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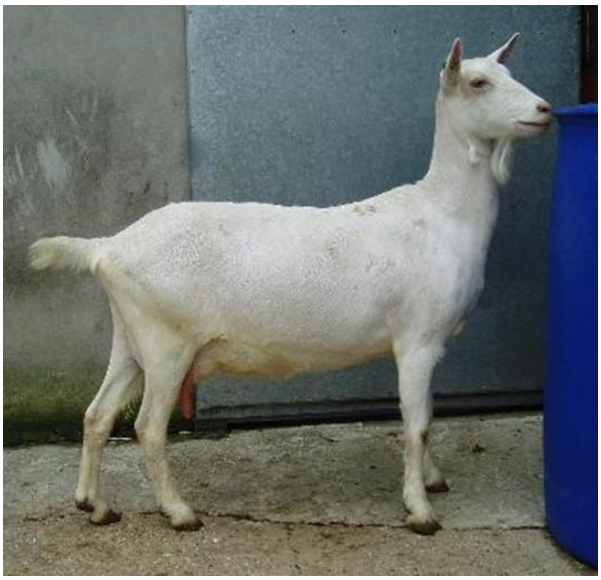

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Abstract

Research that informs the health and production of farmed dairy goats is sparse. Therefore, gaps in knowledge regarding current practices and concerns within the UK dairy goat industry were addressed by a postal survey of farmer members of the Milking Goat Association.

Some 73% of farmers responded. Findings show extensive variation in farm practices. Farmers' top priority for further research was kid health (79.5% of farmers), and pneumonia and diarrhoea were reported as the most prevalent illnesses of kids. The findings, alongside published literature and field experience, were used to inform the choice of a focused research topic for this Ph.D research.

Kid health has important welfare and economic implications. Colostrum management is vital for kid health but sparsely researched. Therefore, three studies of goat colostrum were undertaken.

Study one was an observational study on three commercial dairy goat farms that established baseline measures for the immunoglobulin, nutritional, and energy content of colostrum. Linear regression analyses established that Brix measures significantly predicted the mean 'total solids', energy, and immunoglobulin content of goat colostrum.

In study two, Bland Altman analyses were used to quantify the reliability of Brix refractometer measures of colostrum, with results helpful for informing the methodology of study one as well as practice on farms.

Study three was a single-farm study that measured the colostrum intakes of farmed dairy goat kids that were routinely removed from their mothers at birth and bottle-fed colostrum, providing baseline data for the quantities and timings of colostrum intakes achievable in bottle-fed kids during the first 13 hours of life when real-world factors are in play.

These studies provide essential new baseline data for informing future research and guiding better colostrum management on farms and protecting the health, welfare, and production of the large numbers of kids born on commercial dairy goat farms.

For Giuseppe and Joseph

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Author's declaration

I declare that the work in this dissertation was carried out in accordance with the requirements of the University's *Regulations and Code of Practice for Research Degree Programmes* and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, the work is the candidate's own work. Work done in collaboration with, or with the assistance of, others, is indicated as such. Any views expressed in the dissertation are those of the author.

This research was approved by the University of Bristol Research Ethics committee on 27th October 2017, application number 58923.

Data chapter 3 titled "Survey of husbandry and health on UK dairy goat farms" has been published. (Anzuino et al, Veterinary Record. 2019:185(9):1-10). I declare that this research and paper are my own work, with co-authors providing advice on the text only.

SIGNED: ..... [redacted] ..... DATE:.14th March 2023

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List of Abbreviations

AEA	Apparent efficacy of absorption
AUC	Area under curve
AHDB	Agricultural and Horticultural Development Board
AN	Anglo Nubian
ATC	Automatic temperature control
BCS	Body condition score
CAE/CAEV	Caprine arthritis encephalitis virus
CI	Confidence intervals
CLA	Caseous lymphadenitis
CV	Coefficient of variation
ELISA	Enzyme-linked immunosorbent assay
GCT	Glutaraldehyde coagulation test
GGT	Gamma-glutamyl transferase
GLM	Generalised linear model
IgA	Immunoglobulin subclass A
IgG	Immunoglobulin subclass G
IgM	Immunoglobulin subclass M
IBC	Intermediate bulk container
IQR	Interquartile range
IR	Infrared
LLA	Lower limit of agreement
MAP	*Mycobacterium avium paratuberculosis*
ME	Metabolisable energy
MGA	Milking Goat Association
M	Kids that have suckled their mothers
NM	Kids that have not suckled their mothers
PTI	Passive transfer of immunity
Q1	First quartile
Q3	Third quartile
RID	Radial immunodiffusion
ROC	Receiver operating characteristic
SCC	Somatic cell count
STP	Serum total protein
TMR	Total mixed ration
TB	Tuberculosis
TS	Total solids
ULA	Upper limit of agreement
ZST	Zinc sulphate turbidity

1 Chapter 1

1.1 Introduction

In 2017, UK dairy goat farmers formed an industry body, the Milking Goat Association (MGA). One of their first initiatives was to support this Ph.D. research project. The project started with the broad title of "Identifying constraints to health and production in the UK dairy goat industry" with the expectation that this would be narrowed down to a focused area of study, producing evidence to support improved health, welfare and production of farmed dairy goats. This chapter explains the background of the research project, the choice of research topics, and the layout of the thesis.

1.1.1 Background to the Ph.D. research project

The UK dairy goat industry is small and decentralised compared to the UK dairy cattle industry. At the start of the project, there were an estimated 108,000 goats on agricultural holdings within the UK, with 92,000 goats located in England and Wales.[1] Approximately 46,000 were dairy goats commercially farmed in England and Wales and located over 120 farms.[2] Here, commercial farming is defined as the production of milk or milk-based products for sale for human consumption. This contrasted starkly with a UK dairy cattle population of approximately 1.8 million located over more than 10,000 farms.[3]

Europe's main goat dairy producer countries have much longer traditions of dairy goat farming, with much larger national herds and more industry support structures. Technological advances in genetics, feeding, and general management[4] have made greater productivity per goat possible.[5] France, Greece, and Spain are responsible for approximately three-quarters of the total goat milk production in the European Union.[5]

Dairy goat farms in the UK share similar technological advances, as do many dairy goat industries emerging in higher-income countries such as the USA, Canada, New Zealand, and Australia. This contrasts with the management of the 90% of worldwide dairy goats in Asia and Africa, which are kept mainly by small-scale producers and are not part of specialised production systems.[6] While only 5% of the worldwide dairy goat population is located in Europe,[4,5] approximately 15%[5] of the worldwide goat milk production and 35%[4] of the worldwide goat cheese production occur here.

Of the European countries, France has the most centralised industry and organised milk markets.[4] In France, there are organisations dedicated to dairy goats, many with their roots in the early 20th Century.[4] National professional associations provide producers with information and help them to exchange experiences and innovations,[4] technical centres focus on research and extension on dairy

goats to keep the field responsive to market demand,[4] and genetic selection and widespread artificial insemination for Alpine and Saanen breeds receive government support.[4] Further, all of these organisations collaborate.[4] This approach reflects a longstanding recognition of the importance of such organisations for the growth and stability of the industry.[4] These organisations support farmers in identifying new market opportunities and in responding to changing consumer demands that are driven by a range of factors, such as growing awareness of dairy goat produce, changing dietary preferences, as well as ethical concerns, including animal welfare and the environmental impact of different farming systems.[4]

The UK dairy goat industry is relatively young, with larger-scale commercial farms developing mainly over the last 25 years. It has traditionally had few support structures specific for goats, relying mainly on those available for dairy cattle. Therefore, in 2017, UK dairy goat farmers formed an industry body, the Milking Goat Association (MGA), to better represent their interests, communicate with each other and support industry-driven research.

The broad starting title of the Ph.D. project partly reflects the sparsity of goat research, particularly in the UK. Much information relevant to goats remains in the 'grey literature' of local, non-peer-reviewed studies and information shared informally at veterinary and producer group meetings. Such information is valuable but needs to progress. Producing quality peer-reviewed research that is widely available to different stakeholders is essential for supporting developments in the industry.

1.1.2 Published research relevant to the UK dairy goat industry

Published studies of goat health, welfare, and production are relatively sparse, particularly those concerning UK dairy goats. Those that report on the UK industry include a study that assessed the welfare of dairy goats on 24 UK commercial farms using animal-based measures and found lameness, claw overgrowth, skin lesions, udder, and teat lesions to be particular problems.[7] Several studies of lameness and the causes of lameness have noted a very high prevalence on some farms.[8–12] Despite milk being the primary farm produce, there have been only three studies of mastitis in commercial dairy herds[13–15] and one study estimating the breeding values for milk yield.[16] One study has examined the relationship between genetic parameters for conformation and milk yields.[17] Scrapie is the best-represented infectious disease in the literature, with several epidemiological studies describing infection prevalence and scope for breeding disease-resistant goats.[18–24] Epidemiological studies have described Q fever (*Coxiella burnetti*) infection on two UK farms.[25,26] One study of Johne's disease exists, investigating whether *Mycobacterium avium paratuberculosis bacterium* (MAP) was present in raw milk from bulk tanks.[27] An outbreak of tuberculosis (TB) in a herd of Golden Guernsey goats has also been described.[28] Two postal surveys confirmed ectoparasites to be a particular issue in goats, including those commercially farmed.[29,30]

Globally, research relevant to farmed dairy goats has been growing and no longer appears marginalised. Over the last decade, there has been considerable growth in studies covering diverse topics such as mastitis,[31–39] nutrition,[40–49] reproduction,[50–56] important infectious diseases such as Johne's,[57–65] tuberculosis[66–72] and Q fever,[73–78] as well as goat behaviour[79–83] and practical assessment of welfare on farms.[84–88] Findings from research in other countries can be useful for informing the UK industry, where farming practices can be similar. However, farming practices can vary considerably between nations. Undertaking research specific to the UK situation is essential.

1.1.3 Postal survey of MGA members

Due to this sparsity of goat-specific research, decisions about the focussed area of study were less about identifying gaps in knowledge and more about choosing a logical starting point. It was felt that current practices and concerns within the UK dairy goat industry needed to be better understood for research to have an optimal value. Therefore, the initial research activity was to conduct a postal survey of farmer members of the MGA as a first step in addressing the gaps in knowledge. This study is presented in Chapter 3.

Questions were asked about husbandry practices, farmer observations of their goats, and their priorities for further research. Findings were discussed in light of the published literature available at

that time. Seventy-three percent of MGA members responded, representing 38% of commercial dairy goat farms and 53% of the commercial dairy goat population in England and Wales.[2] Findings were comprehensive and showed extensive variation in farm practices. Farmers reported pneumonia and scours (diarrhoea) as the most prevalent illnesses of their kids. Pneumonia, diarrhoea, failure to conceive, and poor growth were the most prevalent observations of youngstock. Overly fat body conditions, assisted kidding, failure to conceive, and difficulty 'drying off' were the most prevalent observations of adult milking goats. Farmers' top priorities for further research were kid health (79.5% of farmers), Johne's disease (69.5%), tuberculosis (59%), and nutrition (47.7%). The postal survey findings were used alongside the published literature in peer-reviewed scientific journals and goat veterinary texts when deciding the focused area of Ph.D. research.

1.1.4 Kid health as a priority research topic

The research topic around which the largest number of MGA farmers coalesced (79.5%) was kid health, specifically pneumonia and diarrhoea. This was unsurprising as these clinical syndromes are commonly reported as issues of concern at goat veterinary and producer meetings and in veterinary clinical texts.[89–91] However, research in goat kids is minimal and management advice is often based on what is known in calves and lambs.[92]

The health status of kids has both welfare and production implications. Animals in poor health will have reduced welfare, with the degree and type of welfare harm determined by the type and severity of disease. Economic costs are associated with treatment, prophylaxis, and loss of animals that die.[93] Extrapolating from research in dairy cattle,[94] animals that survive will have slower growth,[94] a later age of first parturition resulting in a longer non-productive period,[95] and reduced milk production in first lactation compared to animals that remain healthy early in life.[95] Costs are also associated with the reduced performance of animals with subclinical diseases. A considerable proportion of the herd can be affected by subclinical disease, but the economic impact may be overlooked due to the lack of overt disease signs. Health management involves ensuring animals are in optimal fitness and meeting their full potential, not just avoiding clinical disease.

Common diseases of farmed dairy goat kids

The common clinical syndromes associated with morbidity and mortality in farmed goat kids between birth and weaning are as follows.[92]

Septicaemia has been reported as the most common disease during the first week of life, causing severe illness or sudden death. Diarrhoea may be a part of the septicaemic syndrome.[92] Invasive strains of *Escherichia coli* are thought to play an important role.[92]

Diarrhoea is the most common clinical syndrome between one and four weeks of age. Common infectious causes of diarrhoea include rotavirus and coronavirus,[92] bacteria such as *Escherichia coli,*[92] and protozoa such as *Cryptosporidia parvum*. Cryptosporidiosis is the most frequently diagnosed pathogen, particularly in kids less than 15 days of age,[92] and can cause severe disease with morbidities of between 80% – 100%. Mortalities of 50% are not unusual.[96] Often several pathogens act synergistically.[96] Cryptosporidiosis is a zoonotic disease and, therefore, has public health implications.[96] From four weeks to twelve weeks of age, diarrhoea caused by the infectious protozoa *Eimeria spp* becomes particularly important. Cases of clinical coccidiosis often coincide with the high-stress period around weaning.[97] The intestines of surviving kids can be chronically damaged.[98–100] Enterotoxaemia caused by the bacterium *Clostridium perfringens* is an important cause of sudden death.[92]

The debilitation caused by enteritis predisposes surviving kids of all ages to other diseases, commonly pneumonia. *Mannheimia spp, Pasteurella spp* and *Mycoplasma spp* are likely important respiratory pathogens.[101–103]

Common non-contagious, infectious diseases in the first weeks of life include omphalophlebitis, polyarthritis, and septicaemias, which occur when bacteria enter the kid's body via the umbilicus; hence the importance of disinfecting the umbilicus soon after birth.[97] Excessive tissue damage during disbudding and associated secondary infections may also debilitate goat kids.[104–107]

Research on morbidity and mortality in goat kids

There have been a small number of studies directly observing the prevalence and incidence of mortality of kids on commercial dairy goat farms.[104,108–110] Such studies should produce more accurate results than farmer self-reports[104] but are currently lacking for UK farms.

The most robust data are that of Todd et al. (2019),[104] who studied 1,262 female Saanen and Saanen cross kids located over 16 farms in New Zealand and found that 10.4% of kids died between birth and mating. Ninety percent of these deaths were preweaning. Mortality rates varied greatly amongst farms (median 8.9%, IQR 5.9% – 15.8%, range 0% – 20.5%). Kids that died were submitted for post-mortem, and the leading causes of death were identified as gastrointestinal disorders (33.6% of deaths), disbudding-related injury (15.9%), and septicaemia (12.1%). There was a notable discrepancy between the actual cause of death identified post-mortem and that perceived by the farmer, particularly in cases of septicaemia.[104]

Donkin et al. (2004)[109] found a mean annual mortality over three years of 29% for goat kids on a commercial farm in South Africa. The high mortality was attributed to staffing and management

issues. Kids were clinically identified as suffering from coccidiosis and pneumonia, with deaths falling into two main age categories; those dying soon after birth (average two to three weeks of age, with a range of one to 33 days of age) from pneumonia and those dying between two and four months of age due to a combination of coccidiosis and pneumonia. Other less important morbidities were orf, rotavirus, and limb fractures.

O'Brien et al. (1993)[108] observed 39 consecutively born kids on a farm in the USA, from birth to weaning at six to seven weeks of age. By weaning, 61.5% (24/39) of kids had remained healthy, 10.3% (4/39) of kids had required treatment with antibiotics and electrolytes for pneumonia and diarrhoea and then recovered, and 28.2% (11/39) of kids had died. The presumptive causes of death for the kids that died were pneumonia, enteritis, septicaemia, and umbilical abscess.

Ramírez-Bribiesca et al. (2001)[110] observed a cohort of goats in an extensive system in Mexico. Kids that died were of particularly low body weight for their age. On post-mortem, kids were found to suffer from white muscle disease caused by selenium deficiency, which was suspected of predisposing them to enteritis and pneumonia. Pneumonic lesions were present in 16.2% (12/74) of kids. Starvation, hepatic pathologies, and omphalophlebitis were also reported.

Research into the epidemiology of diseases affecting goat kids is limited. Several studies of cryptosporidiosis describe patterns of faecal shedding of oocysts on farm by kids[111–116] and adults.[113] Species of cryptosporidium have been identified.[113,114,116,117] There has been a limited number of studies examining the preventative and treatment values of oral medications such as halofuginone lactate,[115] oral tilmicosin[112] and a product containing activated charcoal and wood vinegar.[118]

There appears to be a greater research focus on coccidiosis in goats, reflecting its economic importance worldwide and that control remains problematic.[98,99,119] Most studies are in countries with very different environments and farming systems to the UK, somewhat limiting their relevance to UK dairy goat farming. There is some study of the preventative and treatment values of different oral medications such as decoquinate[120] and tannins,[121] as well as the potential of anticoccidial vaccines[122] and differing rearing systems[123] in preventing clinical disease.

There has been little research of other enteric pathogens or pneumonia in goats.[101–103]

Potential research topics

Diseases of goat kids have complex, multifactorial aetiologies involving interactions between disease-causing pathogens, animal factors, husbandry factors and environmental factors. In general, disease incidence can be minimised by preventing animals from being exposed to disease-causing

pathogens[92] combined with ensuring animals are kept fit and resilient, with optimally functioning immune systems.

Given the multifactorial nature of these diseases, there were multiple potential research options. Research that furthers understanding of the pathogens, disease processes, and transmission in goat kids is useful, as much knowledge is currently presumed from knowledge in calves and lambs.[92] Also, research into the various 'stressors' predisposing kids to disease is helpful. Some stress is an inevitable part of life for animals and humans, performing a useful physiologic, protective function.[124] However, stress becomes problematic when it becomes excessive, disrupting the normal homeostatic mechanisms within the body and suppressing the immune defences.[124–126] Kids exposed to multiple, severe, prolonged, or cumulative stressors will be more susceptible to disease.

Stressors are numerous and have both physical and mental aspects.[126] Examples of stressors include excessive heat or cold, poor air quality, lack of comfortable dry resting areas, exposure to dirty environments, competition from pen mates, inability to access sufficient nutrition, restriction of behaviours the animals are highly motivated to perform, routine husbandry procedures such as disbudding, and so on.[96] There is already sufficient knowledge of good husbandry practices to mitigate many of these stressors, by extrapolating from first principles and the evidence base available for other farmed species, though goat-specific evidence would be preferable

However, for other stressors, the best course of action is not apparent. A complete overview is outside the scope of this chapter, but some examples of relevant areas reviewed are as follows.

Gradually more is being learnt about the impact of different prenatal stressors on the doe, such as those related to handling or heat stress, and the impact this has on placental quality and the stress levels of kids after birth.[127–131]

Prolonged parturition due to dystocia can leave kids injured or hypoxic, reducing their viability. Research into areas that can help prevent overly fat does, such as the development of user-friendly body condition scoring systems for goats that are easy to implement on farms[132] and strategies for better managing the nutritional needs of individual goats when they are housed and fed within large groups,[133–135] will be relevant to kid health. It must be noted that overly thin goats may also present a higher dystocia risk than those of the required body condition score, as demonstrated in beef cattle.[136]

Routine disbudding inevitably creates stress for the kid, as there will be thermal damage to tissues in the area of the horn bud and a period of healing. However, the degree of stress and the ability of the kid to cope will depend on the attention to detail paid during and following the procedure.

