrient composition might have implications in regard to milk yield (Rossow and Aly, 2013; Sova et al., 2014). Due to these uncertainties associated with the feeding process, nutrition consultants often times add a safety margin by formulating rations that exceed requirements for critical nutrients such as CP. The downside of this practice is the potential for a higher feeding cost as well as an increase in nutrient excretion, especially those with environmental impact such as N.

Incorporating new technologies, such as a feed management software (**FMS**), may help dairy producers minimize the variation in nutrient composition (James and Cox, 2008). A 2009 California feeding management survey indicated that 44% of the dairy producers had incorporated a FMS into their operations (Silva-del-Río et al., 2010). This technology assists with recipe preparation, inventory management, and feeder performance monitoring. The mixer box has a scale indicator that displays the type and amount of ingredients that should be loaded per recipe, the final weight loaded per ingredient, and the start and end time of each loading action is transmitted through an antenna to the main computer. The time and amount of feed delivered per pen is recorded. This information can be used to generate reports based upon loading and delivery errors, mixing time, time between loads, and loading and delivery sequence of ingredients. Most FMS users reported to find value in the loading errors reports that could be used to evaluate the efficiency of feeders (James and Cox, 2008; Silva-del-Río et al., 2010). Control charts could also be used as a tool to monitor feed management on dairies (Stewart et al., 2011). However, no industry standard exists for an acceptable loading error. To the best of our knowledge, only one study reported loading errors from 7 Virginia dairies (James and Cox, 2008). Thus, the objective of our study was to describe loading deviations from target within and across 26 California dairies throughout a 12-mo period.

MATERIALS AND METHODS

Data Collection and Dairies

Twenty-six California dairy cattle farms using FeedWatch 7 [Valley Agricultural Software Inc. (**VAS**), Tulare, CA] as their FMS for at least 1 yr were enrolled in the study. A 12-mo data backup was obtained from the FMS for each farm. The final data set included information from Jan 2012 to May 2014. California dairy nutrition consultants and VAS personnel assisted with dairy identification. Enrolled dairies were located in the San Joaquin Valley and ranged in size (lactating and dry cows) from 1,100 to 6,900 cows. Each dairy was given a number according to its herd size, from largest (dairy 1) to smallest (dairy 26). Dairies 1 to 6 had over 4,000 cows, dairies 7 to 20 had between 2,000 and 4,000 cows, and dairies 21 to 26 had less than 2,000 cows. Records included information from 2 recipes, high cow ration (**HCR**; including 511,554 ingredient loads) and high cow premix (**HCP**; including 72,726 ingredient loads). A description of feeding variables among dairies in the study is presented in Table 1.

Assembly and Structure of the Data Set

The consultant version of FeedWatch 7 was used to extract records from the setup function and user reports. Data were transferred to an excel spreadsheet (Microsoft Office Excel 2010, Microsoft Corp., Redmond, WA) to create a database for analysis. The variables extracted included date, recipe, recipe drop number, ingredient, loading sequence, target weight,

Table 1. Description of feeding variables for high cow ration and high cow premix based on median values per dairy during a 12-mo period on 26 California dairies

	High cow ration (n = 26)			High cow premix (n = 20)		
Item	Median	Minimum	Maximum	Median	Minimum	Maximum
Recipe loads/day (no.)	6	2	14	2	1	4
Ingredients/recipe load (no.)	8	4	10	7	4	11
Ingredient loads/day (no.)	43	16	108	9	4	19
Recipe load weight (kg)	10,055	4,785	17,998	15,613	8,548	24,298
Feeders (no.)	4	1	6	3	1	6

weight, tolerance level (**TL**), and feeder ID. A description of some of the variables obtained from the FMS is shown below.

- Target ingredient weight: the expected weight that should be loaded.
- Ingredient weight: the weight read by the mixer box scale after loading each ingredient.
- Recipe load number: the number that identifies each recipe load.
- Ingredient type: Over 44 types of ingredients were used in HCR and HCP recipes across all dairies throughout the 12-mo study. Fifteen ingredients were deemed most common, as they were used in at least half of the dairies: premix (n = 26 dairies), alfalfa hay (n = 26), corn silage (n = 26), rolled corn (n = 25), almond hulls (n = 25), liquids (molasses, water, and whey; n = 24), whole cottonseed (n = 23), mineral-vitamins (n = 21), canola (n = 20), dry distillers grains (**DDG**; n = 16), wet distillers grains (**WDG**; n = 15), straw (n = 14), corn gluten feed (n = 14), wheat silage (n = 14), and by-pass fat (n = 14). These ingredients represented 77% of the total ingredient loads. Results presented by ingredient type only include information from the 15 most common ingredient types used in HCR and HCP recipes.
- TL settings: To avoid overloading ingredients, the FMS assigns a TL to each commodity. After reaching the TL, if there is a pause of 5 s or longer the FMS will register the new weight as the next ingredient of the recipe.
- Feeder identification: the unique ID given to each employee operating the FMS.

Calculations

Deviation from the median recipe load target weight allowed by the TL was calculated for each dairy as (a) kilograms, TL assigned to ingredients within a recipe load; and (b) percentage, (Σ ingredient TL within a recipe load/Σ ingredient target formulated weight with the same recipe load number) × 100.

Deviation from the median ingredient type target weight allowed by the TL was calculated for each dairy and ingredient type as (a) kilograms, TL assigned to each ingredient type across dairies; and (b) percentage, (TL per ingredient type/median formulated target weight by ingredient type) × 100.

Deviation from TL for ingredient loads not reaching the target weight set by the TL was calculated as (a) kilograms, [(formulated target weight − TL) − (weight loaded)]; and (b) percentage: [(formulated target weight − TL) − (weight loaded)/(formulated target weight − TL)] × 100.

Deviation from recipe load target weight was calculated as the absolute value and real value for each dairy as (a) kilograms, (weight loaded per recipe load − target weight per recipe load); and (b) percentage, (weight loaded per recipe load − target weight per recipe load)/target weight per recipe load × 100.

The final deviation from target weight was calculated for the 15 most common ingredient types as (a) kilograms, (weight loaded per ingredient type − target weight per ingredient type); and (b) percentage, [(weight loaded per ingredient type − target weight per ingredient)/target weight per ingredient type] × 100.

The proportion of loads with a deviation from target greater than 2% for each day of the week was evaluated. Dairies with a coefficient of variation >10% were considered to have a dissimilar percentage by day of the week and were reported.

For each dairy, the cost of ingredients included in HCR and HCP was obtained from the FMS records. Three dairies (1, 4, and 5) had no records for ingredient cost; consequently, only information from 17 HCP and 23 HCR were used to evaluate recipe load cost deviations. The cost per metric tonne of the target recipe was calculated as (Σ ingredient target weight × ingredient cost)/total target weight per recipe load. The cost per metric tonne of the recipe loaded was calculated as (Σ ingredient weight × ingredient cost)/total weight per recipe load.

Based on the distribution of the deviation from target weight across dairies for the 8 most common ingredients (alfalfa hay, almonds hulls, canola, corn silage, liquids, premix, rolled corn, and whole cottonseed) loading accuracy [based on quartile 1 (**Q_1**; 25th percentile)], loading precision [based on interquartile range (**IQR**) = quartiles 3–1], and extreme observations [based on quartile 3 (**Q_3**; 75th percentile)] were described. Each of these variables was classified based on their quartile distribution among dairies as small, medium, or large deviation from target rounded to the nearest figure in 5-unit increments.

- Q_1 was classified as small (Q_1 = |< 10| kg; 52.0%), medium (Q_1 = |10| to |20| kg; 38.3%), or large (Q_1 = |>20| kg; 9.7%).
- Q_3 was classified as small (Q_3 = |<25| kg; 42.4%), medium (Q_3 = |25| to |40| kg; 34.7%), or large (Q_3 = |>40| kg; 16.3%).
- IQR (Q_3–Q_1) was classified as small (IQR <20 kg; 49.0%), medium (IQR = 20 to 40 kg; 34.7%), or large (IQR >40 kg; 16.3%).

Data Interpretation

To interpret study findings, additional information on feeding management practices was obtained for some dairies through interviews with dairy nutritionists, VAS personnel, or by direct interaction with feeders on dairies.

Data Analysis

Descriptive statistics were calculated with the PROC MEANS and PROC UNIVARIATE procedures of SAS 9.4 (SAS Institute Inc., Cary, NC). Percentiles were computed using the PCTLDEF = 4 option in the output statement of the PROC UNIVARIATE. The relationship between deviation from target in kilograms and percentage by dairy was evaluated using the PROC CORR procedure of SAS 9.4.

RESULTS AND DISCUSSION

Data Screening

There were no feeding records for 2 consecutive months and for 40 nonconsecutive days on dairy 2 and 11, respectively. This could be explained by equipment breakdown, communication problems between the software and mixer box, or unintentional deletion of computer records. On dairy 6, recipe loads prepared with the stationary mixer box (20,498 ingredient loads, 62% of dairy 6 observations) had no recipe load number information. Therefore, all observations were used to evaluate ingredient loading deviations from target, but loads prepared with the stationary mixer were not evaluated at the recipe load level.

Five dairies (2, 6, 18, 20, and 23) did not prepare the HCP recipe on farm. Dairy 11 had only HCP recipe records for 90 nonconsecutive days, so it was removed from the final HCP recipe analysis. Dairy 26 (herd size 1,100) did not prepare HCP recipe during the first 5 mo of the study period, so HCP recipe records from 7 mo were included in the final data set.

On dairy 14, one ingredient load reached a 10-figure number. This observation was eliminated. The FMS automatically generates a 10-figure number when apparent total scale weights are exceeded. This could be due to cell weight errors or to the front-end-loader striking excessive weight on the mixer box.

There were ingredients not loaded into the HCR or HCP recipe. Those ingredients registered a load weight of 0 kg (1,299 total observations). This could be explained if ingredients were listed in the recipe but were not available at the dairy. In this scenario, the feeder must advance manually or by clicker to the next ingredient. However, the movement of the feed inside the mixer box often causes the scale reading to bounce during mixing. If the magnitude of the scale bouncing is higher than the minimum scale detection, an ingredient weight record would exist even if no ingredient was loaded. In the present study, we also considered that ingredients were not weighed down when the amount loaded was <60 kg, the target weight was >100 kg, and the amount loaded represented <10% of the expected target weight. Based on these criteria, a total of 675 ingredients were not loaded and over half of those ingredients (53.6%) were from dairy 15.

The initial data set included information from 584,280 ingredient loads. After data screening, the final data set included a total of 488,359 ingredient loads for HCR [range = 5,900 (dairy 1) to 84,125 (dairy 2)] and 72,422 for HCP [range = 4,190 (dairy 1) to 6,900 (dairy 2)].

TL Settings

All dairies used the TL settings function of the FMS (Figure 1). During the 12-mo study period, the assigned TL was kept constant for all ingredients across dairies. The minimum TL assigned to an ingredient was 0 (n = 15) or 2.3 to 9.0 kg (n = 11) and the maximum TL level ranged from 14 to 36 (n = 14), 45 (n = 6), 90 (n = 2), or 135 kg (n = 4).

The major purpose of assigning commodities with a TL is to minimize the risk of overloading expensive ingredients. During software installation, information systems technicians educated clients on the TL settings

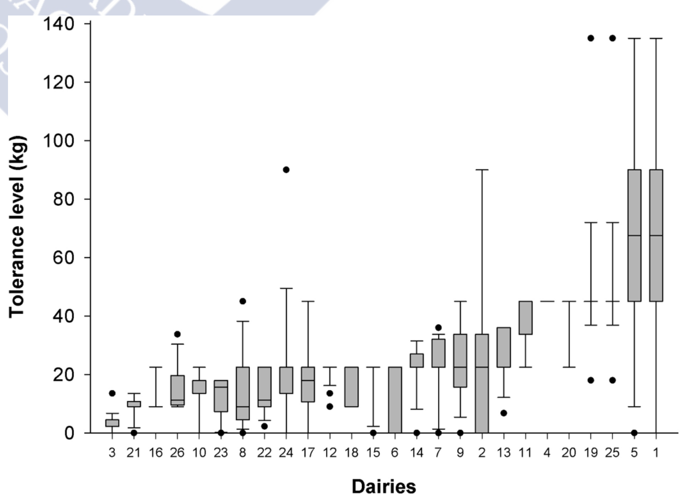

Figure 1. Boxplot of the tolerance level (kg) assigned to the various ingredients of the high cow ration and high cow premix recipe on 26 California dairies. Data are presented sorted by 75th percentile, and then by 50th percentile. Each boxplot shows the 50th percentile (median, line within the box), 25th and 75th percentile (box), 10th and 90th percentiles (whiskers), and outliers (dots).

of the FMS. It is at software installation time when most users decide the TL of ingredients [personal communication with C. Lew, VAS, Tulare, CA]. Settings of 0 kg for TL could be explained due to dairy producers considering irrelevant to assign TL to some ingredients, or the fact they did not know how to use the TL settings of the FMS for new ingredients. Ingredients with 0 kg of TL were feed additives (n = 12), forages (n = 10), by-products (n = 8), seasonal by-products (n = 4), premixes (n = 3), or grains (n = 1; Figure 2). Most of these ingredients (78.9%) were included in the recipe for less than 6 mo. The most common TL assigned to an ingredient was 23 kg, used 11.1 to 91.7% on 18 of the dairies. However, it is unclear the criteria by which dairy producers assigned TL to various ingredient types. Most dairies selected TL values under 36 kg, but some dairies were more liberal with their TL settings. Six dairies assigned a similar TL to all ingredients (IQR = 0 kg), and 4 dairies chose various TL (IQR = 23 to 45 kg). One dairy assigned the same TL, 45 kg, to all ingredients.

Deviation from Target Weight Allowed by TL

The TL added to <200 (n = 14), 200 to 400 (n = 8), or >400 kg (n = 4) for HCR represented 0.4 to 2.3, 1.9 to 6.9, and 3.3 to 4.6% of deviation from the median target weight, respectively. Similarly, the TL added to <200 (n = 15), 200 to 400 (n = 4), or >400 kg (n = 1) for HCP represented 0.2 to 1.2, 1.5 to 4.2, and 2.8% of deviation from the median target weight, respectively. The TL could potentially introduce at least a 4% deviation from target weight for HCR on 3 dairies [dairy 5 (720 kg of TL), 19 (405 kg of TL), and 25 (315 kg of TL)] and on 1 dairy for HCP [dairy 25 (360 kg of TL)].

At the ingredient level, the TL allowed a deviation of 0 (8.7%), >0 to 2 (45.2%), >2 to 5 (25.5%), >5 to 10 (11.6%), or >10% (8.9%) from the median ingredient target weight. Thus, the TL needs to be carefully considered, as it had the potential to introduce a deviation from target of >5% in more than 20% of the ingredients. In most cases, the median formulated target weight for these ingredients was under 1,000 kg. However, some ingredients with a median formulated target weight of over 1,000 kg had >5% of deviation allowed by the TL [liquids (3/6), rolled corn (2/4), wheat silage (1/2), WDG (1/3), DDG (1/4), mineral-vitamins (1/6), and alfalfa hay (2/13)].

Five dairies had 1 ingredient (liquid, straw, or by-pass fat) with an assigned TL that allowed >30% of deviation from the median target weight. On 4 of these dairies, the deviation was explained by the low median target weight set by the recipe (23–83 kg) rather than by the TL assigned to those ingredients (18–23 kg). However, on 1 dairy the TL assigned to liquids was 90 kg whereas the median target weight was 300 kg. For ingredients added in small quantities, the most desirable loading method would be to weigh them before loading; thus, assigning a TL would be irrelevant for those ingredients.

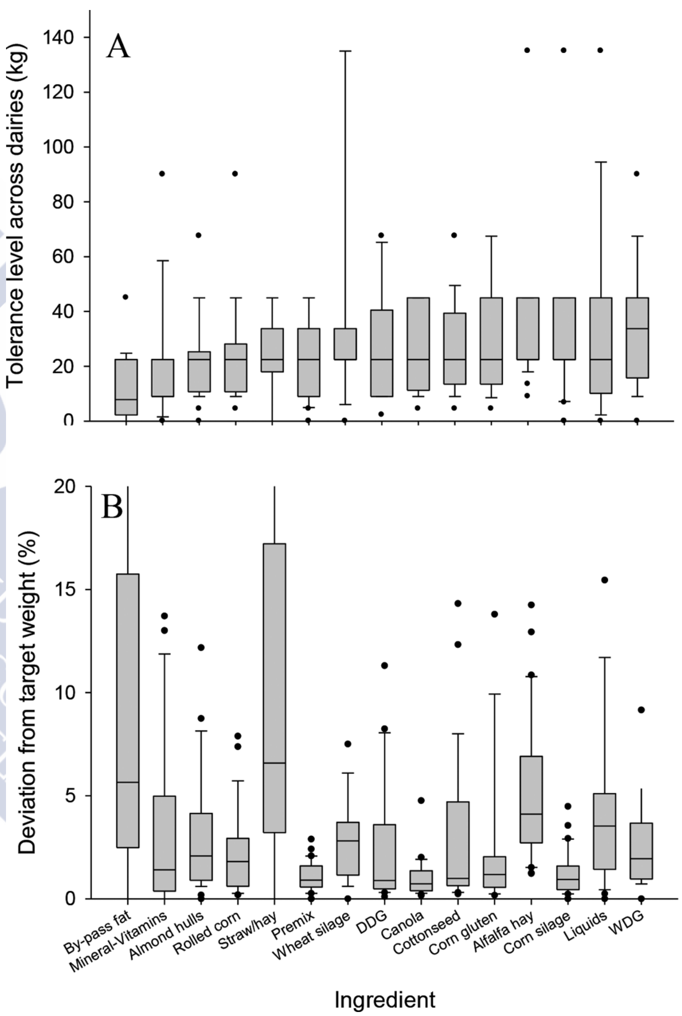

Figure 2. Boxplot of the tolerance level settings (A; kg) and of the median deviation allowed by the tolerance level (B; %) for ingredients included in the high cow ration and high cow premix recipes on 26 California dairies. Data are presented sorted by 75th percentile, and then by 50th percentile (A). The boxplot shows the 50th percentile (median, line within the box), 25th and 75th percentile (box), 10th and 90th percentiles (whiskers), and outliers (dots). Panel B whisker reaches 61.2% for by-pass fat and 36.1% for straw/hay. The deviation allowed by the tolerance level was calculated per ingredient and dairy as follows: [Σ recipe ingredient tolerance level (kg)/Σ recipe ingredient target (kg)] × 100. DDG = dried distillers grains; WDG = wet distillers grains.

Loads not Reaching the Target Weight Set by TL

A total of 12,439 times (2.5% of the total observations) ingredients were loaded under the target weight set by TL. This represented 0.1 to 21.1% loads of feed per dairy (Figure 3). The number of loads not reaching the TL by up to 50 kg [5–80 (n = 11 dairies), 128–500 (n = 10), or 1,230–1,830 loads (n = 5)] or by more than 50 kg [2–36 (n = 12), 54–149 (n = 10), and 207–319 loads (n = 4)] ranged widely across the study dairies.

Four dairies had over 1,000 ingredient loads not reaching the TL by up to 25 kg. The ingredients in most these cases were wheat silage (dairy 3); corn silage, whole cottonseed, and rice grain (dairy 12); corn silage, canola, yeast, rolled corn, and oat silage (dairy 21); and, alfalfa hay, almond hulls, corn silage, premix, and rolled corn (dairy 26). On these dairies, feeders and owners potentially could have agreed it was an acceptable practice to manually advance to the next ingredient if less than 25 kg were left to reach the TL. However, this practice increased the deviation from the formulated target weight by 0.2 to 0.9 percentage units. Feeders and dairy owners should be informed about the implications of routinely not reaching the TL. Based on information from the FMS, we cannot determine if this practice saved the feeder an extra trip to the commodity barn or if the feeder simply did not want to pursue the task of reaching the target weight.

On dairy 1, some ingredient loads did not reach the TL up to 25 kg (n = 651) or from >25 to 50 kg (n = 751). This increased the deviation from the median formulated target weight by 0.9 and 2.5 percentage units, respectively. Sorghum represented 80% of the loads not reaching the TL. This was likely explained because sorghum had 0 kg of TL, whereas the mean TL for all the other ingredients on this dairy was 67.5 kg.

On 7 dairies, a total of 50 to 272 loads were below the TL by over 200 kg. The ingredients that were most commonly underloaded were citrus by-products, liquids, and corn silage. For these ingredients, the deviation from the formulated target increased by 17.7 to 85.4 percentage units.

Over the study period, all dairies but dairy 20 had ingredients that were not loaded either 1 to 15 (n = 11), 23 to 74 (n = 12), 434 (dairy 14; mostly seasonal by-products and by-pass fat), or 641 times (dairy 2; mostly liquids). We are unsure why ingredients were not loaded, but it is likely that occasionally some commodities were used up before a new truck load was delivered or one ingredient was removed from the recipe without updating the FMS. It is extremely important that dairy nutritionists and dairy managers maintain open lines of communication with feeders to understand why some ingredients are not being loaded. If adjustments need to be made to the FMS recipe, it would be recommended to introduce those as soon as possible so feeding records can be accurately evaluated.

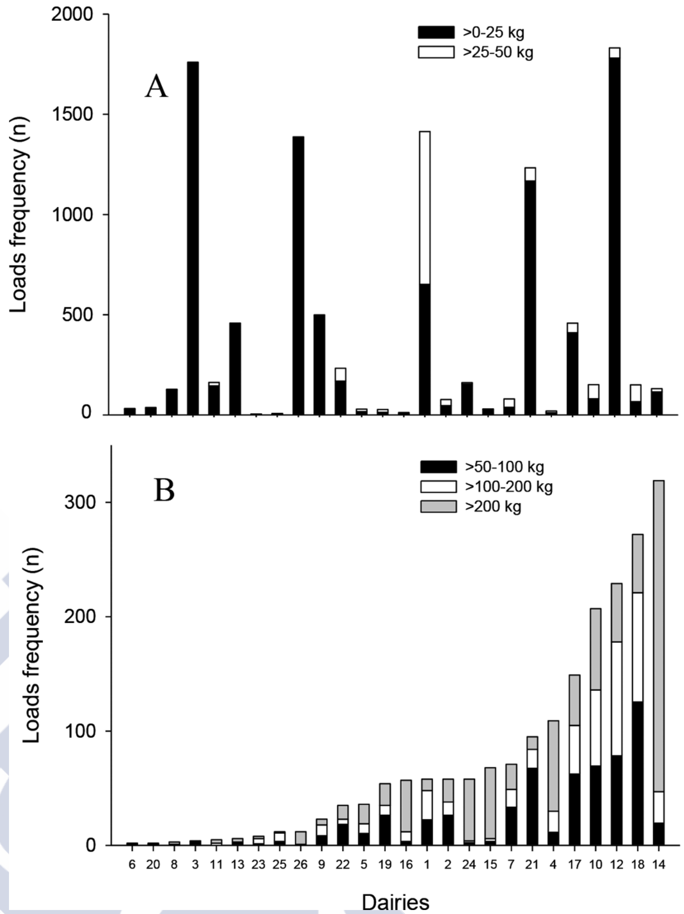

Figure 3. Frequency of loads that did not reach the target weight set by the tolerance level [by 0 to 50 kg (A) and by >50 kg (B)] for ingredients loaded into the high cow ration and the high cow premix recipes on 26 California dairies. Data are presented sorted by the frequency of loads in B.

Deviation from Target Weight by Dairy

The deviation from target weight, as kilograms and percentage, is represented in Figure 4. Across all ingredients loaded, the deviation from the formulated target weight was 49.1% of the time below target [<−10% (2.5%), −10 to <−5% (4.8%), −5 to <−2% (8.9%), −2 to <0% (32.8%)] and 50.9% of the time at or above target [0% (3.9%), >0 to 2% (36.7%), >2 to 5% (8.9%), >5 to 10% (1.2%), >10% (0.2%)].

Deviation from target can be expressed in kilograms or as a percentage. When expressed in kilograms, at least 20% of the time ingredients were loaded with a deviation from target >40 kg on 7 dairies (4, 7, 9, 10, 14, 15, and 23) or <−40 kg on 2 dairies (5 and 25).

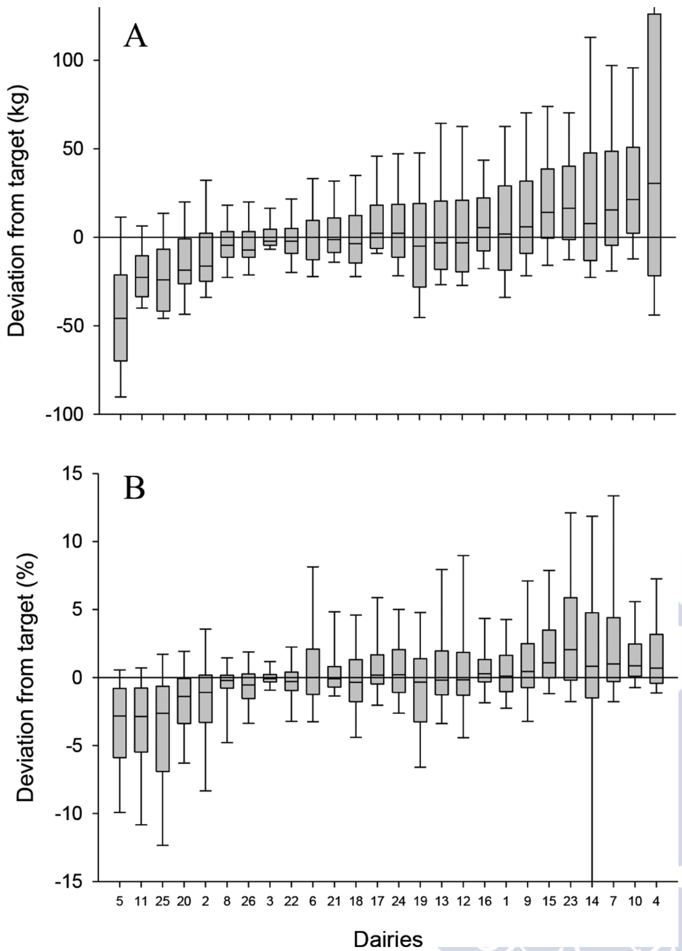

Figure 4. Boxplot distribution of the deviation from the target weight (A, kg; B, %) for ingredients loaded into the high cow ration and high cow premix recipes on 26 California dairies. Data are presented sorted by 75th and then by the 50th percentile (A). The boxplot shows the 50th percentile (median, line within the box), 25th and 75th percentile (box), and 10th and 90th percentiles (whiskers). Whisker reaches: (A) 265 kg (dairy 4); (B) −31% (dairy 14).