Therefore, the growing body of research on managing welfare during this procedure, evaluating different methods of disbudding,[137–142] the impact of different types of anaesthesia and analgesia,[143–146] and the practical reality of reducing stress when disbudding large numbers of kids on farms[107,147] is useful for improving kid health.

Nutritional diarrhoea is a stress factor likely to predispose kids to infection with enteric pathogens, as in calves.[148,149] The importance of the correct temperature and concentration of milk replacers in preventing nutritional diarrhoea[150] is well established. Still, there are other aspects of milk feeding where there needs to be more knowledge. The digestibility of different milk powders in goat kids warrants further study.[150] There is a role for behavioural research to better understand the functioning of individual kids when competing within a large group. Research should consider the optimal group sizes, numbers of teats, and teat placement to ensure all kids can feed well, avoiding periods of poor nutrition interspersed with overfeeding.[150] Behavioural research in goats that is relevant for nutrition is growing but, to date, mainly focuses on adult goats[40,45,80,133–135,151–154] rather than the kids.[155]

There is scope to reduce stress at weaning. For economic reasons, weaning occurs much younger on commercial farms than would naturally be the case in a dam-suckled kid. This requires accelerated development of the rumen, and milk withdrawal is often associated with hunger and thwarted suckling behaviour.[156–158] Whilst this weaning stress cannot be removed altogether, there are practical adjustments that may reduce the severity. Further research into this area, extending that of Zobel et al. (2020),[156] would be helpful.

In summary, there are multiple aspects to kid health, many of which are worthy of further research, with the potential to reduce morbidity and mortality and ensure kids meet their health, welfare and production potential.

1.1.5 Rationale for choosing colostrum as the focused area of research

Colostrum was chosen as the focused area of research for this project as this topic is vital to kid health. Poor colostrum intakes are a key stressor, highly detrimental to kid health, welfare, and production.

General importance of colostrum in neonatal ruminants

The general importance of colostrum for neonatal ruminants is well established. Colostrum provides essential immunity and nutrition. Ruminants are born with little or no humoral immunity[159,160] because immunoglobulins cannot pass across the ruminant placenta from the mother to

foetus.[108,160,161] Instead, they must absorb maternal antibodies from the colostrum they ingest during the first hours of life, providing them with immune protection until they are old enough to produce their own.[108,160,161] Other constituents also provide immune protection and aid the maturation of tissues,[161,162] including hormones, cytokines, growth factors, enzymes, lactoferrins, and cells such as leucocytes.[161,162]

Colostrum provides all essential nutrients during the first days of life.[161,163] The high-fat content is particularly important for meeting the high energy demands of thermoregulation and metabolism as neonates have poor bodily insulation, little in the way of body energy stores, and are exposed to a large drop in temperature at the point of birth.[160,161,164] The high protein content provides the large amounts of amino acids needed for rapid protein accretion.[160] Colostrum is also a highly concentrated source of vitamins and minerals.[160,161,164]

For optimal benefits, neonates must consume adequate quantities of good-quality colostrum within a short time period of birth. Industry bodies for dairy cattle in the UK, such as the Agricultural and Horticultural Development Board (AHDB), have provided evidence-based guidelines emphasising the 3Qs – quality, quantity, and quickly – as general first principles for feeding colostrum.

Good colostrum intakes provide welfare and production benefits in farmed dairy cattle, both immediate and longer term, possibly extending into months and even years of life.[160,161,165–168] Raboisson et al. (2016)[168] quantified some of the more immediate benefits in a meta-analysis of studies of passive transfer of immunity (PTI). Calves with inadequate PTI had an overall morbidity risk 1.91 [95% CI 1.63, 2.24] times that of a calf with successful passive transfer. They were 1.75 [95% CI 1.5, 2.03] times more likely to suffer respiratory disease, 1.51 [95% CI 1.05 – 2.17] times more likely to suffer diarrhoea, and 2.12 [95% CI 1.43 – 3.13] times more likely to die than calves with successful PTI.[168] The mean additional cost per calf due to failure of PTI was 60 euros (prediction interval 10 to 109 euros).[168] Good colostrum intakes are one of the most important preventative measures for calf diarrhoea.[149]

Studies of goats are sparse compared to those of cattle. Similar principles are thought to apply, with inadequate intakes of colostrum significantly increasing susceptibility to infectious diseases in the first weeks of life,[97] particularly septicaemia,[92] pneumonia and enteritis.[169] The main risk period for clinical coccidiosis is when kids are older, often of weaning age, when the maternally derived antibodies are waning and the kid's innate immune response to coccidia is gradually developing. Even so, colostrum still plays an important, indirect role. Good colostrum intakes at birth help prevent disease in young kids, which in turn helps ensure that kids enter the stressful weaning period with a better health history and, therefore, are less susceptible to further infections. [98,99]

Published research on goat colostrum

Despite the sparsity of goat research, a range of relevant published research papers could be located. Studies can be broadly categorised as follows.

Studies of colostrum quality mainly focus on the immune content, predominantly immunoglobulin,[170–188] due to its importance in PTI. The nutritional content,[171,174,175,178,180,183,186,189–194] bacterial content,[173,177,179,185,195] and the presence of specific disease-causing organisms have been studied to a lesser extent.[196–199] The most studied aspect of goat colostrum appears to be how the quality of colostrum produced by the doe alters over time postpartum.[171,172,175,178,189–195,200–206] There is some evaluation of whether different doe characteristics,[170,171,174,175,180,190,200,205] doe management factors,[176,184,207] and colostrum handling factors are associated with colostrum quality.[173,177,185,195–197,199,208] There is little study of the quality of colostrum produced by commercially farmed goats,[170,180,181,183] or of practical measures for assessing the quality of colostrum on farms.[170,180,181,183]

Some studies have evaluated the impact on kids of feeding colostrum. These include studies documenting changes in the microanatomy of the small intestine and the mechanism by which immunoglobulins are absorbed.[209–215] There are estimates of the serum immunoglobulin levels that represent adequate passive transfer in goat kids,[108,216] and some evaluation of potential field measures of PTI.[187,217–219] There are several studies of how variables related to kid health and immunity alter when kids are fed colostrum that has been handled or treated in different ways,[173,182,195,220–224] and several studies exist of the associations between kid characteristics and serum immunoglobulin levels.[108,204,216,219,225,226]

Full details of the colostrum literature specific to goats are presented in Chapter 2.

Further research is needed to develop a robust evidence base to make inferences confidently. Most of the research findings are valuable, preliminary, descriptive information on which to build future research. Common methodological issues include relatively small sample sizes, with underpowering of studies likely, and a need for more confidence intervals to guide the precision of estimates. There needs to be more repetition of studies to check for reproducible results.

A need for robust 'baseline' data was identified. Here baseline data can be defined as valid, reliable, and unbiased estimates of population parameters for important colostrum variables and a clear description of the relationship between these variables. Baseline data provides a strong foundation on which to build future studies. Such baseline data are essential as they can establish the current parameters for variables and allow for the generation of hypotheses and the determination of lines of inquiry that are important to pursue. They also inform the design of studies. For example,

knowledge of the dispersion of measures amongst goats is valuable in informing the necessary sample sizes.

A need for data from commercially farmed goats was identified, producing evidence with high external validity. Research of colostrum from commercially farmed goats has grown since 2018[180,181] but is still sparse, and the UK needs to be represented. A better understanding of colostrum quality from commercially farmed dairy goats is essential as it impacts the health, welfare, and production of very large numbers of kids born on these farms. It is relevant to both the female dairy replacement kids and the male kids who will be reared for meat. It is relevant to all farms. It is also relevant for other issues of concern, such as anti-microbial resistance, as by improving kid health good colostrum management reduces the need for therapeutic antibiotics.[92]

Colostrum was chosen as the area of research that could impact kid health most within the time frame and resources available, expanding the research evidence base and providing evidence with immediate benefits for practice on farms.

1.1.6 Ph.D. research studies of colostrum

For this project, the following three studies focussing on goat colostrum were undertaken.

Chapter 4 presents an observational study titled "Evaluation of the quality of colostrum from farmed dairy goats and the relationship with Brix refractometer measures". This observational study had two primary aims: firstly, to provide information on the nutritional and immunoglobulin content of colostrum from commercially farmed dairy goats, and secondly, to evaluate how well the Brix refractometer estimates these measures. The usefulness of Brix refractometers for estimating the immunoglobulin content of colostrum has been extensively assessed in dairy cattle[227] but little research exists that considers goats.[170,181] Colostrum samples were obtained from a total of 461 Saanen and Saanen cross-breed goats from four different kidding sessions that took place on three different commercial farms. Immunoglobulin levels were measured using radial immunodiffusion, the fat, protein, and lactose content were measured using infrared spectroscopy, and the energy content was calculated from the results of nutritional analysis. The key findings were that values for colostrum measures varied considerably amongst goats, and this variability level persisted when goats were grouped by kidding session. Colostrum samples of similar total solid content comprised differing proportions of fat, protein, and lactose and, therefore, differing energy content. Colostrum samples of similar protein content had very variable immunoglobulin content. Linear regression analyses established that Brix measures could significantly predict the mean total solids, energy, and

immunoglobulin content. Numerical values for the prediction intervals for these variables over a Brix range of 15% – 32% are provided.

Chapter 5 presents a study titled "Repeatability of Brix refractometer measures of goat colostrum". This study evaluates the repeatability of Brix refractometer measures of goat colostrum, and the primary aim was to use the results to inform the methodology of the goat colostrum quality study described in Chapter 4. Comment is also made about the implications of findings when using Brix refractometers on farms as part of routine colostrum management. Brix refractometers use the principle of refraction to estimate the total solid content of liquids. However, colostrum can be considered a novel substance, structurally quite different from the sucrose solutions against which Brix refractometers are calibrated. Not only is colostrum likely to refract light somewhat differently to sucrose solutions, but repeat measures of the same colostrum samples may also refract light differently due to differing dispersion of solids when colostrum is applied to the prism. Colostrum samples were collected from 107 dairy goats on a commercial dairy goat farm. Repeat Brix measures of samples were performed under controlled laboratory and farm conditions, using an optical and digital Brix refractometer. Agreement between repeat measures of colostrum samples was evaluated using Bland Altman plots. The greatest agreements were between paired optical measures and paired digital measures performed under controlled laboratory conditions. The least agreement was found when comparing measures performed on fresh colostrum on the farm with those on thawed colostrum at a subsequent date.

Chapter 6 presents a study titled "Colostrum intakes and serum total protein values of goat kids routinely bottle-fed colostrum on a commercial dairy goat farm in the UK". To the author's knowledge, there are no studies measuring the voluntary colostrum intakes of goat kids on commercial dairy goat farms, whether suckled naturally or artificially fed. Observational studies on farms are useful for providing baseline data with high external validity. When done on farms working to high standards or best practices, such data can be used in benchmarking and informing guidelines.

This case study measures the colostrum intakes and serum total protein values of goat kids routinely bottle-fed colostrum on a UK commercial dairy goat farm. The routine practice was to remove kids from their mothers at birth, which is an increasingly common practice in the UK.[228]

The findings of interest are the timings and quantities of the first and second colostrum feeds, and the total colostrum intakes over the first six hours of life and the whole 13-hour observation period. The study farm worked closely with their veterinary surgeon to implement best practices and routinely monitored kid outcomes in terms of morbidity, mortality and the serum total protein values as an indirect measure of PTI. The kids' serum total protein (STP) values were measured using the

biuret method and a clinical total protein refractometer. Samples were taken as part of a clinical investigation by the farm's veterinary surgeon and are presented, along with the level of agreement between the two measurement methods.

Appendices A, B, C and D contain material that supplements the colostrum quality study in Chapter 4. Appendix A includes data for the precision of Brix measures and radial immunodiffusion (RID) measures of colostrum, when samples were reassessed upon completion of the study as part of data quality control. Appendix B contains data illustrating how some colostrum measures varied according to parity, gravidity, and dry period length. This data should be useful for informing the methodology and sample sizes of future studies that focus on these factors. Appendix C presents a study evaluating the repeatability of the researcher's body condition scoring of goats in the farm environment and was undertaken to improve inferences in the main colostrum quality study (Chapter 4) where body condition scoring is included as a variable. Comment is also made about the implications of findings for routine scoring of goats on farms as part of general management. Appendix D presents the observations made when using the enzyme-linked immunosorbent assay (ELISA) method to measure the immunoglobulin content of goat colostrum, and discusses the reasons for changing to RID in the colostrum quality study (Chapter 4). Appendix E contains the postal survey and the summary of postal survey findings distributed to farmers.

2 Chapter 2

2.1 Review of goat colostrum research

2.1.1 Introduction

Chapter 1 outlined the general importance of colostrum for neonatal ruminants. This chapter reviews in detail the studies specific to goat colostrum.

A literature search was conducted using the PubMed, Google Scholar, and ScienceDirect search engines to create a dataset of relevant research papers using the keywords “goat”, “goat kid”, “colostrum”, “immunoglobulin”, “passive transfer”, “immunity” and “IgG” separately or in combination. A range of studies was found and can be broadly categorised as follows.

Studies of colostrum quality mainly focus on the immune content, predominantly immunoglobulin,[170–188] due to its importance in PTI. The nutritional content,[171,174,175,178,180,183,186,189–194] bacterial content,[173,177,179,185,195] and the presence of specific disease-causing organisms have been studied to a lesser extent.[196–199] The most studied aspect of goat colostrum appears to be how the quality of colostrum produced by the doe alters over time postpartum.[171,172,175,178,189–195,200–206] There is some evaluation of whether different doe characteristics,[170,171,174,175,180,190,200,205] doe management factors,[176,184,207] and colostrum-handling factors are associated with colostrum quality.[173,177,185,195–197,199,208] There is little study of the quality of colostrum produced by commercially farmed goats,[170,180,181,183] or of practical measures for assessing the quality of colostrum on farms.[170,180,181,183]

Some studies have evaluated the impact on kids of feeding colostrum. These include studies documenting changes in the microanatomy of the small intestine and the mechanism by which immunoglobulins are absorbed.[209–215] There are estimates of the serum immunoglobulin levels that represent adequate passive transfer in goat kids,[108,216] and some evaluation of potential field measures of PTI.[187,217–219] There are several studies of how variables related to kid health and immunity alter when kids are fed colostrum that has been handled or treated in different ways,[173,182,195,220–224] and several studies of the associations between kid characteristics and serum immunoglobulin levels.[108,204,216,219,225,226]

Goat colostrum research is far less established than cattle colostrum research. Research is growing but, to date, it appears to have developed ad hoc according to the opportunities presented to researchers and the subject focus of different research groups. This is to be expected in an area of research that has traditionally received little support.

When reviewing studies the following aspects of methodology were considered: whether the population being investigated is defined; whether a representative sampling technique is used; whether sample sizes are sufficient to detect effects; whether data collected is valid, accurate, and reliable; whether treatment groups are compared with control groups; whether confounders are controlled for; whether inferential statistics are used; and whether there is repetition of studies with reproducible results.[229]

Of these criteria, the likely accuracy and reliability of measurement techniques were considered first, followed by a review of the individual studies falling under each of the broad subject areas set out above.

2.1.2 Measurement techniques

General comment

Overall, it is possible to have confidence in most of the measurement techniques used in goat colostrum studies. On 'face value'[230] most measures can be presumed valid, accurate, and reliable from understanding the principles of how they work, from their common usage in other contexts such as veterinary clinical work, and their use in multiple goat colostrum studies as well as studies of colostrum in other species. However, there are some areas of uncertainty. There is now some doubt over the accuracy of the enzyme-linked immunosorbent assay (ELISA) tests when measuring the immunoglobulin content of colostrum.[170] When measuring the somatic cell count, a different measurement technique is likely needed for goat colostrum than for cattle colostrum. Some measures are still at the exploratory stage, with the function of variables less well understood than the more commonly used variables. Measures are described below.

Measures of goat colostrum

Immunoglobulin, specifically subclass G (IgG), is the most measured component of goat colostrum[170–186,189,190,231,232] due to its importance for PTI. IgG comprises 85% – 90% of the total immunoglobulin content of goat colostrum,[183,233] similar to cattle.[234] Occasionally immunoglobulin subclasses A (IgA) and M (IgM) are measured.[183,185,186,189,200,235]

Radial immunodiffusion (RID) and ELISA tests, both specialised laboratory techniques, are commonly used in research. These are direct measures, specifically targeting unique features of the immunoglobulin molecules. RID uses the principle that antigen (IgG) and antibodies (anti-IgG antibodies) react to precipitin when in an agar media, with the amount of precipitin mathematically related to the immunoglobulin concentration of the colostrum.[236,237] Sandwich ELISA tests work by immobilising the antigen on a coated modified polystyrene plate and then detecting them using

antibodies linked to an enzyme detection system, where the colour change allows the quantity of analyte to be estimated by comparing it to that of a standard curve comprised of known analyte concentrations.[237]

RID is one of the oldest techniques available and has traditionally been considered the 'gold standard' method for measuring the immunoglobulin content of colostrum and serum in a wide range of species, including goats.[170–179] The ELISA method has become an increasingly common measure of the immunoglobulin content of goat colostrum.[170,180–188] The reasons for choosing ELISA tests over RID include lower costs, faster testing times and higher throughput[238] due to the wide availability of commercial ELISA kits.

However, recent research by Zobel et al. (2020)[170] found no agreement between RID and ELISA measures when testing 298 colostrum samples that were convenience sampled from two dairy goat farms in New Zealand. The authors commented that results using the different techniques should not be compared. Possible reasons for the poor agreement were not discussed. It must be noted that agreement between RID and ELISA measures of colostrum has been studied in few species (Appendix D).

Many other measures of colostrum are routine, currently giving no cause for concern, and are as follows. Measures of the nutritional content of colostrum focus on the main nutritional categories of fat, protein and carbohydrate (lactose).[171,174,175,178,180,181,183,186,189–192,194,200,201,203,204,207,239–241] Routine laboratory techniques that are commonly used to measure milk, mainly infrared (IR) spectroscopy, are used to measure colostrum. This technique uses the principle that different chemical functional groups absorb infrared light at different frequencies. Other standard laboratory techniques used to measure colostrum's total protein content have included the Kjeldahl method,[171,174,201,204] the biuret method,[241] and the Lowry method.[203] Gel electrophoresis has also occasionally been used to explore the colostrum whey proteins.[172,178,203,204,235]

Less common nutrition measures include the dry matter content, often measured using an oven method.[171,174,178,183,192,204] Total solid values estimated using these techniques should be more accurate than those obtained by summing the fat, protein, and lactose content, as they will include the additional 0.7% to 1.8%[178,192] of solid matter in the form of 'ash'. Ash is the inorganic residue that remains after all organic components have been burnt and largely comprises macro and microelements, which some researchers have identified.[171,178,202,204] Ash has been measured using dry ashing[178,192,204] or the gravimetric method.[240] The vitamin content of goat colostrum has been little studied.[194]

The bacterial content of goat colostrum has been measured[173,177,179,185,195] using standard laboratory techniques, quantifying colony forming units, and sometimes identifying the species of bacteria. Standard methods are used to identify disease-causing pathogens of specific interest in goats, such as *Mycobacterium avium subspecies paratuberculosis* (MAP),[196] caprine arthritis encephalitis virus (CAEV)[179,197,198,242] and *Mycoplasma* species.[199]

Measures derived from the food industry, including pH,[204,240,243] titratable acidity,[189,190,204,240] ethanol stability,[189] rennet clotting time,[189] electrical conductivity,[175,190,] freezing point,[190] and density[175,189] are also used to assess when colostrum has transitioned sufficiently to milk.