However, as a percentage, at least 20% of the time ingredient deviations from the target was >4% on 5 dairies (4, 7, 14, 15, and 23) or <−4% on 6 dairies (2, 5, 11, 19, 20, and 25). Although a significant association was noted between deviation from target weight per ingredient load, expressed as kilograms and as a percentage, the correlation coefficient was poor and only on 6 dairies was it >0.5. When small loads were prepared, deviation from target weight expressed as a percentage will be larger compared with big loads. This could explain why dairies 9 and 10 (the 9th and 10th largest dairies), despite having a large deviation from target in kilograms, did not show the same extend of deviation as a percentage. Likewise, 6 dairies showed an important deviation below the target weight as a percentage, but only 2 dairies when deviation was expressed as kilograms. Dairy 4 showed the largest deviation above target weight in kilograms, but dairy 23 (the 4th smallest dairy) had the largest deviation as a percentage. It is quite common that owners and nutritionists set feeder performance goals based on deviation from target as percentage rather than kilograms. Deviation from target weight expressed in percentage is a good tool to assess the extent of loading errors and their potential implications on the final nutrient composition of the recipe. However, deviation from target weight in kilograms is a better tool to monitor feeder performance. If feeder loading errors are mostly under the target weight, the assigned TL should be re-evaluated. Also, it is important to ensure that inaccuracies at loading are not due to equipment failure. The mixer box scale should be calibrated frequently and scale bouncing during mixing should be kept to a minimum. Based on our field experiences, we have observed mixer scales bouncing up to 40 kg. This situation makes it extremely difficult for the feeder to weigh ingredients accurately. On a 2010 feeding management survey, it was reported that dairy producers and managers neglected to check the mixer box scale enough (Silva-del-Río et al., 2010).

Deviation from Target Weight by Ingredient Type

The deviation from target weight, in kilograms, for the 8 most common ingredient types is represented as a box plot in Figure 5. Straw, wheat silage, by-pass fat, mineral-vitamins, and canola were loaded in 10.0 to 14.3% of the dairies with a median deviation of >2% from the target weight; however, by-pass fat, straw, alfalfa hay, liquids, DDG, whole cottonseed, almond hulls, corn gluten feed, and mineral-vitamins were loaded in 13.2 to 42.8% of the dairies, with a median deviation of <−2% from the target weight. The most extreme deviation over the target weight was observed for by-pass fat on dairy 7 (21.9%), with a median target weight of 76 kg. The most extreme deviations under the target weight were observed for by-pass fat [−24.3% (dairy 17); −44.7% (dairy 11); −78.7% (dairy 14)] and mineral-vitamins [−62.5% (dairy 17)]. This could be explained by the low median target weight loaded for by-pass fat [247 kg (dairy 17); 23 kg (dairy 11); 40 kg (dairy 14)] and mineral-vitamins [135 kg (dairy 17)]. It is possible that most ingredients with extreme deviation from target weight were loaded as whole bags or were weighted before being added into the mixer box. In situations where the mixer was running during loading, the large deviation from target weight could be simply explained by mixer scale errors, such as a scale bouncing, rather than a lack of feeder accuracy when loading minimal quantities.

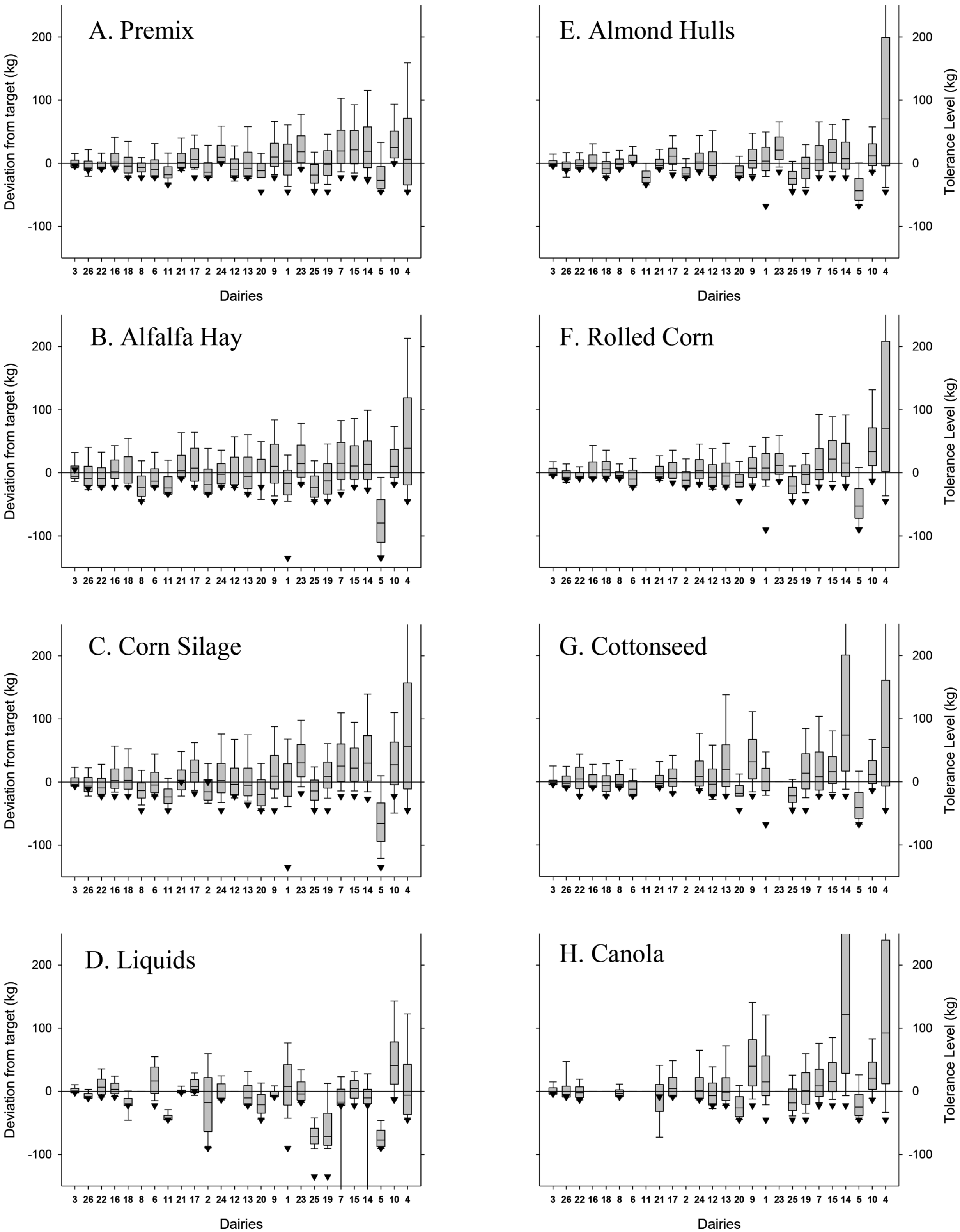

Figure 5. Boxplot distribution of the deviation from target weight for 8 of the most common ingredients of the high cow ration and high cow premix recipes during a 12-mo period on 26 California dairies. The tolerance level is represented in the secondary y-axis as ▼. Data are presented sorted by overall interquartile range (Q_3 to Q_1). The boxplot shows the 50th percentile (median, line within the box), 25th and 75th percentile (box), and 10th and 90th percentiles (whiskers). Whisker reaches: (C) 300 kg (dairy 4); (D) −640 kg (dairy 7), −440 kg (dairy 14); (E) 450 kg (dairy 4); (F) 380 kg (dairy 4); (G) 400 kg (dairy 14), 280 kg (dairy 4); (H) 500 kg (dairy 14; Q_3: 300 kg), 350 kg (dairy 4).

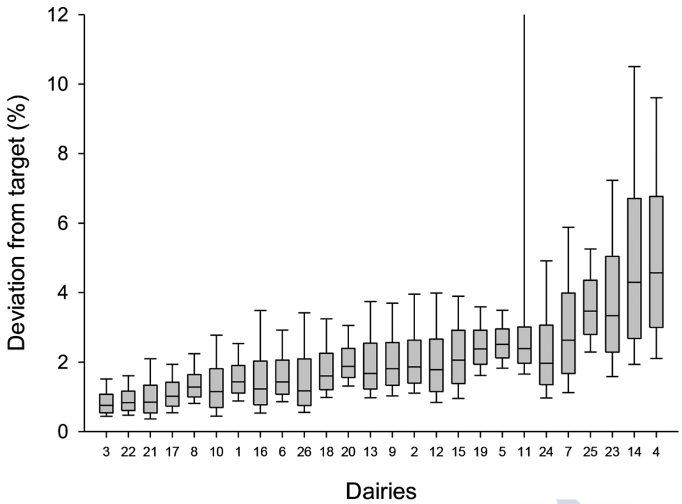

Figure 6. Boxplot distribution of the deviation from target weight (as an absolute value, %) for high cow ration on 26 California dairies. Data are presented sorted by 75th and then by the 50th percentile. The boxplot shows the 50th percentile (median, line within the box), 25th and 75th percentile (box), and 10th and 90th percentiles (whiskers). Upper whisker of dairy 11 reaches 33%.

Deviation from Target Weight for HCR and HCP Recipe

The box plot of the absolute deviation from target for HCR as a percentage is represented in Figure 6. The absolute deviation from target was more than 2% at least 50% of the time on 7 dairies. The real values of the median deviation for HCR recipe were either below the target weight on 10 dairies [<−2% (n = 2), −2 to <−1% (n = 2), −1 to 0% (n = 6)] or above the target weight on 16 dairies [>0 to 1% (n = 11), >1 to 2% (n = 3), >2% (n = 2)].

The box plot of the absolute deviation from target for HCP as a percentage is represented in Figure 7. The absolute deviation from target was more than 2% at least 50% of the time on 3 dairies. The real values of the median deviation from target weight for HCR recipe were either below the target weight on 4 dairies [<−2% (n = 0), −2 to <−1% (n = 2; dairy 5 and 25), −1 to 0% (n = 2)] or above the target weight on 17 dairies [>0 to 1% (n = 13), >1 to 2% (n = 2), >2% (n = 2)].

Our results indicated that, on most dairies, HCP was prepared within a reasonable absolute deviation from its target as percentage. However, opportunities exist to improve the absolute deviation from target for HCR. Although HCP is designed to mix ingredients that otherwise will be added in small quantities into the HCR, 17 dairies were adding at least 1 ingredient under 225 kg into the HCR, most commonly straw, by-pass fat, or yeast. Only 6 dairies included at least one ingredient under 225 kg into the HCP. Thus, dairy producers and nutritionist should evaluate if ingredients added into the HCR should rather be included into the HCP. Furthermore, it should be taken into consideration that ingredients added in small quantities often times come in bags. Feeders prefer to load whole bags as the first ingredient to avoid getting in and out of the loader during recipe preparation. This practice can compromise mixing uniformity. It is likely that feeders would be more compliant with the ingredient order at loading if they had to do it twice (median HCP recipe loads/d) versus 6 (median HCR recipe loads/d; Table 1) times per day.

Deviation from Target Weight by Day of the Week

The percentage of ingredients loaded into the HCR and HCP with a deviation from target greater than 2% by day of the week was similar (CV <10%) in 12 dairies. However, other dairies showed an important deviation (CV ranging from 10.8 to 54.8%, n = 14), that in most cases (n = 12) was explained by an extreme observation on a single day of the week.

On 5 dairies, there was an increase in the deviation from target weight on Wednesday [dairy 24 (extreme day value vs. 6-d average): 27.7 vs 12.3%)], Thursday (dairy 25: 9.7 vs. 5.4%), and Sunday (dairy 1: 22.5 vs. 16.4%; dairy 18: 20.8 vs. 15.7%; dairy 23: 52.8 vs. 36.8%). Nevertheless, on 7 dairies a reduction of deviation from target weight was observed on Monday (dairy 10: 28.7 vs. 37.6%), Wednesday (dairy 9: 27.8

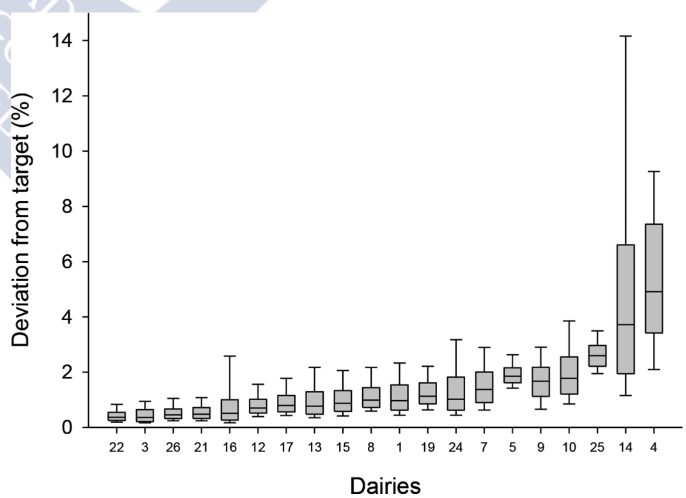

Figure 7. Boxplot distribution of the deviation from target weight (as an absolute value, %) for high cow premix on 26 California dairies. Data are presented sorted by 75th and then by the 50th percentile. The boxplot shows the 50th percentile (median, line within the box), 25th and 75th percentile (box), and 10th and 90th percentiles (whiskers).

vs. 36.0%; dairy 17: 17.6 vs. 23%), Saturday (dairy 8: 9.0 vs. 24.9%; dairy 13: 22.8 vs. 36.1%; dairy 26: 9.3 vs. 11.9%), and Sunday (dairy 16: 21.2 vs. 29.7%).

Variation in deviation from target in relation to the day of the week could be related to differences in loading accuracy between the primary and secondary feeder.