Some measures are still very much at the exploratory stage. There are colostral components, known from studies of cattle colostrum to have immune or nutritional properties[161,162] but less well understood in goats. They include cytokines,[200] insulin-type growth factors,[244, 245] lactoferrins,[246] cells such as leucocytes,[247] oligosaccharides,[191,205,248] free fatty acids,[178,191,206,207,249] polyamines,[250] phospholipids,[191,207] and sterols.[191,207] Chitotriosidase activity[184–186,189,233] has been hypothesised to provide defence against fungal infections. Ruiz-Diaz et al. (2019)[208] measured the antimicrobial activity of goat colostrum, which quantifies the overall immune effect of the different bioactive substances present in the colostrum.

The somatic cell count of colostrum has been little explored in any species. Goat colostrum is likely to require a different measurement technique than those used to examine cow colostrum. This is because the secretion of goat milk is apocrine rather than merocrine, so it is normal for epithelial cells and cytoplasmic particles to be shed into the milk[251–253] and, by extrapolation, this will also apply to goat colostrum. Some automatic cell counters routinely used to measure cattle milk could mistake components for nucleated cells, giving false high counts.[251–253] To mitigate this, studies of goat colostrum use electronic cell counters that specifically count only the cells containing DNA.[179,186,189,190,207]

Where studies measure the somatic cell counts of goat colostrum, the technique has been to measure the count immediately after colostrum collection and to employ a one-minute soak time,[186,189] which are steps thought necessary to obtain accurate results due to the high fat and protein content of colostrum.

The interpretation of somatic cell counts is less certain for colostrum than for milk, both in cattle and in goats. Very high cell counts may be due to a normal physiological response that increases the number of cells with immune function, as opposed to a response to udder inflammation.[189] It must be borne in mind that in goat milk, the somatic cell count can reach very high levels in the absence of

any mastitis, particularly towards the end of lactation or when the goats are in oestrus,[251–253] and there may be similar normal changes regarding colostrum.

Measures of goat kids

Measurement techniques for goat kid variables are standard and currently give no concerns. Circulating immunoglobulin levels, specifically the IgG subfractions, are the most commonly measured variable of goat kids[108,182,187,195,216–218,220–222,224,225,244,254–256] due to the importance of PTI. Occasionally serum IgA and IgM concentrations[195,224] are measured. Direct measures include techniques such as RID[182,221,222,225,244,254–256] and ELISA.[187,195,225] Commonly used commercial ELISA kits are validated for use with serum, which has a very different biological matrix to colostrum.

The quantitative spectrophotometric zinc sulphate turbidity (ZST) test is also used.[108,216–218,220] This test is an indirect measure of immunoglobulins, where knowledge of the weight of different proteins allows the immunoglobulin to be selectively precipitated and quantified. It has been cited as having good accuracy, but the accuracy has not been scientifically evaluated in goat serum.

Serum total protein is used as an indicator of kids' general health status and is also investigated because of its potential to inform about their immune status. The biuret method, which directly measures protein by targeting the peptide bonds, is used[223,244] or presumed used[182,219,220,254] due to it being the primary method used by many clinical veterinary autoanalysers. Serum total protein refractometers are also used.[187,217] The refraction of light is proportional to the serum solute concentration, most of which is protein.[257] However, to date there has been little evaluation of the agreement between biuret and refractometer measures of serum total protein in any species.[257]

A few studies have used gel electrophoresis to further subdivide serum total protein into the main albumin and globulin subfractions[182,223,224,254] and further divide the globulin subfraction into alpha,[224] beta,[224] and gamma globulins.[182,204,223,224]

Electron microscopy and immunohistochemistry have been performed on goat kid intestines post-mortem to evaluate how the cellular structures and enzyme activity alters following colostrum feeding.[209–215]

Routine haematology and serum biochemistry are used to inform about the health and nutritional status of kids.[187,218–221,254] Daily weight gain,[108,258] and morbidity and mortality rates[108,216] are used as measures of health and production.

Kid variables that are still at the exploratory stage of investigation include circulatory chitotriosidase activity, which is hypothesised to protect against parasitic and fungal infections,[224,233] and the total

complement system activity[224] and the phagocytic activity of neutrophils,[182] which are considered important defences against microbes.

2.1.3 Studies of goat colostrum quality

General comment on methodologies

The following general observations are relevant to all areas of study.

Convenience sampling is commonly used, which will introduce selection bias. Representative sampling will have been impractical for many studies. Potential sources of bias are identified by descriptions of characteristics of animals, such as the breeds, sex and age, thereby identifying the subpopulations to which results are likely to apply.

Many studies should probably be considered underpowered. Knowing the optimal sample sizes can be challenging when there is little prior evidence for consultation, as is the case in a young area of research. Whether a sample size is considered large or small is a relative concept, dependent on the size of the effect in the population and the variability in variable values amongst goats in the population. For example, there is little baseline data for variable values in goats, but emerging data suggest that some variables, such as the immunoglobulin content and other immune components, vary greatly.

Therefore, many study findings can be regarded as valuable, preliminary information, meaning further research is needed to produce a robust evidence base. A helpful progression in research would be to optimise data by providing confidence intervals (CI) to enable the precision of estimates to be evaluated, which very few studies currently present. Should these prove too wide for the size effect to be practically meaningful, a larger sample size will be needed. And if not logistically possible, as in very involved controlled studies, then considerable repetition is necessary for the results to ultimately be used as part of meta-analyses. Studies presented below under the different subject headings should be viewed with these caveats in mind.

Changes in colostrum quality over time postpartum

The most studied aspect of colostrum is how the physical, chemical, and immunological composition produced changes over time postpartum,[171,172,175,178,186,189–194,200–203,205,206,240] identifying the period of transition from colostrum to milk. This information is important for deciding which colostrum is suitable for feeding kids and when milk is suitable for processing. Most studies measuring fat, protein, and lactose are undertaken in this context.[178,186,190–192] Some studies have concurrently investigated mineral and trace element content changes.[178,186,202]

In many studies goats have been convenience sampled, and sample sizes appear relatively small. The median sample size for the 19 relevant studies identified is 10 goats, with an interquartile range (IQR) of eight to 25 goats and a range of 10 to 60 goats. Therefore, underpowering and selection bias are likely limiting issues. The postpartum study periods are also variable (10 hours,[186] 72 hours,[201] four days,[184,191,200] five to six days,[175,194,203,206,240,190] seven days,[171,172,178,193] 11 days,[192] and 90 days[189,205]) and sampling frequencies vary amongst studies. However, there appears to be a sufficiently large number of studies with reproducible results for certain inferences to be confidently made.

Overall, the IgG[172,175,178,186,189,190,193,200] and the nutritional content[175,178,186,189,192] were highest immediately postpartum. A large, statistically significant reduction in IgG content occurs over the first five days postpartum.[172,175,176,178,186,189,190,193,200] The three studies that measure the IgA and IgM subfractions suggest that these follow a similar pattern to IgG.[186,189,200]

The dry matter and total solid content changes follow a similar pattern to immunoglobulin, with values highest in the first days postpartum,[178,189,192,194,240] followed by a large, steep reduction over the subsequent three to five days.[194,240] This is unsurprising as much of the total solid content at this time will be protein, and the protein type is largely immunoglobulin.

Some studies where goats are more frequently sampled allow the rate of change of colostrum variables to be captured in more detail. The steepest declines in IgG content are during the first two to three days postpartum,[172,193,200] and those of fat and protein are during the first two to five days postpartum.[175,178,193,194,200,203,240] The decline in variables then becomes more gradual until normal milk levels are reached.

Protein content varies more widely over time than the fat and lactose content,[189,194] due to the large changes in immunoglobulin content. The casein fraction has not been studied. The lactose content generally increases over time postpartum[175,178,186,189–193,200] except for in one study, where there was no statistically significant change.[194] Where the study durations exceed five days, then the colostrum is observed to fully transition to normal milk by five to seven days postpartum.[175,189,190,193]

Studies using measures relevant to milk processing, such as pH,[189,175,190] titratable acidity,[175, 189] ethanol stability,[189] rennet clotting time,[189] electric conductivity,[175,190] and density[175,190] indicate the same transition period. There is evidence that contaminating milk with colostrum interferes with the processing of dairy products and the results of routine tests for antibiotic residues.[259]

The change in other variables over time postpartum is much less studied, and inferences are less robust. Findings suggest that the ash content reduces from birth to six days postpartum when normal milk levels are achieved[178,192,193] and that whey proteins other than immunoglobulin – beta-

lactoglobulin,[172] lactalbumin,[172] and lactoferrin[172] – also decrease over the first few days postpartum. The oligosaccharide content may drastically reduce after the first four hours of lactation.[205] Fat-soluble vitamins A and E may decrease over the first five days postpartum[194] but in these studies descriptive statistics only are presented. A few studies provide preliminary information on how different fatty acids,[178,191,206] sterols,[191] phospholipids,[191] cytokines,[200] and the chitotriosidase activity[186,189,190] in colostrum alter over time postpartum.

Results for the small number of studies mapping the change in somatic cell count over time after birth are contradictory.[186,189,190] Only Romero et al. (2013)[190] observed a statistically significant difference in the count over the first week postpartum. However, studies are likely unpowered, given that somatic cell count values are likely highly variable amongst goats.[189]

There is little data for the quantity of the first colostrum milking produced by does and how this alters over time postpartum.[186,189]

Associations between doe characteristics and colostrum quality

Several studies aimed to establish whether colostrum quality is associated with different doe characteristics, including parity (lactation number),[175,180,190,200] gravidity (litter size),[171,175,190,200] breed,[180,205] the length of the dry period,[174] and age of doe.[170] Some studies analysed a single factor,[170,171,205] while other studies analysed multiple factors.[175,180,190,200]

Zhou et al. (2021)[200] and Romero et al. (2013)[190] found a statistically significant, higher immunoglobulin content in the colostrum from multiparous does compared to primiparous does. In contrast, Argüello et al. (2006)[175] and Kessler et al. (2019)[180] found no statistically significant differences when comparing parities.

Argüello et al. (2006),[175] Zhou et al. (2021)[200] and Romero et al. (2013)[190] reported the immunoglobulin content of colostrum to be significantly higher in does producing single kids than in those producing twins, contrasting with Csapó et al (1994)[171] and Kessler et al. (2019)[180] who found no statistically significant differences according to gravidity.

Kessler et al. (2019)[180] reported on the statistically significant differences in the immunoglobulin concentration according to breed, though the size effect is small. Claps et al. (2014)[205] also found breed differences with statistically significant higher levels of sialyloligosaccharides in the colostrum of the Garganica breed compared with the Maltese breed.

Zobel et al. (2020)[170] reported no statistically significant association between a goat's age and the immunoglobulin content of colostrum (n=86 goats, age stratified into five categories; one year, two years, three years, four years and five years of age).

Studies use relatively small sample sizes (ranging from four to 24 goats per group) and may often be underpowered, especially where a single study explores multiple factors.

Zobel et al. (2020)[170] illustrated the extent to which the above studies may be underpowered by undertaking a retrospective power calculation using the measures of immunoglobulin established in their research. Their power calculation (alpha=.05, 1-Beta=.8, size effect=0.2) suggests that a sample size of at least 383 goats would be needed to detect a statistically significant impact of age on colostral immunoglobulin.

Caja et al. (2006)[174] found that goats with dry periods of 27 days and 56 days have similar colostrum qualities. In contrast, goats that omit the dry period have greatly reduced colostrum quality, with a much lower immunoglobulin and total solid content, similar to normal milk. Logically, the length of the dry (non-lactating) period before parturition will impact colostrum quality, as is the case for dairy cattle.[160] However, only 17 goats are sampled in Caja et al. (2006), and sample sizes for the different groups are small (n=5, n=9, and n=3, respectively), making inferences difficult.

Associations between doe management factors and colostrum quality

A few studies have evaluated how the husbandry practices of inducing parturition[184] and altering the diet[176,207] impact the quality of the colostrum the doe produces.

The researchers could control the factors of interest, allowing for controlled experimental designs and a potentially higher strength of evidence. However, there are still limitations of small sample sizes (eight goats per group,[184] ten goats per group,[176] and seven goats per group[207]) and a lack of random assignment of subjects, which make low statistical power and confounding more likely. Therefore, these findings should be considered descriptive.

Castro et al. (2011)[184] reported that inducing parturition in goats by using prostaglandin causes a slight reduction in the concentration of IgG in colostrum and advances the lactogenic prolactin surge that usually occurs at parturition. They hypothesised that the high concentration of prolactin prepartum is most likely responsible for reducing the transfer of IgG into mammary secretions.

Castro et al. (2006)[176] reported that feeding goats conjugated linoleic acid prepartum does not significantly alter the colostral IgG concentration. However, it significantly enhanced the IgG levels in the doe's blood. They hypothesised that saturation in the selective transport of IgG from blood to

colostrum may be responsible. Cattaneo et al. (2006)[207] reported that adding fish oil to the diet significantly alters the proportions of the differing types of free fatty acids in the colostrum.

Associations between colostrum-handling factors and colostrum quality

Different methods of treating colostrum have been studied, with the aim of preserving the immunoglobulin content while destroying harmful bacteria and disease-causing pathogens. This is important as the immune content of colostrum benefits the kid. In contrast, the bacterial content can harm by causing ill health and potentially inhibiting immunoglobulin absorption from the small intestine.[160,260] Bacterial contamination of colostrum may originate inside the udder, from the udder and teat skin, or from the wider environment.

Changes in colostrum quality following refrigeration,[173,208] repeat freeze-thaw cycles,[173] different modes of thawing,[173] pasteurisation by heat treatment,[173,177,197,199,261] high-pressure treatment,[177] skimming,[208] curding,[208] and the addition of chemicals[185,195] have been studied in the literature.

Most studies use a controlled experimental design,[173,177,195,208] with colostrum samples divided into identical aliquots to produce identical treatment and control groups at the start of the studies. Some studies also use a repeated measures design,[173,208] automatically controlling factors that could cause variability between subjects. Both approaches minimise confounding. However, it is not always possible to gauge the variation in colostrum quality as values are reported as mean values for groups only.[177,185,195,208] Therefore, it is difficult to assess how representative the population samples might be.

Ruiz-Diaz et al. (2019)[208] and Argüello et al. (2003)[173] described changes in the immune properties of colostrum stored refrigerated at 4°C for 10 days and 90 days, respectively. A repeated measures design was used, to compare mean colostrum quality values at sequential time points. Ruiz-Diaz et al. (2019)[208] concluded that samples should not be stored for more than four days, as after this time, the antimicrobial activity greatly decreases by between 75% and 80% (n=12 per group). Argüello et al. (2003)[173] found that the mean IgG content of samples refrigerated at 4°C reduces by 25% after three months (n=50).

Argüello et al. (2003)[173] also compared four different methods of thawing frozen colostrum; hot water at 60°C, room temperature at 27°C, cold-storage room at 4°C, and by microwave with a final temperature of 55°C (n=20 per group). No statistically significant differences in mean IgG content were found when comparing methods, suggesting that farmers can choose whichever method best suits them.

Argüello et al. (2003)[173] also performed seven freeze-thaw cycles for each thawing method. One or two cycles have little impact on colostrum IgG content.[173] Seven freeze-thaw cycles reduce the mean IgG content of the colostrum samples by between 27% and 34%.[173] However, these large sample effects were not found to be statistically significant.

Several studies have investigated the impact of heat treatment on the immune and bacterial content of goat colostrum.[173,177,197,199,261] Across studies, heat treatments consistently produce a large, statistically significant reduction in bacterial counts.[173,177,197,199,261] The consistently large size effect in the samples increases the likelihood that a similarly large size effect exists in the population.

Argüello et al. (2003)[173] compared the impact of two heat treatments, either 56°C for 60 minutes, or 57°C for 10 minutes followed by placing colostrum in a preheated thermos flask for a one-hour period. Bacterial content reduces from a mean of 39,300 cfu/ml (SD 54.400 cfu/ml) pre-treatment to a mean of 100 cfu/ml (SD 316 cfu/ml) following the 56°C heat treatment, and a mean of 0 cfu/ml (SD 0 cfu/ml) following the 57°C heat treatment. Trujillo et al. (2007)[177] found similarly large reductions in total bacterial counts (>95%) when using heat treatments of 56°C for 60 minutes or 63°C for 30 minutes. Plate counts for lactococci, enterococci, and enterobacteriaceae all reduce, and those for lactobacilli and coagulase-positive staphylococci become undetectable. Morales-delaNuez et al. (2011)[195] found that heat treatment at 56°C for the shorter time of 30 minutes also greatly reduces bacterial counts, from a mean of 6.53 cfu/ml down to a mean of 4.34 cfu/ml.

Both Argüello et al. (2003)[173] and Morales-delaNuez et al. (2011)[195] found that the heat treatments produce a statistically significant reduction in the IgG content of the colostrum compared to untreated control samples. In Argüello et al. (2003),[173] the mean IgG content reduced by approximately 35%, not dissimilar to the 29.4% reduction found by Morales-delaNuez et al. (2011).[195] In contrast, Trujillo et al. (2007)[177] found no statistically significant reduction in IgG content following either heat treatment. Ruiz-Diaz et al. (2019)[208] found that pasteurising colostrum at three different temperatures (56°C for one hour, 63°C for 30 minutes, and 72°C for 15 seconds, n=12 per group) does not reduce the mean antimicrobial activity in a statistically significant way. It must be noted that the data are presented as mean values for groups of colostrum samples, making it difficult to evaluate the variation in response amongst samples.

Colostrum is a potential vector for important infectious diseases in dairy goats, with kids infected when they ingest contaminated colostrum. Of these diseases, Lievaart-Peterson et al. (2019)[196] focused on *Mycobacterium Avium subspecies Paratuberculosis* (Johne's disease) and Adams et al. (1983)[197] focused on caprine arthritis encephalitis virus. Both of these are known to be particularly important pathogens in UK goat herds. Paterna et al. (2013)[199] focused on Mycoplasma species.

MAP can be destroyed by heat treatment of 60°C for 60 minutes.[196] Both caprine arthritis encephalitis virus (CAEV)[197] and *Mycoplasma spp*[199] can be destroyed by heat-treating colostrum at 56°C for 60 minutes. Washburn et al. (2001) investigated whether light treatment may have the potential to destroy CAEV in colostrum.

MAP bacteria shed in the faeces of adult goats are the principal source of infection for goat kids. Therefore, Lievaart-Peterson et al. (2019)[196] considered whether pasteurising colostrum is necessary to prevent the transmission of MAP to goat kids. A convenience sample of 120 colostrum samples from MAP-infected dairy goat herds were tested for MAP antibodies using an ELISA test, and for MAP DNA using a polymerase chain reaction test. None of the 120 samples provided a positive or inconclusive test result. An additional 22 colostrum samples from goats showing clinical signs highly suspicious of Johne's disease were also tested, and only two samples confirmed the presence of MAP. These preliminary results suggest that MAP-contaminated colostrum is a much less important route of infection in dairy goats than in dairy cattle.[196] From the perspective of MAP transmission alone, it may not be worth heat-treating colostrum, provided it is collected and handled hygienically before feeding to kids, as heat can damage the beneficial immune components in colostrum.[196] This area should be further explored. However, the authors stressed that pasteurisation will still be necessary if caprine arthritis encephalitis virus is also present in the herd.[196]

Trujillo et al. (2007)[177] evaluated high-pressure treatments as a potential alternative to heat treatment in reducing the microbial content of raw colostrum while preserving the immunoglobulin content. The results suggest that this method is as effective as heat treatment in reducing bacterial counts. Only the highest-pressure treatment of 500 MPa significantly reduces the IgG content. The authors stressed the preliminary nature of their results given the small sample sizes (n=12 per group), small volumes of colostrum treated (20 ml to 30 ml per aliquot), and the laboratory conditions that may not represent those for batch pasteurising on farms.

There are studies where sodium dodecyl sulfate or combinations of glycerol and propylene glycol are added to colostrum to evaluate how well they reduce the bacterial content and preserve the immunoglobulin content. Morales-delaNuez et al. (2011)[195] added sodium dodecyl sulfate to colostrum, finding this chemical does not reduce the mean IgG content of samples (n=20 per group), whereas heat treatment of 56°C for 30 minutes does. Morales-delaNuez et al. (2020)[185] added glycerol and propylene glycol to the colostrum before heat treatment. They found a statistically significant reduction in bacterial content, varying between 40% and 84% depending on the chemical combination added. The immunoglobulin content is preserved. These methods have potential use in colostrum management and storage, but more research is needed.

Ruiz-Diaz et al. (2019)[208] provided preliminary information on the impact of 'skimming' to remove milk fats and 'curding' to remove most total solids, both done to increase the immunoglobulin concentration of colostrum. The results suggest that curding significantly reduces antimicrobial activity, whereas skimming does not,[196] but further research is needed.

Baseline measures of immunoglobulin and fat, protein and lactose

There are few studies of colostrum quality from populations of commercially farmed dairy goats. To date, the farms studied are located in Germany,[180,181,183] Switzerland,[180,181] and New Zealand.[170] Zobel et al. (2020)[170] and Rudovsky et al. (2008)[183] focused on the immunoglobulin content, whilst Kessler et al. (2019, 2021)[180,181] also provided considerable information on the nutritional content. A better understanding of colostrum quality from commercially farmed dairy goats is important as it impacts the health, welfare, and production of the very large numbers of kids born on these farms. Studies of commercially farmed dairy goats will have high external validity.[230]

Summary statistics for the IgG content of colostrum are as follows. Zobel et al. (2020) [170] found a mean IgG value measured by RID of 63.4 g/L, a standard deviation of 35.4 g/L, and a range of 1.8 g/L to 181 g/L. Zobel et al. (2020) also measured 298 of these samples using ELISA tests, finding a mean IgG value of 20.7 g/L, a standard deviation of 11.3 g/L, and a range of 1.6 g/L to 72.5 g/L, which are considerably lower values. Kessler et al. (2019, 2021)[180,181] and Rudovsky et al. (2008)[183] used ELISA tests. Kessler et al. (2019, 2021) found the mean IgG content of colostrum from 116 goats convenience sampled over 28 farms to be 37.2 g/L with a standard deviation of 17.5 g/L. Rudovsky et al. (2008) found a mean IgG of 54.4 g/L with a standard deviation of 26.4 g/L for 30 goats convenience sampled from a single farm.

For other studies, the origins of the goats are less clear, for example, whether from commercial farms or research farms. Further data that helps inform as to the variability in IgG of colostrum amongst goats are from Yang et al. (2009)[178] (mean IgG of 72 g/L, SD 4.13 g/L, n=10), Argüello et al. (2003)[262] (mean IgG of 32.9 g/L, SD 14.9 g/L, n=50) and Levieux et al. (2002)[172] (mean IgG of 48 g/L, SD 28 g/L, range 19.9 g/L – 94.5 g/L, n=20). The remaining studies measuring the IgG content present data as means only for groups of goats.[174–176,184,186,189,190,200,203,207,240]

Data suggest that the immunoglobulin content of colostrum can vary considerably amongst goats, supporting concerns over the underpowering of many studies using this variable.

While there are a considerable number of studies of the nutritional content, few provide measures of dispersion. Table 2-1 presents values for the nutritional content of the first colostrum milkings observed in studies undertaken with varying primary aims.

Table 2-1 Summary statistics for the values of fat, protein, lactose, total solids and dry matter content of goat colostrum found by studies measuring these variables Values have been rounded to one decimal place, SD=standard deviation, n=number of goats sampled.

Study	**Breed**	**n**	**Fat (g/100g)**			**Protein (g/100g)**			**Lactose (g/100g)**			**Total solids or dry matter (g/100g)**		
			Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Yang (2009)[178]	Saanen	10	7.7	0.4	NA	10.2	2.2	NA	1.9	0.1	NA	21.2	0.1	NA
Kessler (2019) [180]	Mixed	116	6	2.8	1.3 – 16.5	12.9	4	4.9 – 25.1	3.7	0.6	2.1 – 6	NA	NA	NA
	Anglo Nubian	8	4.4	1.4	1.5 – 6.4	16.4	4.7	8.2 – 25.1	3.2	0.6	2.5 – 4.3	NA	NA	NA
	Saanen	18	6.6	4.1	1.3 – 16.5	14	5.3	6.9 – 24.1	3.6	0.7	2.3 – 4.6	NA	NA	NA
	Toggenburg	21	7	2.4	2.3 – 12.6	13.2	3.1	8 – 2.1	3.6	0.5	2.7 – 4.4	NA	NA	NA
Hodulová (2014)[194]	White short haired	7	8.9	1.5	NA	13.5	1.3	NA	3.7	0.9	NA	24.7	3.2	NA
Chen (2018)[193]	Laoshan	10	5.9	0.3	NA	9	1.1	NA	3.6	0.2	NA	27.8	2.4	NA
Hadjipanayiotou (1995)[192]	Damascus	12	6.4	1.9	NA	5.6	3.1	NA	4.6	0.5	NA	17.9	47.4	NA
Rudovsky (2008)[183]	WeiBe Deutsche Edelziege	30	9.5	4	NA	14.8	2.9	NA	NA	NA	NA	29	6.3	NA
Marziali (2018)[191]	Murciano-granadina	25	9.4	NA	NA	10.4	NA	NA	2.5	NA	NA	NA	NA	NA
Moreno-Indias (2012)[186]	Majorera	20	8.7	NA	NA	10.4	NA	NA	2.1	NA	NA	NA	NA	NA
Csapo (1994)[171]	Hungarian white	6	NA	NA	NA	15.3	1.8	NA	NA	NA	NA	26.4	3	NA
		4	NA	NA	NA	18.7	1.9	NA	NA	NA	NA	32.3	3.2	NA
Romero (2013)[190]	Murciano-granadina	43	9.5	NA	NA	13.6	NA	NA	2.9	NA	NA	29	NA	NA
Arguello (2006)[175]	Majorera	60	NA	NA	NA	7.5	NA	NA		NA	NA	NA	NA	NA
Sanchez-Macias (2014)[189]	Majorera	10	7.7	NA	NA	10.5	NA	NA	2.4	NA	NA	21.6	NA	NA
Caja (2006)[174]	Murciano-granadina													
	56-day dry period	9	6.4	NA	NA	13.2	NA	NA	NA	NA	NA	23	NA	NA
	27-day dry period	5	5.8	NA	NA	10.5	NA	NA	NA	NA	NA	20.1	NA	NA
	No dry period	3	6.3	NA	NA	4.3	NA	NA	NA	NA	NA	15.7	NA	NA

There has been little exploration of the relationship between different colostrum quality variables. Argüello et al. (2006)[175] reported a moderate positive linear relationship between protein and immunoglobulin content (r=0.695, P<.01, n=60) and a similar moderate positive linear relationship between immunoglobulin content and density (r=0.693, P<.01, n=60). This is unsurprising as the density of colostrum will be closely related to the total solid content, much of which will be protein in the early postpartum period. Unsurprisingly, there was a much weaker relationship between IgG content and the fat content (r=0.308, P<.01, n=60) and IgG content and the lactose content (r=-0.595, P<.01, n=60).

Chen et al. (1998)[203] estimated gamma-globulin to comprise, on average, 50% of total colostral protein at birth, and 20% to 30% of colostral protein at 24 hours postpartum, reducing to less than 10% of total protein by five days postpartum. However, inferential statistics were not used. Rudovsky et al. (2008)[183] estimated colostral IgG, measured by ELISA (n=30), to comprise a mean of 30% of the colostral protein.

There has been little investigation of the relationship between fat, protein and lactose.

Practical methods of measuring colostrum quality on farms

Practical, cost-effective methods of measuring colostrum quality on farms are required for selecting colostrum suitable for feeding kids. Estimating the immunoglobulin content is of particular interest. Several studies have explored the use of potential measurement techniques with goat colostrum. Included are Brix refractometers,[170,181,188,263] hydrometers (colostrometers),[170,183] a colour method,[231] measuring enzyme activity in colostrum,[188,241] the glutaraldehyde coagulation test (GCT),[188,241] and serum total protein refractometer.[188,232]

Zobel et al. (2020)[170] and Kessler et al. (2021)[181] evaluated Brix refractometers, a method based on the principle that light refracts when it moves between substances of different densities, with the angle of refraction used to estimate the total solid content of the liquid. Brix refractometers were developed as a low-cost tool for rapidly evaluating the sugar content of fluids in the food industry. They are a practical tool for use on farms, requiring only one or two drops of neat colostrum for an instant reading. Many possess an automatic temperature control function (ATC), preventing the environmental temperature from confounding measures. Brix refractometers are now used to measure colostrum in various species, including cattle,[160] equines,[264] pigs,[265–267] and sheep.[268]

Zobel et al. (2020)[170] and Kessler et al. (2021)[181] analysed the relationship between Brix values and the IgG content of colostrum, with IgG measured using RID and ELISA methods, respectively. Zobel et al. (2020)[170] used regression analyses, reporting an R-squared (R^2) value of between 0.51 and 0.57

(n=300) depending on whether optical or digital refractometers are used and whether colostrum is fresh or thawed, meaning that a one-unit change in Brix content is responsible for between 51% and 57% of the difference in IgG content. Kessler et al. (2021)[181] reported a strong positive linear correlation between Brix and IgG values (r=0.83, P<.0001, n=116).

Kessler et al. (2021) also found a statistically significant, linear relationships between Brix values and the main nutritional components of fat (r=0.3, P<.01, n=116), protein (r=0.89, P<.0001, n=116), and lactose (r=-0.25, P<.01, n=116).

Zobel et al. (2020) and Kessler et al. (2021) analysed the relationship between Brix refractometer values and immunoglobulin content by dichotomising data according to a chosen threshold value of immunoglobulin above which colostrum might be considered good quality. The most common threshold value of colostrum in dairy cattle is 50 g/L of IgG, derived from studies of passive transfer of immunity in dairy calves when fed colostrum of differing immunoglobulin content,[170] as goat-specific evidence is lacking. The results of Kessler et al. (2021) and Zobel et al. (2020) suggest that Brix values of 21%[181] and 19%[170] respectively, will most accurately categorise goat colostrum as good and poor quality, though again, confidence intervals are not provided for the predictive values. Kessler et al. (2021)[181] reported confidence intervals for the sensitivity and specificity values. These are very wide, suggesting a high level of uncertainty around the sample estimates of predictive values.

There are other studies investigating the use of the Brix refractometer as a predictor of the immunoglobulin content of goat colostrum, but methodological flaws prevent inferences. Buranakari et al. (2021)[263] proposed an 18.5% Brix value as the optimal predictor for good quality colostrum. However, the small sample size should be noted (n=21), as well as the very low threshold value of IgG (6.9 mg/ml or above) taken to represent good colostrum quality. Where confidence intervals (CI) are provided they are too wide for results to be practically useful (sensitivity 50 [95% CI 1.3, 98.7] %, specificity 100 [95% CI 82.4, 100] %. Additionally, the relationship between Brix values and the total solid content is not statistically significant, raising questions about measurement accuracy. In Kaçar et al. (2021)[188] samples are not independent, which could exaggerate the strength and size of the statistically significant correlation found. Three samples were collected from each goat (n=38), with single samples taken at partum, 24 hours postpartum and 48 hours postpartum, creating a total sample size of 114 goats.

Zobel et al. (2020)[170] reported good reliability of Brix measures of dairy goat colostrum (n=300), with Lins concordance correlation coefficient values of between 0.93 and 0.98. The ease of use of the Brix

refractometer combined with promising results as a predictor of colostrum quality means this method will likely supersede other potential methods.

Zobel et al. (2020)[170] and Kessler et al. (2021)[181] reported the Brix values for the colostrum samples from convenience samples of farmed goats. From the first principles of how refractometers work,[257] Brix values can be presumed a reasonable guide to the total solid content of colostrum, though this is still to be evaluated. Zobel et al. (2020) found a mean Brix value of 20% with a standard deviation of 4.3% (n=300), and Kessler et al. (2021) found a mean Brix value of 21.6% with a standard deviation of 5.3% (n=116).

Rudovsky et al. (2008)[183] and Zobel et al. (2020)[170] evaluated hydrometers (colostrometers), a method based on specific gravity or density. Hydrometers are practical for field usage but probably less so than Brix refractometers. Much larger volumes of colostrum are required for each test, and results can vary with the environmental temperature. Rudovsky et al. (2008)[183] found a significant strong positive relationship between reference laboratory measures of colostral specific gravity performed using a pycnometer and measures performed using a hydrometer on farm (r=0.99, P<.01, n=30). This gives some assurance over the validity of the field measures of specific gravity. The relationship between specific gravity and immunoglobulin content measured by ELISA was of moderate strength (R^2=0.44, P<.001), leading the authors to conclude that colostrometers might only have limited usage.[183]

In contrast, Zobel et al. (2020)[170] reported the hydrometer as a promising predictor of goat colostral IgG content measured using RID on the basis of their receiver operating characteristic (ROC) curve analysis. However, sample sizes are relatively small in both studies (n=30 and n=22 respectively), and further research is needed.

Argüello et al. (2005)[231] investigated a colour method whereby the IgG content of colostrum is estimated by comparing the colour of strips dipped into colostrum with that of a reference chart. Initial results are promising, with a one-unit change in colour accounting for 69.5% of the difference in the mean IgG content. However, whilst a large sample size is used (n=1084) it is unclear from the methodology whether these are independent samples or repeat samples from a smaller number of goats. The latter could exaggerate the strength and size of relationship.

There have been preliminary investigations of various colostral enzymes such as gamma glutamyl transferase,[188,241] lactic dehydrogenase,[241] and alkaline phosphatase,[241] as possible useful predictors of colostrum quality, but as yet, insufficient evidence to make inferences. These methods will likely

have limited practical use on farms as the method will likely require colostrum centrifugation to obtain colostral whey for testing.

There has been some evaluation of the use of the glutaraldehyde coagulation test (GCT) test with goat colostrum,[188,241] a rapid, inexpensive test based on the principle that glutaraldehyde binds with immunoglobulins and fibrinogen to form a clot.[269] Again, however, there is too little evidence to support inferences.

Both Castro et al. (2018)[232] and Kaçar et al. (2021)[188] evaluated the use of a serum protein refractometer (range from 0 mg/ml to 12 mg/ml) for estimating the immunoglobulin content of goat colostrum. However, neither study used independent samples. In Castro et al. (2018),[232] the 216 samples tested were obtained from 54 individual goats. Kaçar et al. (2021)[188] also sampled each goat multiple times. Another methodological issue in Castro et al. (2018)[232] is that the timings of colostrum collection indicate that only the first sample from each goat would have been colostrum, with the other three samples being normal milk. These approaches could exaggerate the significance and strength of relationships.

The total protein refractometer is likely less practical on farm than the Brix refractometer. Many neat colostrum samples are expected to be too concentrated to register on the refractometer scale, and will require dilution with distilled water before testing.

2.1.4 Studies of the impact on goat kids of feeding colostrum

The general comment for the methodology of the colostrum quality studies also applies to the studies of the impact on kids of feeding colostrum.

Changes in the small intestine of kids after consuming colostrum

Several studies have documented changes in the microanatomy of the small intestine and the mechanism by which immunoglobulins are absorbed.[209–215] Histologic techniques demonstrate that immunoglobulins pass across the small intestine from the colostrum into the circulation by pinocytosis,[270] as in cattle.[269] Here, the immunoglobulin molecules remain intact in vacuoles as they pass across the cytoplasm of epithelial cells. Studies of four days duration show that pinocytosis occurs for up to two days,[214,270] after which the specialised cells with this function die and are replaced by adult-type cells to which immunoglobulin molecules can bind but not enter.[270]

The jejunum is the most important segment of the small intestine regarding colostrum absorption,[210–213] the only section to possess an apical canicular system and extensive vacuolation.[210,214] Vacuolation is present between 18 to 36 hours of age[210,214] but gone by 96 hours.

Absorption of immunoglobulins tends to be greater when there are smaller numbers of goblet cells present,[211,212] and the positioning of the goblet cells changes from the base of villi to a more diffuse distribution over the first 96 hours of life.

Enzymes that have been measured are extracellular peptidases and disaccharides, including lactase and the intracellular acid phosphatase enzymes.[215] The quantity of the various enzymes in the small intestine alters over time postpartum.[215] Initially, local enzyme activity is not fully developed, thereby preventing immunoglobulins from being digested.

There are contrasting preliminary results for the density of the intestinal villi during the first days of life. Moretti et al. (2012)[214] found no difference between intestinal segments and over time after birth, whereas Nordi et al. (2013)[212] found that both the villous structures (height, crypt depth) and the muscle layer thickness of the small intestine alter.

Circulating immunoglobulin levels of kids

There are few baseline measures for kid serum immunoglobulin. Most research studies present the mean values only for groups of kids,[195,219,221,224,225,255] omitting measures of dispersion. Samples sizes are relatively small at 24 kids or fewer, with Castro et al. (2009)[225] being the exception at 67 kids per group. There is little data from commercially farmed kids.[108,216]

The findings can be summarised as follows. Circulating immunoglobulin levels of goat kids at birth, before colostrum feeding, are negligible or undetectable.[159,182,221,222,224,244,254,256] The mean serum IgG peaks between one and two days,[195,222,225] sometimes three days,[255] of age where kids have been fed colostrum shortly after birth. A statistically significant gradual decrease then occurs,[225] hypothesised due to an overall increase in plasma volume combined with the natural degradation of immunoglobulin.[225,255]

Argüello (2004)[256] found that where goat kids fail to absorb immunoglobulins from ovine colostrum, they start to produce detectable levels of innate circulating immunoglobulins between 15 and 30 days of age.

Serum immunoglobulin levels in kids in the one to two days after consuming colostrum can be highly variable, as illustrated by Massimini et al. (2007)[258] (mean serum IgG of 3170 mg/dL, SD 1030 mg/dL, range 1530 – 5270 mg/dL, n=20), Mellado et al. (1998)[216] (median serum IgG of 115 mg/dL, IQR 0 mg/dL – 1099 mg/dL, n=34), O'Brien et al. (1993)[108] (mean serum IgG of 1182 mg/dL, range 0 mg/dL – 3327 mg/dL, n=41), and Batmaz et al. (2019)[187] (mean serum IgG of 817.76 mg/dL, SD 37.34 mg/dL, n=75).