In our study, we did not use the FMS information on feeder identification, as we observed that the primary user logged at least 85% of the days on 6 dairies and between 82 to 85% of the days on 8 dairies. Taking into account that most feeders get at a minimum 1 d off a week and at least 2 wk of vacation, those besides the primary feeder were likely logged in under the same feeder identification. On Virginia dairies, there was no significant difference in deviation from target between the primary (1.57%) and secondary (1.26%) feeder (James and Cox, 2008). Contrary to their initial hypothesis, secondary feeders had a numerically inferior deviation from target. James and Cox (2008) speculated that bad working habits acquired by the main feeder might have played a role in feeding errors. Information on feeders' performance may be used to establish goals and rewards among operators within a dairy; however, based on our field experience, dairy nutritionists and dairy managers pay little attention to FMS records to evaluate feeders. Thus, dairy managers are giving minimal attention to ensure feeders are logged in with their unique identification each time.

Deviation from Target Recipe Cost

The deviation from target cost for HCR and HCP recipe is represented in Figure 8. As a result of deviations from the target weight, the HCR recipe cost increased by at least \$3 per metric tonne <5% (n = 15), 5 to 20% (n = 6), or >20% (dairies 7 and 14) of the times. It also decreased by \$3 per metric tonne <5% (n = 18), 5 to 20% (n = 4), or >20% (dairy 14) of the times. Some dairies were consistent in the final recipe cost relative to the target cost (IQR = \$0.3/metric tonne, dairy 3), but other dairies fluctuated largely (IQR = \$4.6/metric tonne, dairy 14).

The HCP recipe cost increased by at least \$3 per metric tonne <5% (n = 13) or 5 to 20% (n = 4; dairies 10, 14, 15, and 17) of the times or decreased by \$3 per metric tonne <5% (n = 14), 5 to 20% (n = 2; dairies 14 and 15), and >20% (dairy 17) of the time. The within-dairy variation, based on IQR, ranged between \$0.3 (dairy 22) to \$5.3/metric tonne (dairy 17).

It is accepted that by overloading ingredients the recipe cost will increase. On dairy 14, HCR recipes were mostly prepared under the target cost by at least \$1 per metric tonne, even though the feeder frequently overloaded ingredients (Figure 4). It is likely the feeder was paying attention to detail when loading costly ingredients, but not when loading relatively inexpensive ingredients. Conversely, on dairy 25, HCR and HCP recipes were prepared generally over the target cost per metric tonne, but very few ingredients on this dairy were loaded over the target weight as the TL was very restrictive (Figure 1). Expensive ingredients may have been loaded closer to the target than inexpensive ingredients.

Our results reflect the changes in recipe cost per metric tonne associated with deviations from the target weight. To estimate the true economic implications of loading actions, the effect on production associated with changes in nutrient composition as well as the final amount of feed per pen should have been taken into consideration. On most dairies nutritionists formulate least cost rations, thus any modification to the

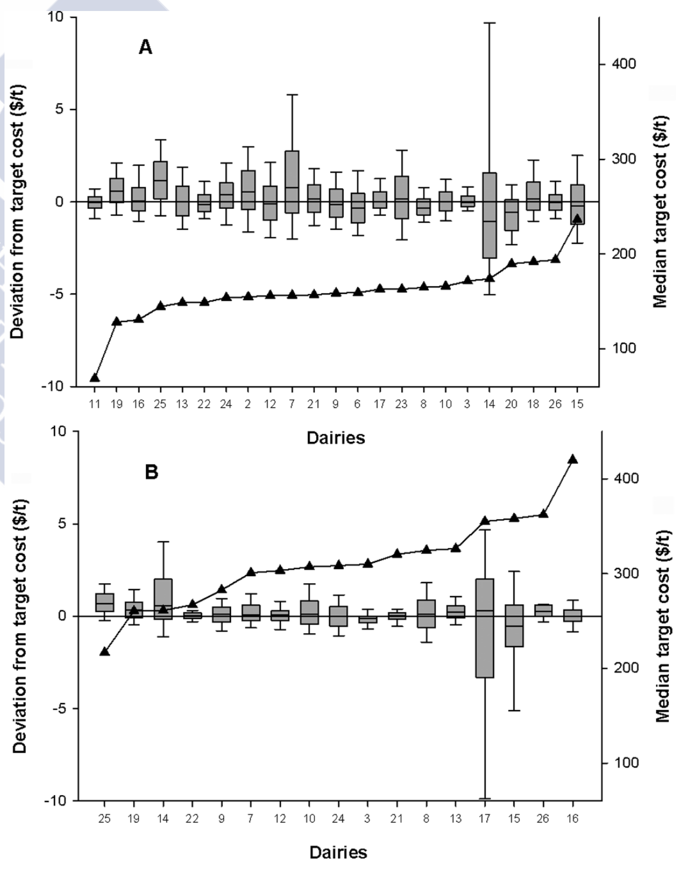

Figure 8. Boxplot distribution of the deviation from target cost by high cow ration (A, n = 23) and high cow premix (B, n = 17) recipes on California dairies. Median target cost is represented in the secondary y-axis as ▲. Data are presented sorted by the smallest to the largest median target cost. The boxplot shows the 50th percentile (median, line within the box), 25th and 75th percentile (box), and 10th and 90th percentiles (whiskers).

formulated recipe will most likely have a detrimental effect on income over feed cost.

Distribution of the Deviations from the Target Weight Based on Q_1, Q_3, and IQR

By Dairy. The deviation from target weight across dairies for the 8 most common ingredients based on Q_1, Q_3, and IQR is represented in Figure 9. These results provide guidelines for producers and the allied industry on achievable goals at loading. There were 5 dairies (3, 16, 18, 22, and 26) that loaded almost all ingredients with adequate accuracy (small Q_1) and precision (small to moderate IQR); however, on 4 dairies feeders showed inadequate accuracy (moderate to large Q_1) by either overloading (dairy 4 and 14) or underloading ingredients (dairies 5 and 11). Loading precision was poor on dairies 4, 5, and 14 (large IQR), but good on dairy 11 (small IQR). It is likely that by reducing or eliminating TL on dairy 11 the feeder could have been accurate. Six dairies (4, 5, 7, 10, 14 and 15) loaded at least 50% of the ingredients with a large deviation from target (Q_3: $|>40|$ kg), that represented up to a 14.5% of deviation. Dairy nutritionists and managers should actively engage with the feeder to improve loading performance on dairies with poor precision and accuracy.

The 2 dairies with the more liberal TL (0 to 135 kg, dairies 1 and 5) were owned by the same dairyman and shared the same manager and dairy nutritionist. However, on dairy 5, deviation from target based on Q_1 was large ($|18|$ to $|44|$ kg), with most ingredients loaded under the target weight, whereas dairy 1 was relatively accurate (Q_1: $|8|$ to $|14|$ kg). On these 2 dairies feeders interpreted differently what the loading target was, either the one set by the TL (dairy 5) or the true target (dairy 1).

On dairy 3, the feeder showed remarkable skills with quality precision (IQR = 0 to 6 kg), and accuracy (Q_1: $|1|$ to $|7|$ kg) with minor deviations from target (Q_3: $|4|$ to $|13|$ kg). Conversely, the feeder on dairy 4 lacked desirable loading skills. On this dairy, precision was poor (IQR = 34 to 208 kg), accuracy was moderate to poor (Q_1: $|18|$ to $|32|$ kg), and extreme deviations from target were noted (Q_3: $|52|$ to $|240|$ kg). On dairy 3, the feeder was directly supervised by a feed manager that tracked inventory and frequently supervised feeder errors. It was likely that this close supervision influenced feeder performance. Moreover, on this dairy, minerals and feed additives were automatically added into the recipe with a micronutrient liquid dispenser, minimizing loading errors. The good accuracy and precision observed for alfalfa hay could be explained by hay processing before loading; however, it is unknown if the dairy was actually doing this. One frequent concern with increasing loading accuracy is the potential detrimental effect on feeder efficiency. After recipe preparation times were evaluated, loading time for dairy 3 was found to be within average (unpublished data). Thus, neglecting accuracy and precision in favor of time efficiency might be a misconception.

By Ingredient. Rolled corn and almond hulls were easy to load. On at least 64 to 80% of the dairies these ingredients were loaded precisely (IQR: <20 kg) and accurately (Q_1 $|<10|$ kg). However, a total of 56.0% of the dairies loaded almond hulls with a deviation from target that ranged from 2.6 to 14.5% based Q_3. Of those dairies, median inclusion rate of almond hulls ranged between 207 to 5,117 kg, representing 2.4 to 29.6% of the as-fed weight of the recipe.

Overall, 60.0 to 61.5% of the dairies had poor precision (IQR: >20 kg) when loading alfalfa hay, corn silage, and canola. Alfalfa hay, corn silage, and canola were loaded with a large deviation from target (Q_3: $|>40|$ kg) on 34.6, 38.5, and 45.0% of the dairies, respectively. This represented a deviation from target weight of 2.1 to 12.9% (alfalfa hay), 2.2 to 5.5% (corn silage), and 2.3 to 7.3% (canola). As expected, alfalfa hay was one of the most challenging ingredients to load accurately and precisely. Alfalfa hay particles are prone to attach to one another, forming flakes that fall together during loading. Alfalfa hay represented 5.4 (Q_1) to 9.9% (Q_3) of the as-fed HCR recipe. Likewise, canola is an ingredient that flows rapidly from the bucket of the loader, requiring excellent skill to load accurately. Canola represented 12.5 (Q_1) to 33.0% (Q_3) of the as-fed HCP recipe.

Corn silage was not expected to be difficult to load, as it flows easily during unloading. Corn silage is a relatively inexpensive ingredient and primary component of HCR, representing 26.5 (Q_1) to 38.9% (Q_3) of the as-fed ration. Feeders may not be as careful when loading corn silage compared with more expensive ingredients. Also, the distance between the mixer and the corn silage structure may play a role in the feeder accuracy. Often the corn silage structure is placed far from the mixer, and the feeder will have to make an extra trip to acquire more silage or return leftovers to the structure. It may be easier for the feeder to dispose of the extra feed in the mixer and move to the next ingredient or manually advance if the target was not reached.

Five dairies (2, 5, 10, 19, and 25) loaded liquids with an extreme deviation from target weight (Q_3: $|>75|$ kg). On those dairies, liquids had a deviation from target that ranged from 6.2 to 25.1%. Liquids are added last to the recipe. Often times, the feeder has to get out of the loading equipment and manually open the faucet. The time to load the formulated liquid depends on the pipe design and viscosity of the liquid, especially for

	Ingredient type	Dairies																									
		3	26	22	16	18	8	6	11	21	17	2	24	12	13	20	9	1	23	25	19	7	15	14	5	10	4
IQR (Q_3 - Q_1)	Premix	2	11	4	12	15	12	14	14	14	16	12	28	15	19	14	24	29	36	23	24	42	41	45	24	42	49
	Alfalfa hay	6	17	14	15	15	24	11	18	23	29	19	14	20	21	41	32	27	33	25	28	35	31	39	66	29	90
	Corn silage	0	14	14	15	15	19	14	20	19	26	21	30	20	22	30	31	29	45	23	27	48	41	61	54	60	128
	Rolled corn	3	6	4	13	13	5	14	—	11	9	14	14	18	14	12	16	20	23	21	19	29	40	36	41	63	175
	Almond hulls	0	11	4	8	13	5	12	16	4	17	11	10	16	—	13	16	16	31	18	22	22	28	24	31	23	171
	Liquids	2	6	17	9	9	—	29	7	1	13	57	8	—	12	24	4	31	10	24	43	9	14	15	26	73	34
	Cottonseed	0	8	14	7	14	5	14	—	7	14	—	25	21	44	11	52	14	—	20	33	36	31	182	34	26	131
	Canola	1	4	9	—	—	6	—	—	47	16	—	15	17	17	25	64	44	—	21	28	27	37	283	24	35	208
25th percentile (Q_1)	Premix	4	6	4	3	6	4	8	12	4	6	10	0	9	10	7	7	11	7	11	9	10	10	12	19	9	22
	Alfalfa hay	7	9	8	6	9	14	11	15	5	9	14	7	9	12	0	13	11	10	14	13	12	10	11	44	8	28
	Corn silage	5	6	7	6	7	9	8	14	7	8	11	9	10	10	11	10	12	13	9	9	12	12	13	41	19	29
	Rolled corn	3	5	4	4	4	3	8	—	4	6	8	6	8	9	10	7	9	7	12	7	8	10	9	32	15	32
	Almond hulls	3	5	4	4	6	3	0	13	4	6	10	5	9	—	9	6	8	9	15	9	9	9	8	28	8	31
	Liquids	1	4	5	3	13	—	9	38	1	4	19	5	9	—	12	4	14	7	58	42	13	6	9	61	18	18
	Cottonseed	4	4	8	4	6	6	8	—	4	5	—	7	9	13	10	14	8	—	13	12	11	9	22	25	7	29
	Canola	3	5	4	—	—	2	—	—	7	6	—	6	9	8	15	17	11	—	12	10	8	8	33	18	10	32
75th percentile (Q_3)	Premix	6	18	9	15	22	16	22	27	18	23	22	29	24	29	22	31	41	43	34	33	52	52	57	43	51	71
	Alfalfa hay	13	26	22	22	25	39	22	34	29	39	34	22	30	34	41	45	39	43	40	41	48	42	51	111	37	118
	Corn silage	6	20	21	22	22	29	22	35	27	34	32	40	30	33	42	42	42	59	33	36	60	53	74	96	79	157
	Rolled corn	7	12	9	18	18	9	22	—	15	16	22	20	26	23	22	24	30	30	33	27	38	51	46	73	78	208
	Almond hulls	4	17	9	13	19	9	12	30	9	24	22	16	26	—	22	22	25	41	33	31	31	38	33	59	31	202
	Liquids	4	11	23	13	22	—	38	45	3	18	76	13	22	—	36	9	46	18	83	85	22	21	24	87	92	52
	Cottonseed	4	13	23	11	21	11	22	—	12	20	—	33	31	58	22	67	22	—	34	45	47	40	205	60	33	160
	Canola	5	10	13	—	—	9	—	—	54	23	—	21	27	26	41	82	56	—	34	39	35	45	316	42	46	240

Figure 9. Distribution of the deviation from the expected target weight (in absolute values, kg) based on the interquartile range (IQR), 25th percentile (Q1), and 75th percentile (Q3) for the 8 most common ingredients (premix, alfalfa hay, corn silage, rolled corn, almond hulls, liquids, cottonseed, and canola) included in high cow ration and high cow premix recipes on 26 California dairies. IQR: white (|<20| kg), gray (|20| to |40| kg), dark (|>40| kg); Q1: white (|<10| kg), gray (|10| to |20| kg), dark (|>20| kg); Q3: white (|<25| kg), gray (|25| to |40| kg), dark (|>40| kg).

molasses in winter. Our results indicate that on these dairies the feeder might often forget to close the faucet in time.

CONCLUSIONS

Opportunities to improve feeder performance were observed based on loading errors. The TL settings introduced an important deviation from target weight for some ingredients. Dairy producers should evaluate if readjusting the TL settings for some ingredients could reduce the deviation from target. Deviation from target may be influenced by ingredient type. Some ingredients (rolled corn and almond hulls) were loaded with mostly adequate accuracy and precision, whereas others (alfalfa hay, corn silage, and canola) were mostly loaded with poor accuracy and precision. Our results indicated that some dairies were able to load ingredients with minimal deviation from target weight, suggesting that some poor-performing dairies could set higher goals for loading accuracy and precision on their operations.

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PLOS ONE

Total mix ration preparation and feeding times for high producing cows on 26 California dairies.

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Corresponding Author:	Noelia Silva del Rio, PhD Univeristy of California, Davis School of Veterinary Medicine Tulare, California UNITED STATES
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Abstract:	Mixing time plays a critical role in feed bunk nutrient uniformity and proper particle length of total mix dairy rations. The objective of this study was to describe within and across dairies the variability of high producing cow ration (HCR) preparation and feeding time. Twenty-six California dairies were enrolled, ranging in size from 1,100 to 6,900 cows. Consecutive records from a 12-month period were extracted from the feeding management software FeedWatch 7 (50,909 HCR loads; 487,218 ingredients loads). Descriptive statistics were conducted with SAS 9.4. The interquartile range (IQR: Q3-Q1) was used as a measurement of variability. The median HCR preparation time across dairies ranged from 9 min 18 s to 27 min 0 s. Four dairies were relatively consistent on their HCR preparation time (IQR < 3 min) whereas 3 dairies were not (IQR > 6 min). The median elapsed time from last ingredient loaded to feeding ranged from 1 min 54 s to 9 min 0 s. After HCR was prepared feeding started in < 3 min at least 70% of the time (n = 6) or > 10 min at least 20% of the time (n = 6). Six dairies were relatively consistent on HCR feeding time (IQR < 1 min) whereas 2 dairies were inconsistent (IQR > 5 min). Feeding took < 2 min at least 20% of the time (n = 4) or > 10 min at least 45% of the time (n = 3). On 8 dairies time elapsed between ingredient loads was under 30 s at least 15% of the time, suggesting that the feeder may have improperly loaded the leftovers from these ingredients as the next ingredient. Extremely long, short, or inconsistent times were observed on some dairies, warranting further evaluation of the implications of these feeding management practices on California dairies.
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Dear Editor,

It is my pleasure to submit to PLOSone the manuscript entitled " Total mix ration preparation and feeding times for high producing cows on 26 California dairies".

This study evaluated the within-dairy and across-dairies variation of high cow recipe preparation times, including loading time, mixing time, feeding time, and time elapsed between ingredient loads on 26 California dairies. Across dairies, recipe preparation time ranged from 9 min 18 s to 27 min 0 s, time from last ingredient loaded to start of feeding from 1 min 54 s to 9 min 0 s, and feeding time from 1 min 30 s to 10 min 48 s. Extremely long, short, or inconsistent times were observed on some dairies, warranting further evaluation of the implications of these feed management practices on California dairies.

There is very little peer-review information regarding feed management practices on dairies (see short reference list). The information presented in this manuscript is quite novel. These results will serve as a reference point (benchmark) for dairies to compare recipe preparation times with peers. Mixing time plays an important role on feed bunk uniformity as well as on proper TMR particle length, with implications on feed efficiency and health. It is expected that our results will increase understanding among consultants, managers and dairy owners on how feed management software data can be used to evaluate within dairy variation in recipe preparation times. Moreover, many nutritionists and dairy producers are evaluating feeder's performance based on time elapsed between ingredient loads. If this time is too short, the feeder could be loading leftovers from the previous ingredient as a new ingredient. This has been a sufficient reason to fire feeders on California dairies. Our results provide insight on how frequent this issue is on dairies.

Overall, understanding what practices are being implemented on dairies are a solid starting point to advance our knowledge in feed management.

This manuscript is a **research article** that describes information on feed management practices from 26 dairies. There has been **no previous interactions with PLOS** regarding the submitted manuscript.

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Total mix ration preparation and feeding times for high producing cows on 26 California dairies

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Short Title: Total mix ration preparation and feeding times

ABSTRACT

Mixing time plays a critical role in feed bunk nutrient uniformity and proper particle length of total mix dairy rations. The objective of this study was to describe within and across dairies the variability of high producing cow ration (HCR) preparation and feeding time. Twenty-six California dairies were enrolled, ranging in size from 1,100 to 6,900 cows. Consecutive records from a 12-month period were extracted from the feeding management software FeedWatch 7 (50,909 HCR loads; 487,218 ingredients loads). Descriptive statistics were conducted with SAS 9.4. The interquartile range (IQR: Q_3-Q_1) was used as a measurement of variability. The median HCR preparation time across dairies ranged from 9 min 18 s to 27 min 0 s. Four dairies were relatively consistent on their HCR preparation time (IQR < 3 min) whereas 3 dairies were not (IQR > 6 min). The median elapsed time from last ingredient loaded to feeding ranged from 1 min 54 s to 9 min 0 s. After HCR was prepared feeding started in < 3 min at least 70% of the time (n = 6) or > 10 min at least 20% of the time (n = 6). Six dairies were relatively consistent on HCR feeding time (IQR < 1 min) whereas 2 dairies were inconsistent (IQR > 5 min). Feeding took < 2 min at least 20% of the time (n = 4) or > 10 min at least 45% of the time (n = 3). On 8 dairies time elapsed between ingredient loads was under 30 s at least 15% of the time, suggesting that the feeder may have improperly loaded the leftovers from these ingredients as the next ingredient. Extremely long, short, or inconsistent times were observed on some dairies, warranting further evaluation of the implications of these feeding management practices on California dairies.

Keywords: dairy cows, feed management software, mixing time, total mix ration

INTRODUCTION

Over the past decades, great progress has been made in understanding nutrient requirements of cattle, and in creating ration formulation models. However, there are opportunities to improve feed efficiency on dairies through management (Sova et al., 2014; Rossow and Aly, 2013). Dairies incorporating a feed management software (FMS) on their operations can track the weight and time of ingredients loaded and generate reports (i.e. sequence of ingredient loading, loading errors, feeding times, mixing time, and time between individual ingredient loads). Mixing time plays a critical role in feed bunk uniformity as well as in total mix ration (TMR) particle length (Zinn, 2004; Biermann, 2009; Buckmaster et al., 2014). Feed bunk mixing uniformity is a function of multiple factors related to recipe type (physical properties of ingredients, order of ingredients, load size), mixer box characteristics (type, brand, horsepower, presence of build-up, worn parts), and mixing time. Thus, the most appropriate mixing time will be a function of both recipe type and characteristics of the mixing equipment. If mixing time is too short, hay could end up being improperly processed. That could promote sorting behavior (Leonardi and Armentano, 2003; Devries et al., 2008) and affect milk yield and milk components (Oelberg and Stone, 2014). Nevertheless, over-mixing may end up favoring segregation of some ingredients and reducing excessively the particle length of forages (Kammel, 1999).

On most dairies, mixing starts as soon as the first ingredient is added. Thus, if recipe load preparation time varies widely within a dairy, physical properties of the TMR might be different across recipe loads. Evaluation of times during loading and feeding can provide insight into management practices implemented on dairies. Moreover, time elapsed between loads of ingredients can be used to monitor feeders. If it is too short it could indicate feeders are not taking time to return commodities leftover in the front-end-loader and they are loading those as the new ingredient. Thus, the objective of this study was to describe the variability within and across 26 California dairies of high producing cow recipe (HCR) preparation and feeding times.

MATERIALS AND METHODS

Data Collection and Dairies

Twenty-six California dairy cattle farms using FeedWatch 7 (Valley Agricultural Software Inc. [VAS], Tulare, CA) as their feeding management software (FMS) for at least 1 year were enrolled in the study. A 12-month data backup was obtained from the FMS for each farm. The final data set included information from Jan 2012 to May 2014. California dairy nutrition consultants and VAS personnel assisted with identifying dairies to participate in the study. Enrolled dairies were located in the San Joaquin Valley, ranging in size (lactating and dry cows) from 1,100 to 6,900 cows. Each dairy was given a number according to its herd size, from largest (Dairy 1) to smallest (Dairy 26). Dairies 1 to 6 had more than 4,000 cows, Dairies 7 to 20 had between 2,000 and 4,000 cows, and Dairies 21 to 26 had less than 2,000 cows. Records were extracted only from the HCR to standardize data interpretation across dairies. The number of recipe loads prepared per day (median [range]) was 6 (2 – 14), the number of ingredients per recipe was 8 (4 – 10), the recipe load weight was 10,000 kg (4,800 – 18,000 kg), the number of feeders registered in the FMS was 4 (1 – 6), the number of pens fed HCR was 8 (3 – 32), and the number of cows per pen was 206 (69 – 395).

Assembly and Structure of the Data Set

The consultant version of FeedWatch 7 was used to extract records from the setup function and user reports. The following records were obtained: date, recipe load number, feeding sequence, start loading time, end loading time, start feeding time, feeding tolerance level, end feeding time, and ingredient type. Time records were extracted from the FMS in military format (hh:min:ss AM/PM) and imported into a Microsoft Excel file for conversion into a 24 h configuration. A description of the variables obtained from the FMS is shown below.

Recipe Load Number. The number that identifies each recipe load.

Start Loading Time. The FMS registers the start loading time of an ingredient only after the minimum scale detection weight is reached. The minimum scale detection weight is set so the scale does not read small weight changes associated with mixing or driving.

Loading Tolerance Level. To avoid overloading ingredients, the FMS assigns a tolerance level (TL) to each commodity. When the amount of feed left to reach the formulated target is equal to or less than the assigned TL, the FMS asks for the next ingredient to be loaded. After reaching the TL, if there is a pause of 5 s or longer, the FMS will register the new weight as the next ingredient of the recipe.

End Loading Time. The FMS registers the end of loading time for an ingredient when the scale does not read any new weight for at least 5 s once the target weight set by the loading TL has been reached.

Start Feeding Time. The FMS registers the start of feeding when the mixer box doors are opened and feed is pushed out into the feed bunk.

Feeding Tolerance Level. To avoid delivering too much feed to a pen, the FMS assigns a tolerance level (FTL) per pen. When the amount delivered to a pen is equal to or less than the assigned FTL, the FMS asks to deliver feed to a different pen.

End Feeding Time. The FMS registers the end of a recipe load feeding by pen when the scale does not read any new weight for at least 5 s once the target weight set by the FTL has been reached.

Ingredient Type. There were 33 different types of ingredients used in HCR recipes across all dairies. However, the most common ingredients used in HCR were 8, representing 63.1% of the total observations and fed on at least half of the dairies: premix (n = 26), alfalfa hay (n = 26), corn silage (n = 26), liquids (n = 20), rolled corn (n = 19), almond hulls (n = 15), wet distiller grains (WDG; n = 14), and wheat silage (n = 14). Data presented by ingredient type only included information from the 8 most common ingredients used.

Calculations

Recipe Load Preparation Time. It is the time elapsed from the start loading time of the first recipe load ingredient to the end loading time of the last recipe load ingredient.

Time from Last Ingredient Loaded to Feeding. It is the time elapsed from the end of recipe load preparation to the start of feeding. During this time, the feeder could be mixing a recipe load, driving to reach the feed bunk, or both.

Feeding Time. It is the time elapsed from the start feeding time of the first pen to the end feeding time of the last pen fed for the same recipe load.

Time from Start of Recipe Preparation to End of Feeding. It is the sum of recipe load preparation time, time from last ingredient loaded to feeding, and feeding time. If the mixer box is working from the start of recipe preparation to the end of feeding, this variable will represent the total recipe mixing time.

Loading Time per Ingredient Type. It is the time that it takes to load each ingredient from start to end loading time. It was calculated for the 8 most common ingredients of the HCR recipe (premix, alfalfa hay, corn silage, liquids, rolled corn, almond hulls, WDG, and wheat silage).

Alfalfa Hay Loading Time. It was calculated as the time elapsed from the start loading time for alfalfa hay to the start loading time for the next ingredient. Thus, it included alfalfa hay loading time and the time elapsed until the next ingredient was added.

Time Elapsed between Ingredient Loads. It is the time elapsed between the end loading time of one ingredient and the start loading time for the next ingredient.