Serum immunoglobulin levels that indicate adequate passive transfer of immunity

Some studies have estimated the serum immunoglobulin levels that represent adequate passive transfer in goat kids[108,216] by analysing the circulating immunoglobulin levels above which kids are better protected from illness and death.

O'Brien et al. (1993)[108,217] recommended that a circulating IgG value of 1200 mg/dL at one to two days of age may indicate successful passive transfer of immunity based on a study of 39 consecutively born goat kids on a dairy goat farm in the USA. By weaning at six to seven weeks of age, 24 kids were healthy, four required treatment and 11 died, with the IgG concentrations of kids surviving greater than those that died.

Mellado et al. (1998)[216] suggested a serum threshold value of 800 mg/dL at one to two days of age to indicate a successful passive transfer of immunity, based on the survival rates of 63 kids born on a farm in Mexico.

Argüello et al. (2004)[222] found that kids that died during an experiment had significantly lower IgG levels in the first days of life.

Some studies have evaluated the relationship between serum immunoglobulin levels at one to two days of age and preweaning daily weight gain. Massimini et al. (2007)[258] found a statistically significant, moderate, positive association (R^2=0.56, P<.05, n=20), whereas O'Brien et al. (1993)[108] (n=39) found no significant relationship.

Potential field measures of passive transfer of immunity

Some studies have evaluated the potential field measures of PTI.[187,217–219]

Serum total protein refractometers are practical and cost-effective for use on farms, requiring only one to two drops of kid serum for an instant result. O'Brien et al. (1993)[217] found that a refractometer serum total protein reading of 5.4 g/dL may be a useful predictor of serum immunoglobulin concentrations of 1200 mg/dL, their suggested threshold for successful passive transfer of immunity (n=41). This STP threshold correctly identified 17 of 17 kids (100%) with failure of passive transfer and 20 of 24 kids (83.3%) with successful passive transfer. Descriptive statistics only are presented, and further research is needed. The authors stressed that serum total protein should only be used to screen for passive transfer status, as kids with similar total protein levels can have quite differing immunoglobulin fractions.[217]

To date, the relationships between serum total protein (STP) and the protein subfractions, including immunoglobulin, have been little explored in goat kids. Moretti et al. (2012)[244] found a statistically

significant, moderate, positive correlation between serum total protein measured by biuret and circulating immunoglobulin in goat kids (r=0.58, P<.05, n=29). The mean proportions of serum total protein that are immunoglobulin are calculated as 16.1% for a group of 14 kids and 20.4% for a group of 15 kids.[244]

Ramos et al. (2010)[254] and Fernandez et al. (2006)[182] found statistically significant, positive, moderate to strong, linear relationships between serum immunoglobulin and serum gamma globulin concentrations (r=0.64, P<.01 for Ramos et al. (2010); R-squared values of 0.394 – 0.857, P<.05 – <.001 for Fernandez et al. (2006)). However, it is surprising that these relationships are not consistently stronger as much of the gamma globulin fraction is presumed to comprise immunoglobulin.

Other potential field measures of passive transfer of immunity have been evaluated. Relevant measures of kid serum include the sodium sulphite precipitation test,[217] the level of enzyme activity,[218] the glutaraldehyde coagulation test,[218]and Brix refractometer measures.[187,219]

The sodium sulphite precipitation test is a promising predictor of PTI, with solutions in the range of 14% to 18% specifically precipitating immunoglobulins.[217] It is reported to be less costly than the ZST test.

Yalcin et al. (2010)[218] found no statistically significant correlation between serum IgG levels and the serum enzyme gamma glutamyl transferase activity (GGT) when analysing data from 21 kids. Lashari et al. (2020)[219] considered whether GGT, alanine transaminase, and aspartate transaminase can predict passive transfer status. However, in Lashari et al. (2020), the values for kid serum immunoglobulin levels are likely inaccurate as they were calculated from Brix measures of serum using a regression equation obtained from a research study of dairy calves,[219] rather than measured using an established technique.

Yalcin et al. (2010)[218] also evaluated whether the GCT test can predict passive transfer status, finding no statistically significant correlation between GCT and serum IgG. Therefore, the conclusion that GCT is a useful predictor of serum immunoglobulin applies to this study sample only.

Batmaz et al. (2019)[187] found the serum Brix values of day-old kids that had suckled colostrum at birth to be a mean value of 9.33%, with a standard deviation of 0.17% (n=75). The use of a ROC curve analysis found that a Brix value of 8.6% best predicted PTI, defined as serum IgG values of 800 mg/dL or greater. These are helpful preliminary findings, but much further research is needed to guide the use of the Brix refractometer in goat kids. The strength of the relationship between IgG and Brix values (r=0.43, P<.01, n=75) was similar to that between serum IgG and serum total protein

readings (r=0.44, P<.001, n=75), which is unsurprising given that both were measured using refractometers that work using the same principle.

The impact of different factors on colostrum absorption by kids

There are several studies of the impact of different factors on colostrum absorption by kids. Many studies have used controlled experimental designs, usually with random assignment of kids to the treatment and control groups,[182,220–223,256] sometimes with prior trait matching,[195,221,224,225] which is generally according to gender. For some studies, the assignment of kids is unclear.[219,244]

However, there are still potential methodological issues of relatively small sample sizes and underpowering. In most studies, there are fewer than 21 kids per group[182,195,219,221,222,224,225,244,255,256] with the minimum number being five per group.[223] Castro et al. (2009)[225] is the exception, with much larger sample sizes of 67 kids per group.

- *Quantity, quality, and timings of feeds*

Several studies have evaluated the impact of the quality, quantity and timings of colostrum feeds.[221, 244]

Castro et al. (2005)[221] and Moretti et al. (2012)[244] evaluated the quantities of IgG fed. Castro et al. (2005) found that kids consuming 4g of IgG per kg of birthweight will achieve a mean serum IgG level over 1200 mg/dL, in contrast to Moretti et al. (2012), where kids fed a higher concentration of IgG at 8.2g of IgG per kg of birthweight have a mean serum IgG of less than 1200 mg/dL.

Moretti et al. (2012)[244] and Argüello et al. (2004) considered the timings of colostrum feeds. Moretti et al. (2012)[244] measured the mean apparent efficacy of absorption (AEA) of immunoglobulin in kids during the first 24 hours of life, finding it maximal at seven hours of age, after which it gradually declined. Argüello et al. (2004) found a significant, positive, moderate to strong correlation between IgG ingested and the serum IgG levels in a group of bottle-fed kids (n=40) at differing time intervals during the first 72 hours of the life, concluding that the first 24 to 48 hours of life are particularly important for immunoglobulin absorption in kids.

Castro et al. (2005)[221] evaluated the timings and quantity of colostrum feeds in a single study. Two groups of kids were fed a high quantity of IgG in colostrum (1684 mg of IgG per kg of body weight), and two groups were fed a low quantity (842 mg of IgG per kg of body weight). For each concentration, one group was fed the full allowance over the first day of life, and the other group received the same allowance over two days. The group fed the high total colostrum allowance over a single day achieved a higher mean serum immunoglobulin level than the group fed the same

allowance over two days. No significant differences were found when comparing the two groups of kids fed the low total immunoglobulin (842 mg of IgG per kg of body weight).

Rodríguez et al. (2009) evaluated feeding colostrum of differing IgG concentrations. A group of kids fed colostrum paste with a high IgG concentration (80 g/L) had a mean efficacy of absorption of 24.4%, which is almost twice that of the groups fed less concentrated pastes (20 g/L, 40 g/L or 60 g/L). These findings align with expectations that the apparent efficacy of absorption (AEA) will increase as the concentration of immunoglobulin in the colostrum increases.[160,269]

Ramos et al. (2010)[254] measured the mean total apparent efficacy of absorption for two groups of goat kids as 25.5% and 24.5%. Kids were fed natural goat colostrum or goat colostrum to which trypsin inhibitor was added, respectively.

- *Method of feeding colostrum*

Several studies have evaluated different methods of feeding colostrum.[225 222]

Castro et al. (2009)[225] compared natural suckling durations of one, two, or five days, finding the mean serum IgG concentration to exceed 1200 mg/dL for all groups. However, the extent to which the quality of colostrum produced by the different dams differs needs to be clarified; this could confound the results.

Argüello et al. (2004)[222] compared natural suckling with two methods of artificial rearing; bottle-feeding ad-lib quantities of colostrum and bottle-feeding restricted amounts of colostrum. No statistically significant difference in the mean IgG of goat kids was found.

- *Colostrum handling*

There are studies evaluating the impact of feeding colostrum that has been handled or treated in differing ways, including stored frozen,[256] stored refrigerated,[256] pasteurised using heat treatment,[182] or lyophilized (freeze-dried).[221,224] Lyophilising[221,224] is a means of preserving colostrum as a powder so that it can be conveniently stored for extended time periods without the immunoglobulin content deteriorating.

The mean serum IgG of goat kids fed colostrum that has been stored refrigerated at 4°C does not differ significantly from those fed the identical colostrum that has been stored frozen.[256]

Fernandez et al. (2006)[182] found that kids fed goat colostrum heat treated at 56°C for 30 minutes receive fewer immune components than those fed untreated colostrum. Relevant measures of immunity are circulating IgG levels, phagocytosis by neutrophils to indicate the amount of activity

against bacterial infection, and delayed-type hypersensitivity as a measure of the cell-mediated immune response.[182]

Studies have shown that lyophilised goat colostrum can also be absorbed well by goat kids.[221,223]

There have also been some comparisons of lyophilized colostrum with natural goat colostrum. Castro et al. (2005)[221] found that the mean serum IgG is greater in kids fed lyophilised goat colostrum than when fed untreated goat colostrum. However, the results will likely be confounded by the greater concentrations of IgG in the lyophilised colostrum, which could lead to greater efficacy of absorption of the former compared to natural goat colostrum.

Morales-delaNuez et al. (2011)[195] found no significant differences in serum IgG levels or general biochemical screens of kids fed goat colostrum to which 1% sodium dodecyl sulphate had been added compared to the control group, suggesting this chemical is not detrimental to kid health during the first three days of life. Sodium dodecyl sulphate had shown promise for sanitising colostrum while maintaining the immunoglobulin content.[195]

Ramos et al. (2010)[254] found that adding soybean trypsin inhibitor to colostrum does not alter the immune status of the kids. Colostrum naturally contains more trypsin inhibitor than mature milk, so trypsin inhibitor was hypothesised to prevent the trypsin secreted in the small intestine from degrading colostral antibodies.[254]

- *Colostrum replacers or supplements*

Several studies have explored the impact of feeding kids with colostrum replacers and supplements. Colostrum whey is a more concentrated source of IgG than natural colostrum due to the removal of non-immune proteins and other solids. Therefore, Castro et al. (2007)[255] hypothesised that kids consuming colostrum whey would absorb more immunoglobulins than those fed natural goat colostrum, but no statistically significant difference was found. Mellado et al. (2008)[220] found that feeding kids commercial colostrum supplements by stomach tube before the natural suckling of colostrum from the dam does not alter the serum IgG, blood profiles, growth, and survival of kids compared to those that naturally suckled only. However, the quantities and qualities of colostrum naturally suckled by different kids may have differed, confounding the results. Argüello et al. (2004)[256] found that neonatal kids do not absorb immunoglobulins when fed a commercial colostrum replacer derived from ewe colostrum. Commercial colostrum replacers are generally derived from bovine colostrum, not ovine colostrum.

- *Bovine colostrum*

Several studies have evaluated whether goat kids can absorb immunoglobulins from bovine colostrum, in natural or lyophilised form.[209,211–213,223,244] The reasons for using bovine colostrum include avoiding diseases that can be transmitted from does to kids in untreated goat colostrum, such as caprine arthritis encephalitis virus. Moretti et al. (2012)[244] demonstrated that goat kids can absorb immunoglobulins from lyophilized bovine colostrum, finding no significant differences in the mean serum IgG of groups fed lyophilised bovine colostrum compared to natural goat colostrum. In Linhares Lima et al. (2013), goat kids also readily absorbed lyophilized bovine colostrum, but the small sample sizes (n=5 kids per group) make comparisons with groups fed goat colostrum difficult.

Histologic studies of the small intestine have also demonstrated that goat kids can absorb natural bovine and lyophilized bovine colostrum. Some studies have found no difference when comparing tissues after feeding lyophilized bovine colostrum and goat colostrum. Nordi et al. (2012)[213] found similar positions of the vacuoles and nuclei within enterocytes. Moretti et al. (2012)[215] found similar levels of enzyme activities in the small intestines. Nordi et al. (2013)[212] found similar villous structures (height, crypt depth), muscle layer thickness, and the number of goblet cells in the small intestine during the first 96 hours of life. Moretti et al. (2012)[214] found no differences in the villus density, measured up to 96 hours of age.

Other studies do suggest differences. Machado-Neto et al. (2013)[211] found that kids fed lyophilized bovine colostrum have a higher number of goblet cells containing sialomucins, suggesting a reaction of intestinal epithelium increasing secretion in response to non-recognised substances in the lyophilized goat colostrum. Moretti et al. (2014)[209] quantified the total protein, DNA, and RNA contents of different segments of the small intestine, liver, and muscle until the kids were 96 hours of age. The results suggest greater absorption of proteins and greater maturity of enteric and muscle tissue in the groups of kids fed lyophilized bovine colostrum.

Associations between kid characteristics and colostrum absorption

Several studies have evaluated whether different kid characteristics are associated with the absorption of colostrum. Factors include litter size,[225,226,254,271] gender,[108,216,219,225,271] age,[219] birthweight[204,222,225,255] and parity of mother.[219]

Some studies have reported statistically significantly higher serum variable values in single kids than in twins or triplets.[225,226] In contrast, others have reported lower values in single kids.[204] Several studies have found that kid gender has no significant impact.[108,204,216,219,225] Various hypotheses have been proposed for the findings, including the potential relationship between low birthweight and

being a triplet[225] and a less vigorous suckling of single kids during the critical absorption period.[204] However, the methodologies used require further discussion. The studies are likely underpowered, especially where a single study compares multiple factors using generalized linear model (GLM) style analyses. Also, confounding is probable. In Pisarska et al. (2002)[225] and Chen et al. (1999),[203] the kids being compared may have ingested differing qualities and quantities of colostrum, as colostrum quality is likely to have varied amongst does. In O'Brien et al. (1993),[108] the males naturally suckled their mothers, whereas the females were fed heat-treated colostrum.

When analysing the impact of birthweight, Castro et al. (2009)[225] and Argüello et al. (2004)[222] split kids into three weight categories. In Castro et al. (2009) these were 1.7 kg to 2.78 kg, 2.8 kg to 3.2 kg and 3.3 kg to 4.2 kg and in Argüello et al. (2004) these were under 2.5 kg, from 2.5 kg to 3.2 kg, and over 3.2 kg. When analysing the impact of kid age Lashari et al. (2020)[219] split kids into groups based on three age categories of one to four days, five days, and more than five days. It would be helpful to have further details on why these categories were chosen.

2.1.5 Summary

Further research is needed to develop a robust evidence base to make inferences confidently. Most of the research findings are valuable, preliminary, descriptive information on which to build future research. Common methodological issues include relatively small sample sizes, with underpowering of studies likely, and a need for more confidence intervals to guide the precision of estimates. There needs to be more repetition of studies to check for reproducible results.

A need for robust 'baseline' data was identified. Here baseline data is defined as valid, reliable, and unbiased estimates of population parameters for important colostrum variables and a clear description of the relationship between these variables. Baseline data provides a strong foundation on which to build future studies. Such baseline data is essential as it establishes current parameters for variables, allows for the generation of hypotheses and allows for lines of inquiry that are important to pursue to be determined. It also informs the design of studies. For example, knowledge of the dispersion of measures amongst goats is valuable in informing the necessary sample sizes.

A need for data from commercially farmed goats was identified, producing evidence with high external validity. Research of colostrum from commercially farmed goats has grown since 2018 but is still sparse, and the UK needs to be represented. A better understanding of colostrum quality from commercially farmed dairy goats is essential as it impacts the health, welfare, and production of very large numbers of kids born on these farms. It is relevant to both the female dairy

replacement kids and the male kids who will be reared for meat. It is relevant to all farms. It is relevant for other issues of concern, such as anti-microbial resistance, as by improving kid health good colostrum management reduces the need for therapeutic antibiotics.[272]

Colostrum was chosen as the area of research that could most impact kid health within the time frame and resources available for this study, expanding the research evidence base and providing evidence with immediate benefits for practice on farms.

3 Chapter 3

3.1 Survey of husbandry and health on UK commercial dairy goat farms

(As published in the Veterinary Record. 2019:185(9):1-10)[228]

3.1.1 Abstract

Published research relevant to the UK dairy goat industry is scarce. Current practices and concerns within the UK dairy goat industry must be better understood if research is to have optimal value. A postal survey was conducted of the farmer membership of the Milking Goat Association as a first step in addressing gaps in knowledge. Questions were asked about husbandry practices, farmer observations of their goats and their priorities for further research. Seventy-three percent of Milking Goat Association members responded, representing 38% of commercial dairy goat farms and 53% of the commercial dairy goat population in England and Wales. Findings were comprehensive and showed extensive variation in farm practices. Farmers reported pneumonia and scours (diarrhoea) as the most prevalent illnesses of their kids. Pneumonia, diarrhoea, failure to conceive and poor growth were the most prevalent observations of youngstock. Overly fat body condition, assisted kidding, failure to conceive and difficulty drying off were the most prevalent observations of adult milking goats. Farmers' top priorities for further research were kid health (79.5% of farmers), Johne's disease (69.5%), tuberculosis (59%) and nutrition (47.7%).

3.1.2 Introduction

There are an estimated 108,000 goats on agricultural holdings within the UK, with 92,000 goats located in England and Wales.[1] Approximately 46,000 are dairy goats commercially farmed in England and Wales and located over 120 farms.[2] Here commercial farming is defined as the production of milk or milk-based products for sale for human consumption. The UK dairy industry is small and decentralised compared to the UK dairy cattle industry. It is a relatively young industry, with large scale commercial farms developing mainly over the last 25 years. In 2017, the UK dairy goat farmers formed an industry body, the Milking Goat Association, to better represent their interests, better communicate with each other and to support industry driven research,

To date, published studies of goat health, welfare and production are scarce, particularly those concerning UK dairy goats. Those that do report on the UK industry include our previous study, which assessed the welfare of dairy goats on 24 UK commercial farms using animal-based measures and found lameness, claw overgrowth, skin lesions, udder and teat lesions to be particular problems.[7] Several studies of lameness and the causes of lameness have noted a very high prevalence on some farms.[8–12] Despite milk being the primary farm produce there have been only three studies of mastitis in commercial dairy herds[13–15] and one study estimating the breeding values for milk yield.[16] Scrapie is the best represented infectious disease[18–21,23,24] with several epidemiological studies describing infection prevalence and scope for breeding disease resistant goats. Epidemiological studies have described Q fever (*Coxiella Burnetti*) infection on two UK farms.[25,26] One study of Johne's disease exists, investigating whether *Mycobacterium avium paratuberculosis bacterium* was present in raw milk from bulk tanks.[28] An outbreak of tuberculosis (TB) in a herd of Golden Guernsey goats has been described.[28] Two postal surveys confirmed ectoparasites to be a particular issue in goats, including those commercially farmed.[29,30]

An evidence base from other countries is growing, but these are not specific for UK farms. Current practices and concerns within the industry must be better understood if further research is to have optimal value. Therefore, a postal survey was designed as a first step in addressing gaps in knowledge within the UK dairy goat industry to direct future research efforts.

3.1.3 Materials and methods

A postal survey was designed, covering husbandry practices and farmer observations of different age groups of goats, as well as farmer preferences for further research. Questions were informed by published peer-reviewed literature on goats, non-peer-reviewed secondary literature such as Goat Veterinary Society journals, goat veterinary texts and researcher experience of dairy goat farming. Kids were defined as goats from birth to weaning, youngstock as from weaning to first service and adult milking goats as those within the main milking herd, including dry does. Billies were defined as adult male goats. In total, there were 55 questions with subparts, comprising both open and closed questions.

To promote return rate, the survey was designed to be completed within 15 minutes from memory with no requirement to locate exact figures. This was emphasised in a covering letter, which also explained that the results would be treated confidentially. Farmers could complete the questionnaire anonymously or choose to provide contact details to receive an anonymised summary of the results.

A draft survey was pilot tested with 10 dairy goat farmers. Following feedback, the percentage categories used in the section concerning observations of goats were altered, and a ranking activity was provided in the research priorities section instead of a completely open question. For the ranking activity, 13 issues were presented in a table and farmers were asked to circle and rank the five issues that concerned them the most. This was supplemented by an open question on whether there were additional issues they would have liked the opportunity to include in their top five.

In November 2017, the survey was posted to all full members of the Milking Goat Association, 70 in total with 67 members located in England and Wales, one in Scotland, one in Northern Ireland. A reminder letter was sent three weeks after the initial survey and then again three weeks later.

3.1.4 Data Handling and Statistics

Data were entered into a spreadsheet (Excel, Microsoft) and analysed using IBM SPSS, V.24.0. Results are reported as simple summary statistics. Where percentages are given, the actual numbers are presented in brackets when necessary to avoid ambiguity.

3.1.5 Results

Seventy-three percent (51 out of 70) of Milking Goat Association members responded. Surveys from 46 individual farms were completed. The other five respondents informed the researcher that they either worked with a farm that already completed a survey or they no longer kept goats.

Seventy percent of farms answered all 55 questions, 17.4% of farms answered 54 questions and 13% of farms answered 53 questions.

The 46 farms that responded represented approximately 38% of the commercial dairy goat farms in England and Wales and held at least 24,372 goats, representing at least 53% of the commercial dairy goat population at the time of the survey (one farm did not answer the question about herd size).

Farm background information

Herd sizes, defined as number of adult milking goats including dry does, ranged from 6 to 2,300 goats with a median value of 400 goats (IQR 150 – 725).

The 46 farms that completed the survey comprised 18% of all farms in England and Wales with herd sizes of 50 or fewer goats, 27.6% of all farms with a herd size of 51 – 200 goats, 52.9% of all farms with a herd size of 201 – 500 goats, 61.9% of all farms with a herd size 501 – 1000 goats and 33.3% of all farms with a herd size of more than 1000 goats.

The periods of time producers had been farming dairy goats ranged from 1 to 42 years, with a median of 11 years (IQR 3 – 29). Reported milk yields ranged from 700 to 1,800 l/goat/year (median 1022, IQR 900 – 1184). All 100% (46) of the farms reared their own replacement goats. Some 31% (14/45) of farms ran a completely closed herd for both male and female animals. Some 67.4% (31/46) of the farms practised out-of-season breeding. Some 17% (8/46) of farms grazed goats outdoors. Some 87% (40/46) of farms had Saanen and Saanen crosses as their main breed. Toggenburg/Toggenburg crosses were present on 54.3% (25/46) of farms, Alpine/Alpine crosses were present on 26.1% (12/46) of farms, Anglo Nubian/AN crosses were present on 19.6% (9/46) of farms and Golden Guernseys on 2.2% (1/46) of farms.

Responses to questions about husbandry in kids are given in Table 3-1. Responses to questions about husbandry in adult milking goats are given in Table 3-2. Responses to the survey question 'has your herd ever been affected by the following diseases?' are given in Table 3-3. Vaccines used by farmers are given in Table 3-4. Factors associated with different herd sizes are given in Table 3-5. Farmers' observations of kids and milking goats over the previous 12 months are given in Table 3-6.

Farmers' observations of adult male goats over the previous 12 months are given in Table 3-7. Farmers' priorities for future research are given in Table 3-8.

Questions where farmers gave more than one response were those concerning: the types of colostrum fed, methods of feeding colostrum, methods of feeding milk to kids, types of forage offered to kids, types of market for male kids and routine hygiene practices undertaken in milking goats.

Based on vaccines used, 56.5% (26/46) of farms vaccinated for Johne's disease, 98% (45/46) of farms vaccinated for clostridial enterotoxaemia, 28.3% (13/46) of farms vaccinated for infections that commonly cause abortion, 23.9% (11/46) of farms vaccinated for Pasteurella infection and 6.5% (3/46) of farms vaccinated for caseous lymphadenitis.

For each age group of goats, farmers were asked if they had seen any other signs over the previous 12 months. The number of farmers responding 'yes' were 21.7% (10/46) for kids, 6.5% (3/46) for youngstock, 17.4% (8/46) for adult milking goats and 10.9% (5/46) for billies.

Additional signs reported for kids were bloat, sore heads due to infections following disbudding, weak hind legs, coccidiosis, cryptosporidia, persistent diarrhoea, navel hernias, sudden death at nine days of age, scours and meningitis. Additional signs for youngstock were listeria, coccidiosis and orf. Those for adult milking goats were caseous lymphadenitis (CLA), ketosis, listeria, twin lamb disease, laminitis, Yersinnia, chlamydia and teat biting and those for billies were CLA, excessive horn growth, listeria, blocked urethra, mastitis and pneumonia.

Table 3-1 **Husbandry practices in kids**		
Survey question	**Response**	**Percentage (number) of farms**
For how long do kids remain with their mothers?	Removed at birth	21.7% (10/46)
	< 12 hours	8.7% (4/46)
	Between 12 and 24 hours	21.7% (10/46)
	Between 25 and 48 hours	21.7% (10/46)
	> 48 hours	26.1% (12/46)
Are kids fed colostrum other than by suckling their mothers?	Yes, sometimes	42.2% (19/45)
	Yes, routinely	40% (18/45)
	No	17.8% (8/45)
If yes, what type of colostrum is fed?	Colostrum from another doe	89.2% (33/37)
	Colostrum from another source	18.9% (7/37)
How is this colostrum fed?	Bottle fed	75.7% (28/37)
	By stomach tube	43.2% (16/37)
For how long are kids fed this colostrum?	< 1 day	21.6% (8/37)
	Between 1 day and 2 days	64.9% (24/37)
	> 2 days	13.5% (5/37)
Is this colostrum pasteurised before feeding?	Yes	10.8% (4/37)
	No	89.2% (33/37)
Is colostrum quality measured?	Yes	10.8% (4/37)
Are kids fed milk replacer?	Yes	87% (40/46)
	No	13% (6/46)
At what age are kids first fed milk replacer?	1 – 2 days	60.5% (23/38)
	3 – 4 days	26.3% (10/38)
	5 – 7 days	10.5% (4/38)
	14 – 21 days	2.6% (1/38)
How are kids fed milk?	Ad lib (always available)	85% (36/40)
	Restricted (in meals)	15% (6/40)
Are kids fed starter/creep feed?	Yes	95.7% (44/46)
	No	4.3% (2/46)
At what age are kids first fed starter/creep?	Less than 7 days	45.2% (19/42)
	7 – 14 days	37.5% (15/42)
	14 – 21 days	2.5% (1/42)
	Over 21 days	17.5% (7/42)
Are kids fed forage?	Yes	95.7% (44/46)
	No	4.3% (2/46)
What type of forage is fed to kids?	Hay	50% (21/42)
	Straw	59.5% (25/42)
	Haylage	9.5% (4/42)
	Silage	4.8% (2/42)
At what age are kids first fed forage?	Less than 7 days	47.6% (20/42)
	7 – 14 days	42.9% (18/42)
	over 21 days	9.5% (4/42)
Do you have a target weaning age?	Yes	75.6% (34/45)
	No	24.4% (11/45)
Do you have a target weaning weight?	Yes	41.3% (19/46)
	No	58.7% (27/46)

What is your target weaning age?	Under 6 weeks (minimum 5 weeks)	3.4% (1/29)
	6 – 8 weeks	69% (20/29)
	12 – 16 weeks	17.2% (5/29)
	Over 18 weeks (maximum 32 weeks)	10.3% (3/29)
What is your target weaning weight?	Under 15kg (minimum 12kg)	10.5% (2/19)
	15kg	57.9% (11/19)
	Over 15kg (maximum 20kg)	31.6% (6/19)
Do you have a market for your male kids?	Yes	76% (35/46)
	No	24% (11/46)
What is your market for males?	Breeding	28% (13/46)
	Meat	74% (34/46)
Do you rear any kids for meat on your own farm?	Yes	54% (25/46)
	No	46% (21/46)
Are kids disbudded?	Yes	100% (46/46)
What age are kids disbudded?	Less than 14 days age	93.3% (42/45)
	Between 14 days and 28 days	0% (0/45)
	28 days or older	6.7% (3/45)
Does your local vet have sufficient knowledge and experience of dairy goats?	Yes	82.6% (38/46)
	No	6.5% (3/46)
	Not sure	10.9% (5/46)

Table 3-2 **Husbandry practices in adult milking goats**		
Survey question	**Response**	**Percentage (number) farms**
Are milking goats fed forage?	Yes	100% (46/46)
What type of forage is fed?	Hay	51.1% (23/45)
	Haylage	40% (18/45)
	Silage	26.7% (12/45)
	Straw	24.4% (11/45)
Is forage analysed?	Yes	50% (23/46)
	No	50% (23/46)
Are milking does fed concentrate?	Yes	98% (45/46)
How are concentrates fed?	Ad lib	37.8% (17/45)
	Set ration per goat	37.8% (17/45)
	Mixed with forage	24.4% (11/45)
Are goats fed according to yield?	Yes	35% (16/46)
	No	65% (30/46)
Are goats fed in the parlour?	Yes	50% (23/46)
How are these goats fed in parlour?	Small amount for encouragement	50% (11/22)
	Individual ration	50% (11/22)
Do you aim to give goats a dry period?	Yes	100% (46/46)
For how long is this dry period?	< 2 weeks	5.3% (2/38)
	3 – 4 weeks	17.4% (8/46)
	5 – 7 weeks	43.5% (20/46)
	7 weeks or more	34.8% (16/46)
How often are goats milked at peak yield?	Twice daily	93.3% (42/45)
	Three times daily	6.7% (3/45)
Which of the following are done routinely at milking?	Gloves worn	54.3% (25/46)
	Foremilk checked	37% (17/46)
	Teat wiped	56.5% (26/46)
	Teat dip premilking	6.5% (3/46)
	Teat dip post milking	34.8% (16/46)
	No routine practices used	17.4% (8/46)
Do you record milk yields?	Yes	52% (24/46)
	No	48% (22/46)
If yes, how do you record milk yields?	Electronic/automatic recording	45.5% (10/22)
	Manual	54.5% (12/22)
	Yields for individual goats	90.9% (20/22)
	Yield for groups of goats	9.1% (2/22)
What is your target kidding interval?	12 months/annual	38.5% (15/39)
	Between 12 and 24 months	46.2% (18/39)
	Between 24 and 36 months	7.7% (3/39)
	Flexible according to yield	7.7% (3/39)
Do you have a target age for first service?	Yes	98% (45/46)
	No	2% (1/46)
What is your target age at first service?	6 – 7 months	40.9% (18/44)
	8 – 9 months	20.5% (9/44)
	10 – 12 months	20.4% (9/44)
	13 months or more	18.2% (8/44)

Do you have a target weight for first service?	Yes	67.4% (31/46)
	No	32.6% (15/46)
If yes, what is your target weight at first service?	Less than 35kg	11.1% (3/27)
	From 35 to 40 kg	70.4% (19/27)
	More than 40kg	18.5% (5/27)
Are goats routinely foot trimmed?	Yes	100% (46/46)
What age are goats first foot trimmed?	< 3 months	8.7% (4/46)
	3 – 5 months age	15.2% (7/46)
	6 – 8 months age	32.6% (15/46)
	9 – 12 months age	28.3% (13/46)
	Over 12 months	6.5% (3/46)
	As necessary	8.7% (4/46)
How often are the feet trimmed?	Every 1 – 2 months	15.6% (7/45)
	Every 3 – 4 months	35.6% (16/45)
	Every 5 – 6 months	33.3% (15/45)
	Every 7 – 12 months	6.7% (3/45)
	When needed/as often as possible	8.9% (4/45)
Are goats routinely footbathed?	Yes	20% (9/45)
	No	80% (36/45)

Table 3-3 **Responses to the question 'Has your herd ever been affected by the following diseases?'**				
Disease	**Yes**	**No**	**Don't know**	**Never heard of it**
Johne's	48.9% (22/45)	42.2% (19/45)	8.9% (4/45)	0
Caseous lymphadenitis (CLA)	22.2% (10/45)	71.1% (32/45)	6.7% (3/45)	0
TB	6.7% (3/45)	93.3% (42/45)	0	0
Caprine arthritis encephalitis (CAE)	11.1% (5/45)	73.3% (33/45)	15.6% (7/45)	0
Scrapie	8.7% (4/46)	93.3% (42/45)	0	0

Table 3-4 **Responses to the question 'Which vaccines do you use?'**		
Name of vaccine(s) used	**Percentage (number) of farms (n/46)**	**Diseases the vaccine is intended to prevent**
Guidair (CZ vaccines)	56.5% (26)	Johne's disease
Lambivac (MSD Animal Health)	82.6% (38)	Clostridial enterotoxaemia
Covexin (Zoetis)	2.2% (1)	Clostridial enterotoxaemia
Bravoxin (MSD Animal Health)	2.2% (1)	Clostridial enterotoxaemia
Enzovac (MSD Animal Health)	19.6% (9)	Enzootic abortion
Cevac Chlamydia (Ceva Animal Health Ltd)	6.5% (3)	Enzootic abortion
Toxovac (MSD Animal Health)	26% (12)	Toxoplasmosis
Coxevac (Ceva Animal Health Ltd)	8.7% (4)	Q fever
Ovipast (MSD Animal Health)	13% (6)	Pasteurellosis
Heptavac P Plus (MSD Animal Health)	17.4% (8/46)	Clostridial enterotoxaemia and pasteurellosis
Glanvac (Zoetis)	4.3% (2/46)	Caseous lymphadenitis
Glanvac 3 (Zoetis)	2.2% (1/46)	Caseous lymphadenitis and clostridial enterotoxaemia

Table 3-5 **Factors associated with different herd sizes**				
Factors	**Median herd size of farmers responding 'yes'**	**Median herd size of farmers responding 'no'**	**Mann-Whitney U test**	***P***
Out of season breeding used	600	196	311.5	.001
Goats grazing outdoors	34	600	17	.001
Kids fed milk replacer	560	50	206	.002
Forage analysed	700	200	412	<.001
Feeding total mixed ration	870	250	319.5	<.001
Automatic/electronic recording of milk yields	815	150	119.5	.002
Fed individual ration in parlour	60	600	27	.016

Table 3-6 **Percentage (number) of farms where farmers observed specified signs in their goats over the previous 12 months**					
Age group	**Signs observed**	**Proportion of affected goats within farm**			
Kids		<2%	>2% – <5%	5 – 15%	>15%
	Poor growth	68% (30/44) farms	13.6% (6/44) farms	15.9% (7/44) farms	2.3% (1/44) farms
	Deaths	47.8% (22/46)	26.1% (12/46)	17.4% (8/46)	8.7% (4/46)
	Skin problems or itch	85.7% (36/42)	9.5% (4/42)	4.8% (2/42)	0
	Scour/diarrhoea	39.5% (17/43)	20.9% (9/43)	32.6% (14/43)	7% (3/43)
	Pneumonia/excess cough	36.4% (16/44)	38.6% (17/44)	15.9% (7/44)	9% (4/44)
	Swollen joints or swollen navel	88.1% (37/42)	9.5% (4/42)	2.4% (1/42)	0
Youngstock	Poor growth	62.8% (27/43)	23.3% (10/43)	11.6% (5/43)	2.3% (1/43)
	Deaths	72.7% (32/44)	18.2% (8/44)	6.8% (3/44)	2.3% (1/44)
	Skin problems/itch	54.8% (23/42)	4.9% (2/42)	7.3% (3/42)	0
	Scour/diarrhoea	62.8% (27/43)	23.2% (10/43)	14% (6/43)	0
	Pneumonia/excess cough	57.1% (24/42)	26.2% (11/42)	16.7% (7/42)	0
	Difficult to get in kid	54.8% (23/42)	23.8% (10/42)	16.7% (7/42)	4.8% (2/42)
Adult milking goats	Overly thin	65.9% (27/41)	24.4% (10/41)	4.9% (2/41)	4.9% (2/42)
	Overly fat	31% (13/42)	21.4% (9/42)	31% (13/42)	16.7% (7/42)
	Difficult to get in kid	41.9% (18/43)	25.6% (11/43)	25.6% (11/43)	7% (3/43)
	Difficult to dry off	39.5% (17/43)	27.9% (12/43)	23.3% (10/43)	9.3% (4/43)
	Assisted kidding	41.3% (19/46)	34.8% (16/46)	17.4% (8/46)	6.5% (3/46)
	Abortion or stillbirths	6.4% (28/44)	22.7% (10/44)	6.8% (3/44)	6.8% (3/44)
	Cloudburst	55.8% (24/43)	14% (6/43)	23.3% (10/43)	7% (3/43)
	Lame	61.4% (27/44)	15.9% (7/44)	13.6% (6/44)	9.1% (4/44)
	Mastitis	63.6% (28/44)	34.1% (15/44)	2.3% (1/44)	0
	Scour/diarrhoea	41.9% (18/43)	27.9% (12/43)	27.9% (12/43)	2.3% (1/43)
	Pneumonia/excess cough	71.4% (30/42)	28.6% (12/42)	0	0
	Skin problems/itch	70.5% (31/44)	13.6% (6/44)	15.9% (7/44)	0

Table 3-7 **Farmers' observations of their billies (adult male goats) over the previous 12 months**	
Signs	**Percentage (number) of farms (n/46)**
Overly fat	6.5% (3)
Overly thin	13% (6)
Lameness	26.1% (12)
Scour/diarrhoea	26.1% (12)
Skin problems/itch	17.4% (8)

Table 3-8 **Farmers' priorities for future research**	
Issue	**Percentage (number) of farms ranking this issue in their top 5 concerns (n/44)**
Kid health (pneumonia and/or scour)	79.5% (35)
Johne's	65.9% (29)
Tuberculosis	59% (26)
Nutrition/feed management	47.7% (21)
Lameness	27.3% (12)
Abortion/stillbirth	25% (11)
Mastitis	22.7% (10)
Fertility	18.2% (8)
Colostrum	18.2% (8)
Caseous lymphadenitis	13.6% (6)
Carine arthritis encephalitis	11.4% (5)
Growth rates	11.4% (5)
Skin problems	6.8% (3)

3.1.6 Discussion

A substantial proportion of the UK commercial dairy goat population was represented by this survey, although findings are skewed towards larger farms, probably because these are more likely to be Milking Goat Association members.