Data Analysis

Descriptive statistics were conducted with the PROC MEANS and PROC UNIVARIATE procedure of SAS 9.4 (SAS Institute Inc., Cary, NC). The 25th percentile (Q_1), the 75th percentile (Q_3), and interquartile range (IQR: Q_3 - Q_1) were computed using the PCTLDEF = 4 option in the output statement of the PROC UNIVARIATE. The IQR was used as a measure of variability within dairy.

RESULTS AND DISCUSSION

Data Screening

There were no feeding records on Dairy 2 for 2 consecutive months or on Dairy 11 for 40 non-consecutive days. This could likely be explained by equipment breakdown, communication problems between the software and the mixer box, or unintended deletion of historical information. On Dairy 6, recipes prepared with the stationary mixer box (20,498 ingredient loads, 62% of Dairy 6 observations) were assigned a recipe load number, but this number was discontinued when the TMR was transferred to a truck for feed delivery. Therefore, all Dairy 6 observations were used to evaluate recipe load preparation time, but loads prepared with the stationary mixer were not evaluated for time from last ingredient loaded to feeding and feeding time.

The same end and start time was registered for 2,697 (0.5%) ingredient loads on 4 dairies. All these observations were removed. They represented between 1.1 and 3.8% of the ingredient loads. For some ingredient loads, a value of 0 s corresponded to 0 kg loaded (n = 1,078), indicating that the feeder likely advanced manually to the next ingredient without loading it. But, for some loads, a value of 0 s corresponded to > 0 to < 60 kg (n = 675; representing < 10% of the target weight) or from 500 to 5,000 kg (n = 944; representing 10 to 30% of the target weight). The final data set at the recipe level did not include any of the recipe loads with one or more ingredients with a loading time of 0 s.

The same end and start feeding times were recorded from 2,411 (1.7%) feedings. Although some loads with the same start and end feeding time corresponded with 0 kg fed (n = 320), records indicated that on most loads (n = 2,091), there were less than 1,500 kg fed, representing < 10% of the target weight. All these observations were not included when feeding time was evaluated.

The final data set for loading times included 50,909 HCR recipe loads and 487,218 ingredient loads. The final data set for feeding times included information from 51,195 HCR recipe loads and 128,477 individual pen feedings.

Recipe Load Preparation Time

The median HCR recipe load preparation time across dairies ranged from 9 min 18 s to 27 min 0 s (Fig. 1 - A). Based on IQR, 4 dairies were consistent in their HCR recipe preparation time (IQR < 3 min), whereas 3 dairies were not (IQR > 6 min). On 4 dairies at least 10% of the time recipe preparation time was over 25 min. Recipe preparation could take longer if commodities are located far away from the feeding center, if there is a large number of ingredients included in the recipe, if the feeder gets interrupted during recipe preparation (i.e., signing for commodities just delivered), or if there are equipment problems. Based on the field experience of researchers, other factors may explain a lengthy recipe preparation time. For example, when knives are worn, some feeders try to improve hay processing by extending the loading process and increasing mixing time. Moreover, the payroll system implemented on dairies could influence time efficiency, with feeders slowing down when paid by the hour. On Dairy 20, the one with the lengthiest recipe preparation time, feeders were paid on a hourly base.

Figure 1. Boxplot distribution of the preparation time (A), time between the last ingredient load to the first feeding (B) and feeding time (C) for the high cow ration recipe during a 12 month period in 26 dairy cattle farms in CA. The median recipe load weight is represented in the secondary Y-axis as ▲. Data is presented sorted by 25^{th} percentile (Q_3), and then by the interquartile range (IQR) for panel A. The boxplot shows the 50^{th} percentile (median, line within the box), 25^{th} and 75^{th} percentile (box), and 10^{th} and 90^{th} percentiles (whiskers). **Notes**: whisker reaches: (**B**) 50 min (Dairy 13).

Feeders have raised the concern that loading ingredients accurately may require more time. However, the four dairies (Dairy 3, 26, 22 and 16) with the highest loading accuracy (Trillo et al., 2016) had a median recipe loading time within the IQR (Fig. 1-A).

At least 20% of the time, recipe preparation was under 10 min on 5 dairies. On these 5 dairies alfalfa hay was included in the HCR, with a median as-fed inclusion rate ranging from 4.4 to 12.1%. One important concern when recipes are prepared in a short span of time is the adequacy of ingredient mixing and hay processing, especially if not enough mixing time is allowed after the last ingredient is added before feeding. Insufficient mixing could have implications on health and production (Oelberg and Stone, 2014), especially if particle length of forages are long enough to be sorted.

Time from Last Ingredient Loaded to Feeding

The median elapsed time from last ingredient loaded to feeding ranged from 1 min 54 s to 9 min 0 s (Fig. 1 - B). Based on IQR, within-dairy variation ranged from 50 s to 10 min 50 s. The time from last ingredient loaded to feeding can be explained by the extra-mixing time allowed by the feeder, the driving distance from the feeding center to the high cow pens, or by the feeder performing other tasks in between (i.e., lunch break). Dairies with a large IQR should evaluate the possible sources of variation that explain the disparity of time from last ingredient loaded to feeding, and the possible implications of TMR physical properties.

On 6 dairies, at least 70% of the time there were < 3 min elapsed from last ingredient loaded to feeding. Most likely, on these dairies pens receiving HCR recipes were near the feeding center and feeders allowed minimal extra-mixing. However, there were 6 dairies that at least 20% of the time had > 10 min elapsed from recipe load preparation to feeding. On Dairy 6, at least 20% of the time the time from recipe preparation to feeding was 30 min to 1 h 30 min. Those recipe loads were always fed to the same 2 pens at around 11:00 AM. This observation could be explained by the feeder taking a break at the end of recipe load preparation but before feeding.

Twenty dairies added liquids as the last ingredient. In order for liquids to be uniformly incorporated into TMR, mixing time is critical. The time elapsed from last ingredient loaded (liquids) to feeding was < 3 min (n=8), 3 to 5 min (n=8) or > 5 min (n=4) on these 20 dairies.

Unfortunately, FMS are not designed to capture information on the mixing activity of the mixer box. Thus, it is not known if recipe loads with an extended time from recipe preparation to feeding were mixing for a long time, or if the mixing equipment was standing still whereas the feeder was performing other tasks.

Feeding Time

The median recipe load feeding time ranged from 1 min 30 s to 10 min 48 s (Fig. 1 - C). Six dairies were consistent on their feeding time (IQR < 1 min) whereas 2 dairies were inconsistent (IQR > 5 min). The time that it takes to feed a recipe load might be explained by a combination of the number of pens fed the same load of feed, the proximity of the pens fed the same recipe load, the final recipe load size, and the feeder driving skills.

On 4 dairies, at least 20% of the time feeding took < 2 min, with most loads (> 75%) fed to a single pen. However, on 3 dairies feeding took > 10 min at least 45% of the time. Most loads were fed to 2 to 4 pens. Some dairies might choose to offer fresh feed multiple times a day by splitting each load among multiple pens throughout the day. However, this practice may increase overall feeding time per day. On these 3 dairies that offered fresh feed multiple times a day, feeding took up to 3 h/day.

Time from Start of Recipe Preparation to End Feeding

The time elapsed from the start of recipe load preparation to the end of feeding is shown in Fig. 2 for the first quartile (Q_1; Fig. 2 - A) and third quartile (Q_3; Fig. 2 - B). The median time from the start of recipe load preparation to the end of feeding was 25 min and ranged from 14 to 42 min. Based on IQR, within-dairy variation ranged from 5 to 50 min. If the mixer box was operating from loading to feeding, this time will correspond with mixing and hay processing time per recipe. The most desirable mixing and hay processing time is a function of multiple variables such as ingredient type, ingredient loading order, type of mixing equipment, and rpm of mixing equipment. Data from FMS can provide information on some factors affecting time from recipe preparation to feeding (i.e., number of ingredients, recipe load size, and number of pens being fed). However, if FMS data indicates important variability within a dairy, the most desirable approach would be to evaluate the TMR physical properties and feed bunk mixing uniformity as well as to understand the feeder work organization. In our study, 15% of the time Dairy 20 spent > 50 min from the start of recipe preparation to the end of feeding, whereas 16% of the time it took < 11 min. The large within-dairy variation observed on Dairy 20 warrants further investigation to identify potential management issues and their implications.

Figure 2. Time from high cow ration recipe preparation (loading), elapsed time from the last ingredient loaded to start feeding (last loading - first feeding), and feeding time (feeding) for the

first quartile (Q_1: 25th; A) and the third quartile (Q_3: 75th; B) on 26 dairy cattle farms in CA. Dairies are presented sorted from the smallest to the largest time.

Loading Time per Ingredient Type

The median loading time per ingredient type ranged from 14 s (almond hulls) to 1 min 25 s (corn silage; Fig. 3 - A). On at least half of the dairies, the median loading time was under 30 s for almond hulls, rolled corn, and wheat silage, whereas it was over 1 min for liquids, alfalfa hay, and corn silage.

On most dairies, the within-dairy variation for loading time was large (IQR > 40 s) for alfalfa hay, corn silage, and wheat silage (Fig. 3 – B). Possible explanations for this observation could be changes in silage DM that result in different number of trips to the silage pit or changes in the forage inclusion rate throughout the year to adjust for silage inventory. Liquid feeds were expected to show a large within-dairy variation, as the cold weather could make them more viscous and difficult to load, especially for molasses. However, in our study we failed to see that, most likely because of the mild winters in the Central Valley of California. It is likely that in regions with extreme cold winters the within-dairy variation would be more obvious.

Figure 3. Boxplots of the median (A) and interquartile range (IQR = $Q_3 – Q_1$; B) of the loading time by ingredient among loads of the high cow ration recipe on 26 California dairies. Data is presented sorted by IQR (B). The boxplot shows the 50th percentile (median, line within the box), the 25th and 75th percentile (box), the 10th and 90th percentiles (whiskers), and outliers (dots).

Alfalfa Hay Loading Time

The time elapsed between the start loading of alfalfa hay to the next ingredient is represented in Fig. 4. The median time ranged from < 1 min (n = 1; alfalfa hay median load size of 315 kg), 1 to 3 min (n = 20; 330 to 1,500 kg), and > 3 min (n = 4; 900 to 2,000 kg). On most dairies (n = 19), alfalfa hay was loaded consistently (IQR < 1 min). To provide a good mixing of the TMR and prevent cattle from sorting against long particles, it has been recommended to process alfalfa hay before loading it into the TMR (Oelberg and Stone, 2014). Alternatively, alfalfa hay could be added slowly into the mixer box to allow for extra processing before loading the next ingredient (Kammel et al., 1999). Most California dairies prefer to process hay at the time of TMR preparation. On 20 dairies, alfalfa hay was loaded within 1 to 3 min; however, it is uncertain if this will allow proper hay processing before the next ingredient is added.

Figure 4. Boxplot of the time elapsed from start loading alfalfa hay to start loading the next ingredient for the high cow ration recipe on 26 California dairies. The median alfalfa hay load weight is represented in the secondary Y-axis as ▲. Data is presented sorted by 75th percentile (Q_3), and then by the interquartile range (IQR = $Q_3 – Q_1$). The boxplot shows the 50th percentile (median, line within the box), the 25th and 75th percentile (box), and the 10th and 90th percentiles (whiskers).

Time Elapsed Between Ingredient Loads

The median time elapsed between ingredient loads ranged across dairies from 40 s to 1 min 24 s (Fig. 5). Based on IQR, 5 dairies were consistent on the time elapsed between ingredient loads (IQR < 30 s), whereas 5 dairies were not (IQR > 1 min). The frequency that 0 to 15 s, > 15 to 30 s, and > 30 to 45 s elapsed between ingredient loads is represented in Fig. 6. On 8 dairies, at least 15% of the time (up to 49%) there were < 30 s elapsed between ingredient loads. However, on 3 dairies rarely (< 1%) time between ingredient loads was < 30 s.

Figure 5. Boxplot of the time (s) elapsed between ingredients loaded in the high cow ration recipe on 26 California dairies. Data is presented sorted by 25th percentile and then by the interquartile range (IQR = $Q_3 - Q_1$). The boxplot shows the 50th percentile (median, line within the box), the 25th and 75th percentile (box), and the 10th and 90th percentiles (whiskers).

Figure 6. Distribution of the time elapsed between ingredient loads [0 to 15 s (black), > 15 to 30 s (white) and > 30 to 45 s (grey)] for the high cow ration recipe on 26 California dairies.

Once one ingredient is loaded, the feeder should take the leftovers back to the commodity barn before loading the next ingredient. If the time between loading ingredients is too short (i.e., <15 s), it is likely that the feeder is unloading the leftovers from the previous ingredient as the new ingredient. Based on our field experience, some feeders load a new ingredient without taking back leftovers from the previous ingredient. However, a short time lapse between ingredients might not always indicate poor feeder performance. It should be taken into account that the FMS can be used to set a fixed loading time per ingredient. The purpose of this feature is to allow extra mixing time, especially for hay. In this case, the feeder may have time to load the next commodity and be waiting with a full front-end loader for the FMS to ask for the next ingredient.

On 3 dairies, time elapsed between ingredient loads was < 15 s at least 15% of the time after loading premix, alfalfa hay, and corn silage. These results suggest that the feeder may have improperly loaded the leftovers from these ingredients as the next ingredient. The impact of these actions cannot be determined. However, some dairy producers and nutritionists are using this information as a quality control variable to assess the performance of feeders. Based on our field experience, there are dairies where the feeder and dairy producer have reached an agreement and accepted, to some degree, these practices with the expectancy to improve time efficiency. However, this practices might not be recommended.

At least 15% of the time, 10 dairies loaded ingredients after more than 2 min elapsed from the previous ingredient, most often corn silage (n = 6), premix (n = 3), or wheat silage (n = 3). Time between ingredient loads of more than 10 min represented 0.1 to 3.0% of the loads across dairies. On some dairies, commodities and silage structures could be stored far from the feeding area, increasing the time elapsed between ingredient loads. Also, we have observed that some feeders performed additional tasks during loading such as defacing silages. When a long span of time is observed between ingredient loads, it is important to talk to the feeder and evaluate if his work organization is as efficient as it could be.

Conclusion

Feed management software data can provide valuable insights on management practices implemented on dairies. There was wide variation within and across dairies on time from start of recipe load preparation to feeding based on FMS records. Dairy producers and consultants are likely underutilizing FMS to evaluate feed management practices. The present information on time from recipe loading to feeding could be used to compare a dairy operation with their peers and re-evaluate current practices. Records of time between ingredient loads could be a useful tool to evaluate if feeders are returning leftovers to the commodity barn or if they are loading them as a new ingredient.

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Figure

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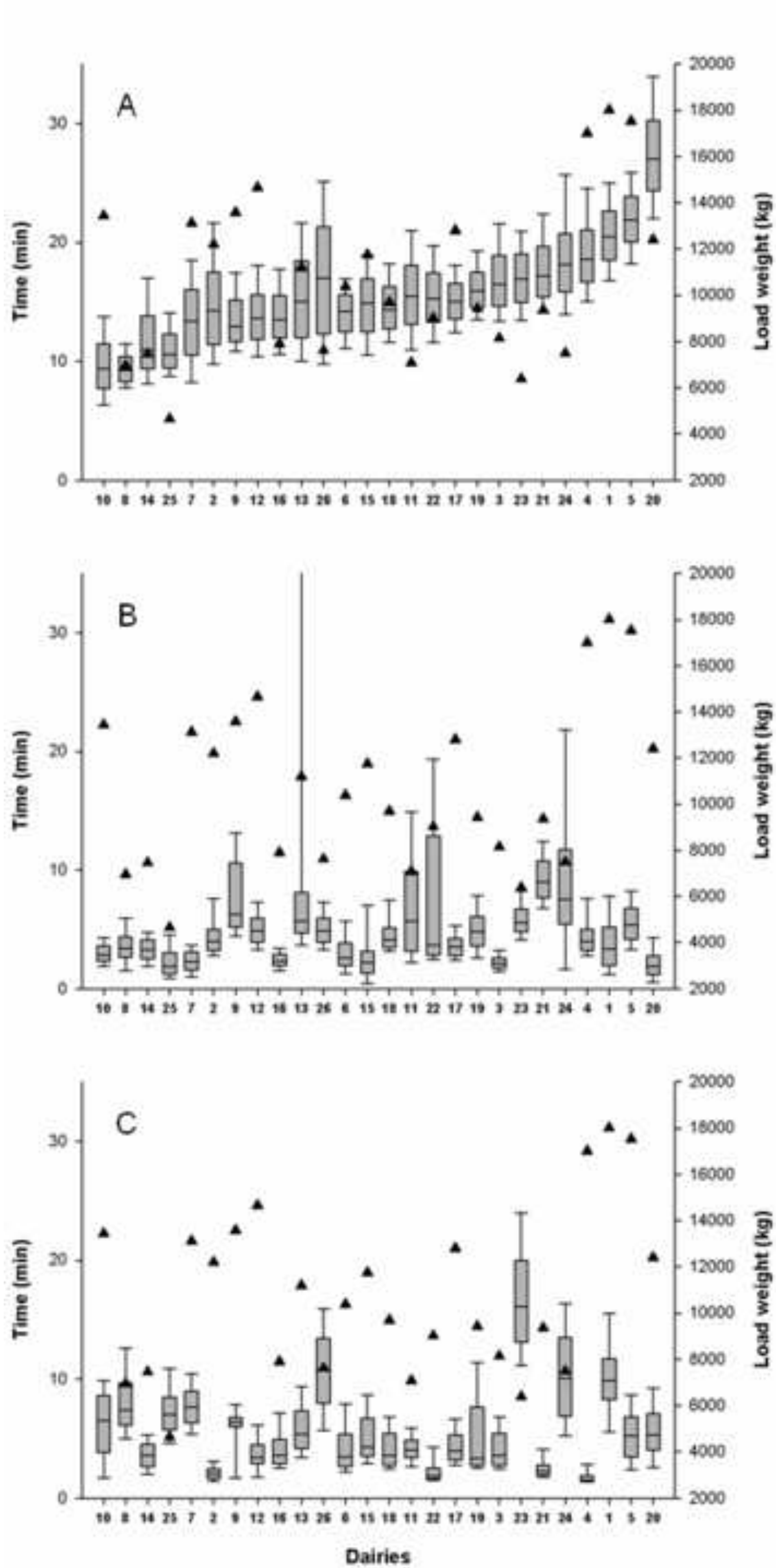

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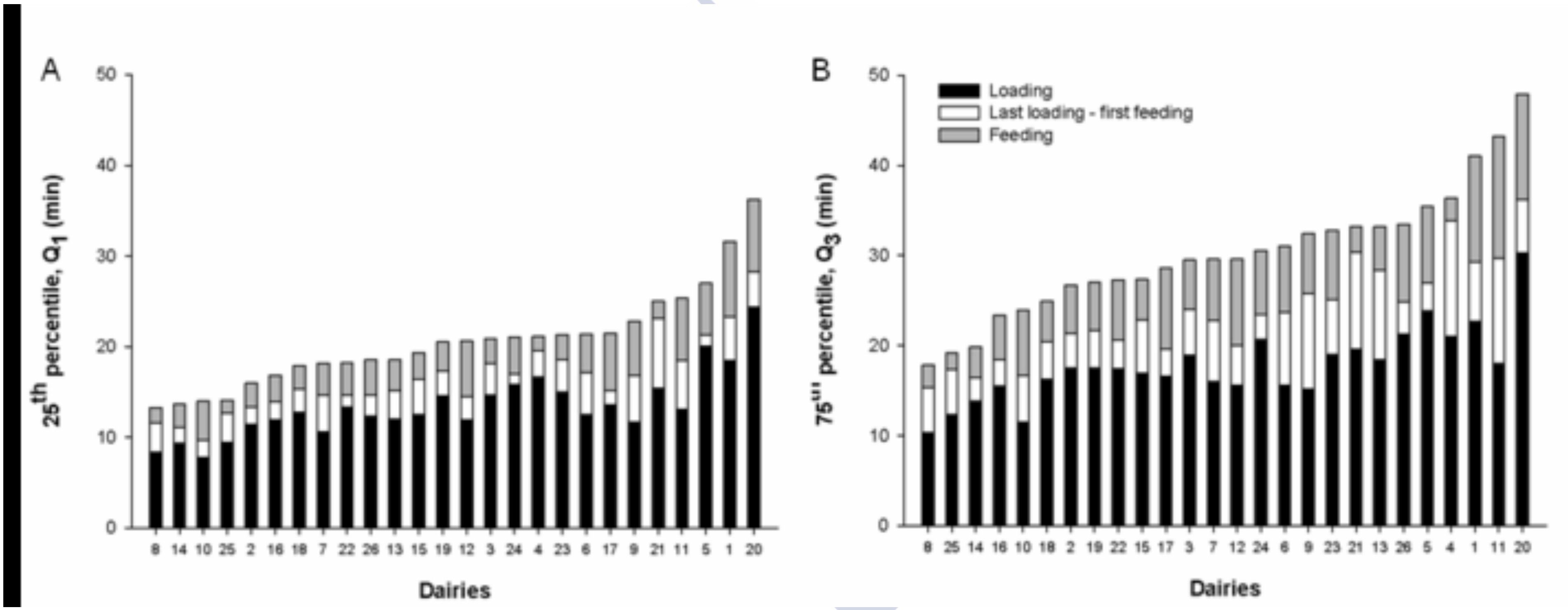
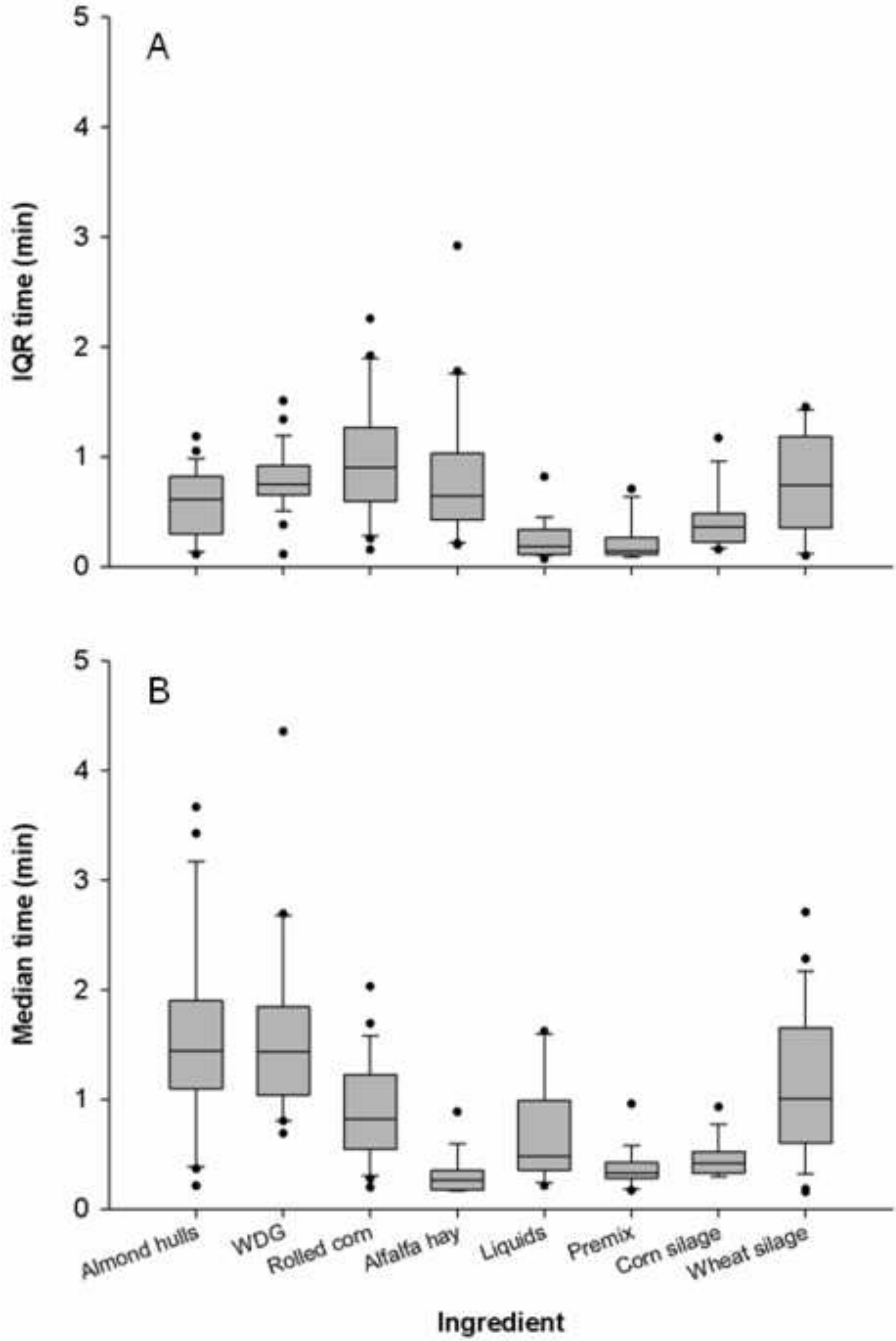
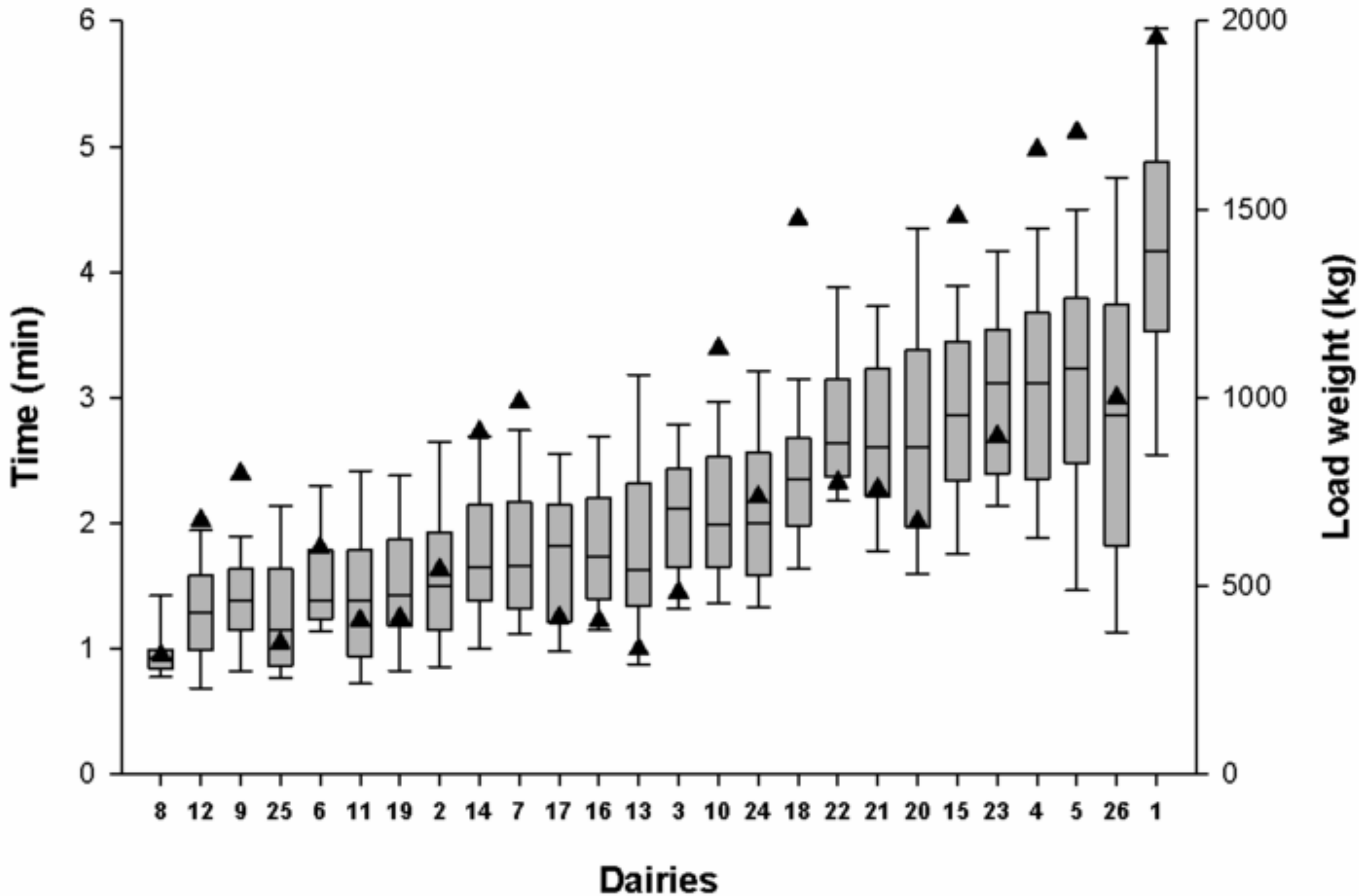