Farm background

Reported average milk yields (median 1022 l/goat/year, IQR 900 – 1184) were higher than those previously reported for UK farms (median 825 l/goat/year, IQR 640 – 904),[7] perhaps reflecting changes in breeding and husbandry that better support production. There was no relationship between herd size and milk yield.

Only 17% of farmers grazed goats outdoors, probably because managing such large numbers of goats outdoors is impractical, partly due to difficulties in managing the nutrition of high yielding goats at pasture and partly because goats remain susceptible to infections with gastrointestinal parasites.

Sixty-seven percent of farmers manipulated the breeding season, which would enable them to produce a more even volume of milk throughout the year and to take advantage of the higher milk prices paid in the autumn and winter months.

Thirty-one percent of farmers operate a completely closed herd that optimises their biosecurity. Further investigation is needed to establish how these farms maintain genetic diversity and how the questions were interpreted, for example, whether farmers considered a closed herd to be one that allowed some males onto the unit every few years.

Kids

Whatever feeding strategy is used, kids must ingest sufficient quantities of good quality colostrum within the first hours of life in order to absorb enough immunoglobulins to protect them from disease.[175] On most farms, kids remained with their mothers for at least the first hours of life, enabling them to suckle colostrum naturally. However, there is little information about the quality of colostrum produced by does on UK farms as studies to date have involved different breeds and management system in different countries, with none from the UK. Refractometers, used by two farms to measure colostrum quality, have not been validated for use in goats. The colostrometer, used by one farm, has been found moderately accurate.[183]

There are benefits in feeding kids colostrum beyond the initial six hours when they best acquire immunity because it provides local immune protection in the gut, has superior nutrition to milk and contains many other beneficial substances such as growth hormones. Colostrum gradually

transitions to milk over three to five days postpartum.[189] However, just under half the farms kept kids with their mothers for over 24 hours and some farms for up to 48 hours, meaning much colostrum and transition milk is wasted as once kids are separated from their mothers it is practically difficult to isolate and feed this milk.

Possible reasons for removing kids from their mothers at or shortly after birth include limiting contact with the adult environment to reduce disease risks, preventing the doe and kid bonding to reduce the stress of separation and kids potentially more readily learning to suck an artificial teat than if removed later. Possible reasons for leaving longer include saving labour and ensuring full use of colostrum. Of the ten farms that left kids with their mothers for over 48 hours, eight farms specified the duration. For seven farms this was between three and seven days whereas one farm of herd size 500 had a unique system of leaving kids with their mothers for five weeks.

Some farms routinely provided doe colostrum in addition to that which the kid suckled, either via a stomach tube or bottle. It would be useful to know the source of this doe colostrum as feeding colostrum from another doe, or pooled from several does, can accelerate the spread of diseases that pass from infected adults to kids via the milk, for example caprine arthritis encephalitis and scrapie.

Four farms fed colostrum replacer routinely as their only source of colostrum. For these farms, the type of replacer used will be particularly important. For example, lyophilised or freeze-dried bovine colostrum can be adequately be absorbed by goat kids[210,221,223] whereas replacer derived from ewe colostrum has been found inadequate.[256]

Details of volumes of colostrum fed and whether these align with recommendations in goat texts, of 10% of bodyweight in the first 12 hours or 20% of bodyweight in the first 24 hours of life,[273] are needed.

Most farmers follow colostrum feeding with milk replacer as this is considered more economical and practical than feeding goat's milk, despite the higher digestibility, faster growth rates[274] and better immune function of kids when fed goat's milk.[275]

Most farms indicated that they fed milk replacer ad lib, which produces higher growth rates than restricted feeding due to the larger volumes of milk ingested.[274] However, intake may not be truly ad lib for all goat kids in the group as they share access to teats with varying numbers of pen mates and, unlike calves, the individual milk intakes cannot be monitored or rationed. The intake of some kids could well be reduced by competition from pen mates.

Optimal milk intakes for kids in the first weeks of life are unknown. Few studies have looked beyond the first weeks of life and the effect milk feeding will have on solid food intake and any growth check

and hunger at weaning.[150] The digestibility of different milk replacers should also be investigated further.

Goat kids, as with all young ruminants, must ingest solid feed to develop a functioning rumen. Most farms offered kids both forage and starter feed before they were two weeks age, which gives kids the opportunity to become familiar with this feed before they begin to ingest substantial quantities.

As in calves, the fermentation of starter feeds is likely to provide the butyrate needed to develop rumen papillae and forage is likely to promote muscular development of the rumen, as well as stimulate rumination and flow of saliva into the rumen.[276] However, the optimal balance between forage and starter, as well as the types used, needs further investigation.

Weaning age and weaning weight are proxy measures of rumen development. The target weaning weights of most farms are in line with the recommended weaning weights for goats[277] of 2.5 times their birthweight, though little research underpins these values. Further details, such as numbers of farms that weigh their goats at weaning and whether milk feeding is stopped abruptly or gradually at weaning, are needed.[150]

Female goat kids are routinely disbudded on all farms, as dehorned goats can be housed at higher stocking densities than horned goats and are thought less likely to become trapped in pen structures.[278] Most farms met the recommendations of disbudding within the first week of life.

UK law specifies that the disbudding of goat kids must only be performed by a veterinary surgeon (Veterinary Surgeons Act 1966, Schedule 3, Part 2). Farmers' comments about veterinary input were mostly positive, implying that many farms can find a vet able to disbud their goat kids to a satisfactory standard. However, 20% of farmers still experienced some difficulties with accessing veterinary input to a standard that met their needs. Disbudding kids is more technical than disbudding calves due to the double innervation of the horn bud in the kid, making anaesthesia more difficult and the thin skull of the kid risking thermal injury to the brain.[279] Disbudding goats is often not a routine part of veterinary training.

Markets for goat meat have rapidly expanded in recent years, reducing the number of male billy kids that are killed at birth, with 75% farms having a market for their male kids. Further investigation is needed into the proportion of male kids these farms have a use for. To date, very little is known about the health, welfare and production on dedicated kid rearing units.

Adult milking goats

In the survey, the term forage was intended to mean those feeds that are predominantly cellulolytic and slowly fermented in the rumen and concentrate those feeds that are predominantly amylolytic and rapidly fermented.

All farms fed their milking goats forage and for the 50% (23/46) of farms that analyse forage, there is potential to use this information to better match the feed to the animals' nutrient requirements. All farms fed concentrates, which is expected as forage alone would not meet the energy requirements of high-yielding does.

The 24% (11/45) of farms that offer goats concentrate mixed with forage do so as a total mixed ration (TMR). It is unsurprising that farms with larger herd sizes tended to feed TMR as they are more likely to have the necessary resources and space.

Of the 23 farms that feed goats in the parlour, 11 of these fed an individual ration of concentrate in the parlour, ensuring their intake is known as they can consume this without competition. These were smaller farms, who could probably milk at a slower rate. On many farms goats only stay in the parlour for the duration of milking, often only one minute to two minutes, which is insufficient time for them to eat their individual concentrate ration.

The remaining farms offered goats concentrate whilst housed in their pens, either ad lib or calculated as a set amount per goat. However, this may not have been the amount each goat has access to or consumes when in a group situation.

Those 52% of farms that record the milk usage have the potential to use these records to select individuals for breeding or to guide feeding strategies. Thirty-five percent of farms reported they fed to yield. More information is needed about how farmers interpreted this term and how they are implementing the practice, for example, whether they feed individual goats based on their individual yields, manage groups with a stepped approach or do otherwise.

Milking

Routine hygiene practices, such as teat wiping and teat dipping, were minimal. Seventeen percent of farms do not use any sort of udder and teat preparation. Potential reasons include goats being much cleaner than cattle,[7] goats being perceived as being less susceptible to mastitis than cattle and time pressures, with the stockperson attending to a different goat every few seconds. Fore-milking is often omitted, in part because visual inspection of milk and measuring somatic cell counts using a California mastitis test are less reliable indicators of udder infection than in cattle.[253,280] In addition,

between 60% – 80% of udder milk is cisternal in goats, requiring little udder preparation to stimulate milk let down. However, many of the routine hygiene practices used in cattle are still considered to benefit udder health in goats.[280]

There is currently little evidence on optimal dry period lengths, with very few studies investigating how it affects colostrum quality[174] or milk yield in subsequent lactations.[281,282]

Goats have the potential to milk for extended periods of time, often years, without giving birth, therefore, potentially reducing the frequency of kidding and associated health risks. However, there have been few studies of the management needed for extended lactations to be successfully used.[283,284]

All farmers were aware of the main infectious diseases of dairy goats. However, where farmers answered 'no' to presence of disease, they may have been unaware that their goats can be infected without showing obvious clinical signs. Also, this survey did not establish whether disease presence or absence was confirmed by veterinary diagnostic tests.

Almost half of farms reported that they had been affected by Johne's disease (infection with MAP). Vaccination will control, but not prevent, infection in goats. To date, there have been no prevalence studies of Johne's disease on UK goat farms, despite its economic significance and the potential to cause a public health scare due to suggested links, currently unproven, between ingestion of MAP in dairy produce and Crohn's disease in humans.

Commercially farmed goats are at particular risk of clostridial enterotoxaemia,[272] a fatal disease caused by the usually commensal *Clostridial perfringens* type D bacteria. Hence, it is positive that 98% of farms vaccinate to reduce risks. All clostridial vaccines are multivalent. Owners of goats are advised to use vaccines with the lowest number of pathogen strains, as these will provide the best possible immune response to the main clostridial diseases of dairy goats, clostridial enterotoxamia disease caused by *Clostridial perfringens.*[272] Therefore, it is positive that 82.6% of farmers use Lambivac.

Overall, few vaccines have been developed for, properly evaluated in or licensed for use in goats.

Farmer observations

The farmer observations of clinical signs in their goats provide useful information but have their limitations and biases. For example, interpretation of and detection of the various signs will vary between farmers. Also, farmers may have been unlikely to circle the upper value, whatever the figures presented, unless they felt they had a particularly large problem on their farm. Although

some signs would have been better served by different percentage values, presenting too many different numbers could have made completion more difficult, producing fewer responses.

When trialling the questionnaire, farmers advised that 'under 2%' was a more useful figure than zero, as virtually no farms are free of the signs listed. Also, they naturally tended to choose the category with the lowest appropriate incidence, so 'less than 2%' being within the 'less than 5%' bracket was not a problem in practice.

Scour, followed by pneumonia, poor growth and deaths, were the most prominent signs observed by farmers in their kids, in line with findings from the small number of studies of dairy goat kids intensively reared in other countries[108–110,217] and with studies of dairy calves.[285]

Farmers still observed considerable pneumonia and scour in their youngstock though to a lesser extent than in the kids. Failure to conceive was also prominent and is likely to be costly, as in heifers.[286] Possible underlying causes, such as failure to meet recommended weaning weights at target weaning ages, need further investigation. Larger herds had lower target weights for first service, probably due to more intensive management, emphasising reaching this stage more quickly.

Overly fat milking goats (body condition score > 3[273]) produce less efficiently and are predisposed to metabolic problems, dystocia and infertility than goats in the correct condition for their stage of production. Body condition scores developed for goats[287] require the sternal area to be palpated, as sternal fat reserves are a better indicator of total body fat than the lumbar reserves are. However, little is known about their use in the field and how farmers currently gauge the body condition of their goats.

Cloudburst, or hydrometra, is prominent on some farms, lowering conception rates, but this has been little studied.

Anecdotally goats are more difficult to dry off during the summer months, which is thought could lead to a shortened dry period.

Few farms reported lameness prevalence greater than 5%, which contrasts with previous research findings[7] where overall lameness prevalence of goats on 24 farms was 19.2%, ranging from 7.7% to 52.5% of goats per farm. However, farmer reports could well be underestimates.[9] Detection can be difficult where large numbers of goats housed are housed at a high stocking density on straw bedding.[7] Lameness is more easily detected when goats exit the parlour, but they are less likely to be observed at this time. Also, mild to moderate lameness can become normalised.

Signs of diarrhoea are more prominent in adult milking goats than in youngstock, which could be due to suboptimal feed management and sudden diet changes in adults.

Few farmers reported mastitis incidence to be over 5%, which is in line with other studies of mastitis in goats.[280,288] However, further research is needed. Subclinical mastitis may affect production more than previously thought,[288] and the prevalence of this on three UK dairy goat herds was reported as 26%, 39% and 24%.[13] Also, udder abnormalities, defined as asymmetry of udder halves, irregular swelling and skin lesions, were prominent on UK farms.[7]

Farmers' priorities for future research

Whilst many farmers selected and ranked five issues as requested, there were also farmers that chose fewer issues or chose five issues without ranking. However, the proportion of farms ranking certain issues in their top five, in association with the open question, was used to gauge farmers' main concerns.

Although 76.1% of farmers ranked kid diseases, pneumonia and scour highly, only 18.2% considered colostrum management a priority, despite the importance of colostrum for kid health in the early weeks of life. Farmers may feel that colostrum management was automatically a part of kid health and omitted it for this reason. Alternatively, farmers may be less aware of the role of colostrum in disease protection in kids or may assume they have already optimised their colostrum feeding practices, ruling this out as an underlying cause.

Johne's disease was reported as a major concern. This is unsurprising as there has been growing awareness of this disease amongst farmers and milk buyers, with potential for a damaging public health scare due to purported links between Crohn's disease in humans and ingestion of MAP bacterium by humans when they consume dairy products. At present, the scientific evidence for such a link is inconclusive.

Tuberculosis (TB) remains a high priority, probably due to public health concerns and the economic consequences of TB diagnosis on farm. To date, in the UK confirmed cases of TB in goats have been caused by *Mycobacterium bovis*.

At the time of the survey, little compensation was paid for goats slaughtered due to suspected infection. Most farmers will not know their TB status as routine surveillance testing is not mandatory in goats.

It is unsurprising that nutrition was a high priority, as feed cost is a substantial component of farm costs on dairy farms and farmers are generally aware of its importance to health and production.

Only 21.6% (12/46) of farms considered lameness to be a top priority, which could reflect difficulties with lameness detection as already described. Abortion and stillbirths were also ranked relatively low, perhaps because farmers saw milk produced as being the main product and not live kids.

No farms added claw overgrowth to the list, despite a previous survey of 24 farms identifying this as a major issue.[7]

Where farmers added issues to their list of main concerns, they tended to extrapolate on or emphasise aspects of an area they had already ranked. New issues raised were worming strategies, listeria and disbudding.

3.1.7 Conclusion

This survey provides a better understanding of current practices and concerns on dairy goat farms within this UK cohort, enabling further research to have optimal value by staying relevant and focusing on areas where most impact can be made. Such research is urgently needed as currently there is little evidence base available to support farmers in achieving good health, welfare and production on UK dairy goat farms.

4 Chapter 4

4.1 Evaluation of the quality of colostrum from farmed dairy goats and the relationship with Brix refractometer measures

4.1.1 Abstract

The importance of colostrum for the health and welfare of neonatal ruminants is well established. However, the evidence base for goat colostrum is sparse, despite goat kid health being identified as a priority for further research by dairy goat farmers taking part in a postal survey instigated by the Milking Goat Association in the UK. The primary aims of this study were two-fold; firstly, to provide information on the nutritional and immunoglobulin content of colostrum from commercially farmed dairy goats, and secondly to evaluate how well the Brix refractometer estimates these measures. Colostrum samples were obtained from a total of 461 Saanen and Saanen cross-breed goats from four different kidding sessions that took place on three different commercial farms. Immunoglobulin levels were measured using radial immunodiffusion, the fat, protein, and lactose content were measured using infrared spectroscopy and the energy content was calculated from the nutritional analysis results.

Values for colostrum measures varied considerably amongst goats and this level of variability persisted when goats were grouped by kidding session. Colostrum samples of similar total solid content comprised differing proportions of fat, protein, and lactose and therefore differing energy content. Colostrum samples of similar protein content had very variable immunoglobulin content. Linear regression analyses established that Brix measures could significantly predict the mean total solids, energy, and immunoglobulin content. Numerical values for the prediction intervals for these variables over a Brix range of 15% to 32% are provided.

4.1.2 Introduction

The importance of colostrum for neonatal ruminants is well established. Colostrum provides essential immunity and nutrition. Ruminants are born with little or no humoral immunity[159,160,222] because immunoglobulins cannot pass across the ruminant placenta from the mother to the foetus.[160,182] Instead, they must absorb maternal antibodies from the colostrum they ingest during the first hours of life, providing them with immune protection until they are old enough to produce their own.[108,160,217,224] Other constituents are also known to provide immune protection and aid the maturation of tissues,[161,162] including hormones, cytokines, growth factors, enzymes, lactoferrins, and cells such as leucocytes.

Colostrum provides all essential nutrients during the first days of life.[163] The high fat content is particularly important for meeting the high energy demands of thermoregulation and metabolism as neonates have poor bodily insulation, little in the way of body energy stores, and are exposed to a significant drop in temperature at the point of birth.[289–291] The high protein content provides the large amounts of amino acids needed for rapid protein accretion.[289,290] Colostrum is also a highly concentrated source of vitamins and minerals.[160,164,290]

Good colostrum intakes have been shown to provide welfare and production benefits in farmed dairy cattle, both immediate and longer term, extending into months and even years of life.[161,165,166,168,269,292–294] For optimal benefits, neonates must consume adequate quantities of good quality colostrum within a short time period of birth.[160] Industry bodies such as the Agricultural and Horticultural Development Board (AHDB) in the UK have provided evidence-based guidelines emphasising the '3 Qs' – quality, quantity, and quickly – as general first principles for feeding colostrum. There are several aspects to colostrum quality, including the immunoglobulin content, nutritional content, hygiene or bacterial contamination, and the presence of any disease-causing pathogens.[160]

Goat colostrum has been far less researched than cattle colostrum. This is despite the fact that goat kid health, specifically pneumonia and diarrhoea, was identified as a priority for further research by dairy goat farmers in the UK during a postal survey instigated by the Milking Goat Association.[228]

Although studies of goat colostrum appear numerous, the robust evidence base is small because, whilst providing useful preliminary information, many studies involve small sample sizes and the methodologies limit the inferences that can be confidently made. Topics specific to goats that have been researched can be summarised as follows.

Several studies have evaluated how the physical, chemical, and immunological composition of goat colostrum changes over time postpartum,[171,172,175,178,189–195,200–206] identifying the period of transition from colostrum to milk.[178,189,192,201,202,206] Most studies of fat, protein, and lactose content have been undertaken in this context.[178,186,190–192] Some studies concurrently investigated changes in the mineral and trace element content.[178,202]

An increasing number of studies are examining main nutritional components in more detail.[178,191,205–207,248,249] The roles of newly identified components, such as chitotriosidase,[233] are being investigated.

Different methods of treating colostrum, aimed at preserving immunoglobulin content whilst destroying harmful bacteria and disease-causing pathogens, have been studied. Methods include refrigeration and freezing,[173] and the effect of repeat freeze-thaw cycles,[173] mode of thawing,[173] heat

treatment,[173,177,195,199,208] and the addition of chemicals.[185,195] Lievaart-Peterson et al. (2019)[196] focused on Johne's disease, whilst Adams et al. (1983)[197] focused on the viral disease caprine arthritis encephalitis, both important diseases in UK goat herds. Paterna et al. (2013)[199] focused on the *Mycoplasma* species. One study has examined whether contamination of milk by colostrum affects the results of routine tests for antibiotic residues.[259] Several studies have considered associations between colostrum quality and different factors, including parity,[175,180,190,200] age of doe,[170] gravidity [171,175,180,190,200] induced parturition,[184] length of dry period,[174] breed[180,205] and diet.[176,207]

There have been few studies of colostrum quality from populations of commercially farmed dairy goats. To date, farms examined were located in Germany,[180,181,183] Switzerland,[180,181] and New Zealand.[170] Zobel et al. (2020)[170] and Rudovsky et al. (2008)[183] focused on the immunoglobulin content, while Kessler et al. (2019, 2021)[180,181] also provided considerable information on the nutritional content. A better understanding of colostrum quality from commercially farmed dairy goats is important as it impacts the health, welfare, and production of the very large numbers of kids born on these farms.