A
IQR time (min)
0
1
2
3
4
5
B
Median time (min)
0
1
2
3
4
5
Almond hulls
WDG
Rolled corn
Alfalfa hay
Liquids
Premix
Corn silage
Wheat silage
Ingredient


Time (min)
Load weight (kg)
Dairies
0
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3
4
5
6
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1000
1500
2000
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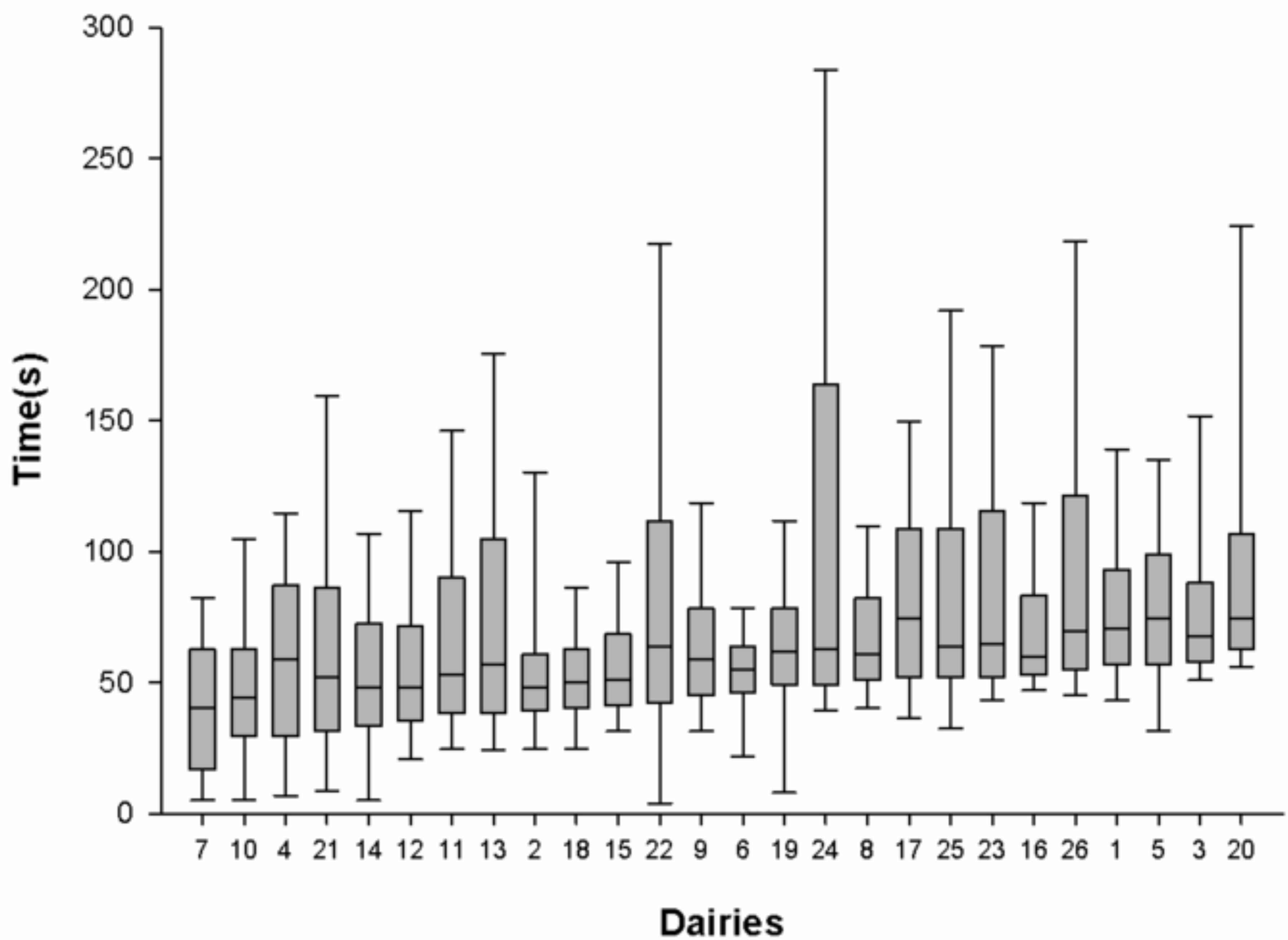
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200
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50
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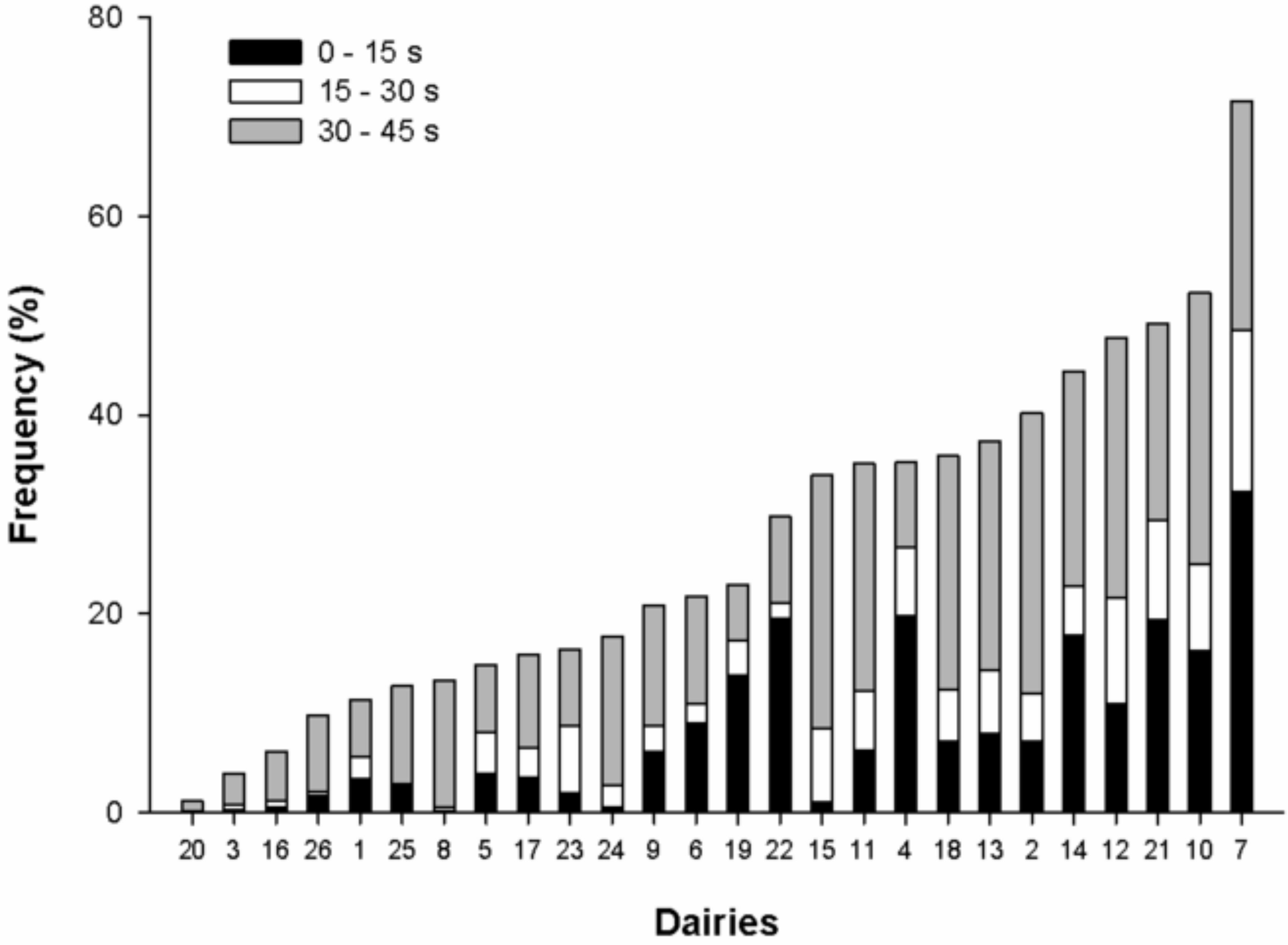
Dairies



80
60
40
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Frequency (%)
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15 - 30 s
30 - 45 s
20
3
16
26
1
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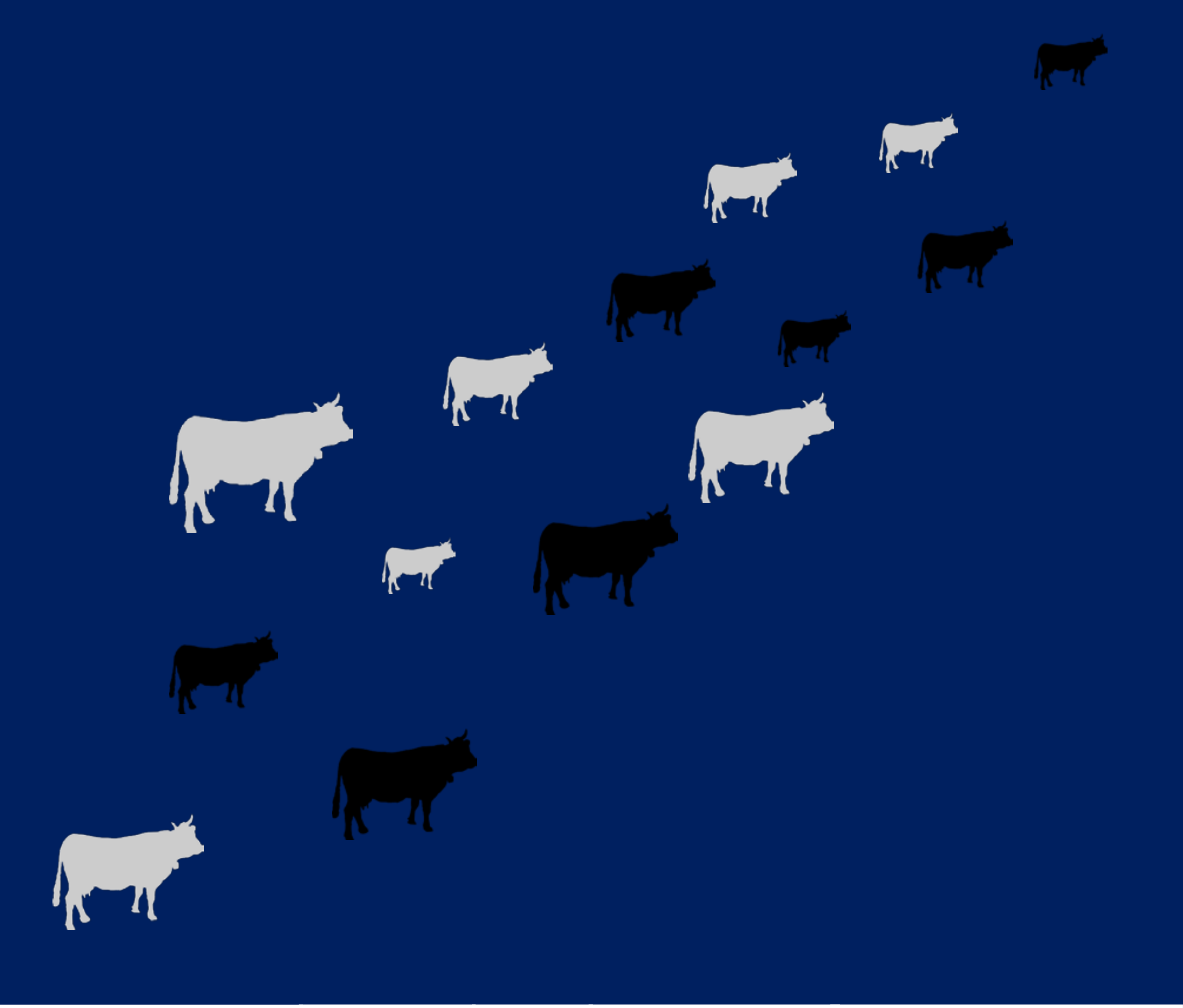
Dairies



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