Practical, cost-effective methods for measuring colostrum quality enable efficient selection of which colostrum to feed. The usefulness of colostrometers and Brix refractometers for estimating the immunoglobulin content of colostrum has been evaluated extensively in dairy cattle[160] but little in goats. Rudovsky et al. (2008)[183] and Zobel et al. (2020)[170] evaluated the use of colostrometers, a method based on specific gravity. Zobel et al. (2020)[170] and Kessler et al. (2021)[181] evaluated the use of Brix refractometers, a method based on the refraction of light when it moves between substances of different densities. The angle of refraction can be used to estimate the total solid content of a liquid. Brix refractometers are a particularly useful tool on farms as they are low cost, handheld and portable. Unlike colostrometers, they only require one or two drops of neat colostrum for an instant reading. Many possess an automatic temperature control function (ATC), preventing the environmental temperature from confounding measures. The ease of use of this method means it is likely to supersede other potential markers previously studied, such as a colour method,[231] enzyme markers[188,241] and the glutaraldehyde coagulation test.[188,241]

The primary aims of this study were two-fold; firstly, to provide information on measures of the fat, protein and lactose content, the energy content, and the immunoglobulin content of colostrum from commercially farmed dairy goats in the UK, and secondly, to evaluate how well the Brix refractometer estimates these measures.

Due to the scarcity of goat research, a short description of how colostrum varied according to dry period length, parity, and gravidity is provided in Appendix B to help inform the methodology and sample sizes of future studies focusing on these factors.

4.1.3 Materials and methods

Colostrum samples were obtained from goats on three commercial dairy goat farms in the UK, referred to as farms 1, 2, and 3. Farm sizes were 2,400, 1,500, and 1,000 adult milking goats respectively. On farms 1 and 2 adult milking goats were fed a total mixed ration (TMR). On farm 3 they were fed an ad-lib pelleted diet. The main breeds were Saanen and Saanen crosses.

For farm 1, samples were collected from two separate kidding sessions. These were kidding session 1A in August 2018 and kidding session 1B in March 2019. For farm 2, samples were collected during kidding session 2, which took place in January and February 2019. In each of these kidding sessions, approximately 400 goats gave birth over a 4-week period. For farm 3, samples were collected during kidding session 3 which took place in May and June 2019 when approximately 200 goats gave birth over a 4-week period.

Convenience sampling was used. A single researcher collected all samples, except for on farm 2 where additional help was available from a stockperson skilled in measuring and collecting colostrum samples. The researcher was present on the farm from early morning until evening for the third week of kidding session 1A, for two weeks during the middle of kidding session 1B, for three weeks from the beginning of kidding session 2, and for two weeks in the middle of kidding session 3.

Sample collection

The collection of colostrum samples was designed to fit around the normal kidding routine for each farm. Sample collection practices common to all farms were as follows. Pregnant goats were housed in groups of between 60 and 200 goats, where they gave birth. Shortly after birth the goat was caught and restrained. The teats were thoroughly cleaned with a fresh udder wipe. The operator wore clean gloves (TouchNTuff®, 92-660, Ansell). Before collecting samples, the first two to three ejections of colostrum were hand milked from each teat and discarded in order to remove any debris from the teat canals and to check that the colostrum appeared visually normal.

Colostrum was then collected into a clean container, by hand milking on farms 1 and 2 and machine milking on farm 3. It was thoroughly mixed before dispensing into multiple sample pots, either screw-top polystyrene containers (7 ml or 30 ml, Thermoscientific™ Sterilin™ Universal containers) or microcentrifuge tubes (2 ml Eppendorf®, Thomas Scientific). Each pot was labelled with the goat's individual ear tag number and date of collection. Colostrum samples were placed in a freezer within

30 minutes of collection and stored at minus 20°C until further analysis. Samples were collected before the kids suckled.

Routine kidding practices and therefore colostrum collection varied between farms in the following ways. Normal practice in farm 1 was to catch goats shortly after parturition and place them in individual pens with their kids, located adjacent to the main herd of pregnant goats, where they remained for a minimum of 12 hours. Kids were fed their first colostrum by stomach tube, using colostrum milked from their own mother, before being left to suckle their mothers naturally. The colostrum was collected from one or both udder halves. Colostrum samples were obtained from the first 400 ml to 500 ml milked into a clean, dry, plastic, measuring jug before feeding the remainder to her kids. All samples were collected within 20 minutes of the goat giving birth and before the kids had a chance to suckle.

Normal practice on farms 2 and 3 was to remove kids from their mothers at birth and before they had a chance to suckle. Generally, kids were removed within 10 minutes of the goat giving birth, though at very busy periods this time might be extended. Kids were transferred to a specially designated kid-rearing area away from the adult goats where they were bottle-fed pooled goat colostrum. After giving birth, goats were collected from the pregnant group and the full volume of the first colostrum milking was saved for feeding kids. Most goats were collected and milked within two hours postpartum but at very busy times this could extend to four hours. On farm 2, goats were transported in a mobile stable holding up to six goats to an area housing a freezer and sink to facilitate good practice in collecting and storing colostrum. Primiparous goats were milked manually, either by hand or using an Udderly EZ milker™. Multiparous goats were machine milked in the parlour. Colostrum samples were decanted into sample pots from the first 500 ml to 700 ml of colostrum collected from the goat. On farm 3, goats were walked to the parlour adjacent to the pen where they had given birth and machine milked into a clean metal container. Colostrum samples were obtained from the first full milking volume.

Measures of colostrum

- *Brix readings*

A digital refractometer (PAL-1 Digital Hand-held “Pocket” Refractometer, 0% – 53.0% Brix, ATC, Atago®, Atago Co. Ltd, Japan) and an optical refractometer (HHTEC®, ATC 10°C to 30°C, 0% – 32% Brix Refractometer) were used to measure each colostrum sample. Both refractometers were used according to the manufacturer’s instructions.

Usually, one digital and one optical reading were performed on fresh colostrum samples within minutes of collection. This was done for all samples from kidding session 1A. However, during very busy periods in kidding sessions 1B, 2, and 3, one Brix reading was performed goat-side on fresh colostrum and additional Brix measures were performed later using thawed colostrum. Optical and digital readings were used interchangeably and the means of at least two Brix values per sample were used in the analysis, based on prior findings of a repeatability study undertaken using colostrum from kidding 1A (Chapter 5). On completion of colostrum collection from kidding sessions 1B, 2, and 3 the repeatability of multiple measures was again checked to determine whether it remained within expected parameters (Appendix A).

- *Fat, protein, and lactose*

Fat, protein, and lactose content (g/100g) were measured using infra-red spectroscopy (Delta Combiscope 600HP (Delta Instruments B.V., Drahten, The Netherlands) by Quality Milk Management Services Limited, Wells, Somerset, UK). Colostrum samples that were too viscous to test neat were diluted 50:50 with distilled water. The sum of fat, protein, and lactose content is referred to as total solids.

- *Energy*

The metabolizable energy (ME) content of colostrum aliquots were estimated from the fat, protein, and lactose results using the formula:

ME (Mcal/kg of dry matter) = [0.057 x CP(%) + 0.092 x Fat(%) + 0.0395 x Lactose(%)] x 0.9312 provided by J.Quigley (2001).[295] Values were then converted into megajoules (MJ).

It must be noted that these ME values are broad estimates for goat kids as they are based on figures of ME derived from calf nutrition, as published in the National Research Council nutrition guidlelines.[295] Similar calculations/formulae specific for goat kids are not available.

- *Immunoglobulin (IgG)*

Throughout this study, the term immunoglobulin refers to immunoglobulin subclass G (IgG), which is the main immunoglobulin in ruminant colostrum.[183] Immunoglobulin content was quantified (g/L) using radial immunodiffusion (RID), performed by the Saskatoon Colostrum Company Limited, Saskatoon, Canada. Individual samples of goat colostrum were diluted in a buffered saline solution. The diluted samples were applied in duplicate to wells in a thin layer of agarose gel containing antiserum reactive to goat IgG. The RID plates were incubated at room temperature in a sealed container to maintain a high humidity environment. Over time, a visible precipitin zone formed by

the binding and lattice formation between the stationary antiserum in the gel and the antigen (goat IgG) diffusing radially through the gel from the well in which it was applied. After 18 to 24 hours of incubation, the diameter of the visible precipitin zone of each sample was measured and plotted on a standard curve. The standard curve was created by applying doubling dilutions of a "standard" of known IgG concentration to each RID plate. The IgG concentrations and corresponding precipitin zone diameters of the standards were plotted on a graph and a regression line equation was created. The IgG concentrations of each test sample were calculated by entering the zone diameter into the regression line equation created from the standards.

The researcher collected and handled samples according to good practice, as described above, and radial immunodiffusion was performed by a laboratory experienced in using the method and in testing colostrum. Measurement error was expected to be low and, for logistical reasons, only single measures were done on each sample. However, as part of quality control, a subset of colostrum samples was tested more than once, and the repeatability of measures was assessed to ensure they were within expected and acceptable limits (Appendix A).

The protein fraction comprising immunoglobulin was estimated by dividing the immunoglobulin content (g/L) by the protein content (g/kg). These values will be slight overestimates, as one litre of colostrum could weigh from 1.02 kg to 1.07 kg, extrapolating from summary statistics for goat colostrum specific gravity.[170,183]

Measures of goats

For farms 1 and 2 it was possible to assess the body condition of goats when confined for colostrum collection. The scoring system appropriate for dairy goats, described by Smith and Sherman (2009)[273] and illustrated by Mendizabal et al. (2007),[296] where both the lumbar and sternal areas of the goat are palpated, was used. The body condition scoring is on a scale of one to five where score one is a thin goat and score five is an overweight goat.

Parity was established from a combination of farmer knowledge and farm records. Goats could confidently be categorised as primiparous or multiparous. The length of the dry period was calculated as the interval in days between the date the goat gave birth and the date of the last recorded milking. Gravidity (whether the goat gave birth to singles, twins, or triplets) was recorded by direct observation.

On farms 2 and 3, goat kids were removed from their mothers at birth so the full volume of first colostrum milking could be measured by decanting colostrum collected into a measuring jug calibrated in millilitres.

Description of goats sampled

Colostrum samples were obtained from a total of 461 individual goats. Farm identification was known with certainty for 455 of the colostrum aliquots. Kidding identification was known with certainty for 454 goats. Table 4-1 shows the number (proportion) of goats from each kidding session sampled for each of the different measures.

The four different kidding sessions from which goats were sampled are described regarding the dates of the kidding session, total number of goats kidding and goat parity. The number (proportion) of goats sampled from each kidding session for colostrum variables and for goat variables are presented.

Table 4-1 **Description of goats sampled**

Parameter	**Kidding session**			
	1A	**1B**	**2**	**3**
Kidding dates	August 2018	March 2019	Jan/Feb 2019	May/June 2019
Total number of goats kidding this session	400	400	400	200
Parity	Both multi & primiparous	Primiparous only	Primiparous only	Primiparous only
Measure undertaken	**Number (percentage) of goats sampled from each kidding session**			
Brix	116 (29%)	102 (26%)	[1]177 (44%)	59 (30%)
Immunoglobulin	60 (15%)	73 (18.3%)	88 (22%)	45 (23%)
Fat, protein and lactose	108 (27%)	89 (22%)	92 (23%)	34 (17%)
Length of dry period	[2]58/65	NA	NA	NA
Gravidity (singles, twins or triplets)	[3]35 (9%)	79 (20%)	177 (44.3%)	40 (20%)
[4]Volume of first milking	NA	NA	141 (35%)	21 (11%)
[5]Body condition score	73 (18.3%)	68 (17%)	160 (40%)	NA

[1]A relatively high proportion (44%) of goats from kidding session 2 were sampled due to additional assistance from a stockperson skilled in measuring and collecting colostrum. The stockperson performed and recorded Brix measures for 35 samples, saving samples as described in the materials and methods section, meaning they could later be thawed and remeasured by the researcher.

[2]The length of the dry period was known for 58 of the 65 multiparous goats sampled from kidding session 1A, as seven animals could not be identified in the farm records. The proportion of multiparous goats comprising kidding session 1A was not known but presumed to be close to the sample proportion.

[3]Gravidity was known with certainty for only 35 (9%) goats from kidding session 1A, due to concerns over discrepancies between the farm recording system and direct observations. For subsequent kidding sessions gravidity was recorded by direct observation only.

[4]Goats from kidding session 2 were manually milked whilst those from kidding session 3 were machine milked.

[5]The body condition scoring is on a scale of one to five where score one is a thin goat and score five is an overweight goat.

4.1.4 Data handling and statistics

Goat measures were recorded using a combination of a digital Dictaphone (Olympus® digital voice recorder VN-711PC) and paper and entered into a Microsoft Excel spreadsheet. Analyses were performed using R Studio (RStudio Team (2021). rStudio: Integrated Development Environment for R. rStudio, PBC, Boston, MA URL http://www.rstudio.com/.), libraries tidyverse, boot, blandr and reportROC and IBM SPSS Statistics.

Bootstrapping techniques were used for calculating confidence intervals and for running hypothesis tests. Some 10,000 replicates with replacement were used. All confidence intervals are at the 95% threshold and denoted by square brackets after the relevant statistic. The significance level (alpha) for hypothesis tests was set at .05.

Descriptive statistics for colostrum measures for all goats sampled and for each kidding session are provided. One-way analysis of variance (ANOVA), combined with post hoc tests (Games Howell), was used to determine whether there were any statistically significant differences between the means of colostrum measures for the different kidding sessions.

Pearson product-moment correlation coefficients (*r*) were calculated as a measure of the strength and direction of association between pairs of colostrum variables, after first checking for the linearity of relationships by creating scatterplots.

Simple linear regression was run to describe the relationship between Brix values and each of the dependent variables of total solids, energy and immunoglobulin content, and to describe the relationship between protein and immunoglobulin content. The linearity of relationships was first assessed using scatterplots. Standardised residual plots were examined for homoscedasticity of residuals and regression analysis was performed for the data range of the independent variable where residuals were unbiased. Prediction intervals were calculated with 95% confidence.

An alternative analysis for predicting colostrum quality from Brix readings, where data were dichotomised, is also presented. A receiver operating characteristic (ROC)[297] curve was generated to identify the Brix value that most accurately identified a threshold colostral immunoglobulin content of 50 g/L, that is, provided the most true positives and least false positives. This threshold was derived by extrapolating from dairy cattle due to the scarcity of robust evidence for goats.[170] Values for sensitivity, specificity, predictive values, and likelihood ratios were calculated for diagnosing colostrum with IgG content of 50 g/L or greater, according to the threshold Brix value identified.

4.1.5 Results

Table 4-2 **Additional descriptors for the goats sampled where data on body condition scores, dry period lengths, and volumes of first milking were available.**

n=number of goats sampled, IQR = interquartile range

Variable	Kidding	n	Median	Mean	IQR	Range
[1]Body condition score	All goats	309	2.75	2.8	2.5 – 3	1.25 – 4
	1A	73	3	3	2.75 – 3.25	2.5 – 4
	1B	68	2.75	2.82	2.5 – 3	1.25 – 4
	2	160	2.75	2.67	2.5 – 3	1.5 – 4
[2]Dry period (days)	1A	58	32	33	28 – 39	13 – 71
Volume of first milking (ml)	2 (manual)	141	700	888.2	453.8 – 1187.5	60 – 5500
	3 (machine)	21	2000	2084	1131 – 3000	220 – 3900

[1] The body condition scoring is on a scale of one to five where score one is a thin goat and score five is an overweight goat.

[2]The dry period is the non-lactating, time period between kidding and the previous lactation

Gravidity was known for 460 goats; 242 (52.6%) goats gave birth to a single kid, 184 (40%) to twins, and 34 (7.4%) to triplets.

Total solids, fat, protein and lactose content of sampled colostrum

Table 4-3 **Summary statistics for the various colostrum measures in samples from 461 goats across the three farms**

n = number of colostrum samples, square brackets [ ] contain 95% confidence intervals for values, Q1 = first quartile, Q3 = third quartile, SD = standard deviation.

Variable	n	Median	Mean	Q1	Q3	SD	Range
Mean Brix (Brix %)	461	24.3 [24, 25]	23.9 [23.4, 24.5]	20 [18, 20]	27.7 [27, 28.1]	6.1 [5.7,6.5]	9 – 41
total solids (g/100g)	324	25.4 [24.6, 26.2]	24.7 [24.1, 25.3]	20.4 [19.2, 21.9]	29.2 [28.3, 29.7]	5.6 [5.2,6]	11.9 – 38
Fat (g/100g)	324	7.6 [7.4, 8]	8 [7.7, 8.3]	5.9 [5.5, 6.4]	10 [9.4, 10.4]	2.8 [2.6,3.1]	1.2 – 18.8
Protein (g/100g)	324	14.6 [13.9, 15.1]	13.8 [13.4, 14.3]	11.2 [10.3, 11.6]	16.8 [16.5, 17.1]	4.2 [3.8, 4.5]	3.1 – 23
Lactose (g/100g)	324	3.1 [2.9, 3.2]	3 [2.9, 3.1]	2.4 [2.1, 2.6]	3.6 [3.5, 3.7]	0.9 [0.8, 1]	0.1 – 5.1
IgG (g/L)	273	82.7 [77, 91.6]	81.9 [77.4, 86.4]	55.4 [47.7, 60.4]	107.3 [100.3, 111.2]	38.1 [35.1, 41.5]	1.4 – 203
Protein fraction that is IgG (%)	228	56.8 [54.2, 58.9]	55.1 [52.8, 57.3]	46.8 [40.8, 49.5]	65.7 [63.2, 68.7]	17.1 [15.5, 19]	4.5 – 92.4
Total solid fraction that is fat (%)	324	31.4 [30.5, 32.9]	31.9 [31.1, 32.6]	27.2 [26.2, 28.3]	36.6 [35.9,37.7]	7.1 [6.5,7.7]	8.8 – 55.9
Total solid fraction that is protein (%)	324	55.4 [54.5, 56]	54.9 [53.9, 55.9]	51.5 [50.3,52.1]	60.5 [59.5, 61.2]	9.2 [8.2,10.1]	19.6 – 80.1
Total solid fraction that is lactose (%)	324	12 [11.2, 12.7]	13.2 [12.5, 13.9]	9.1 [8.1,9.4]	17.1 [15.6, 18.3]	6.7 [6.1,7.2]	0.3 – 36.9
Protein:fat ratio	324	1.7 [1.7,1.8]	1.9 [1.8, 2]	1.4 [1.4, 1.5]	2.2 [2.1, 2.3]	0.8 [0.7, 1.0]	0.4 – 9.2
Energy (MJ/kg)	324	7 [6.7, 7.1]	6.8 [6.6, 7.0]	5.5 [5.1, 5.8]	8.1 [7.9, 8.3]	1.7 [1.6, 1.9]	3.1 – 11.7

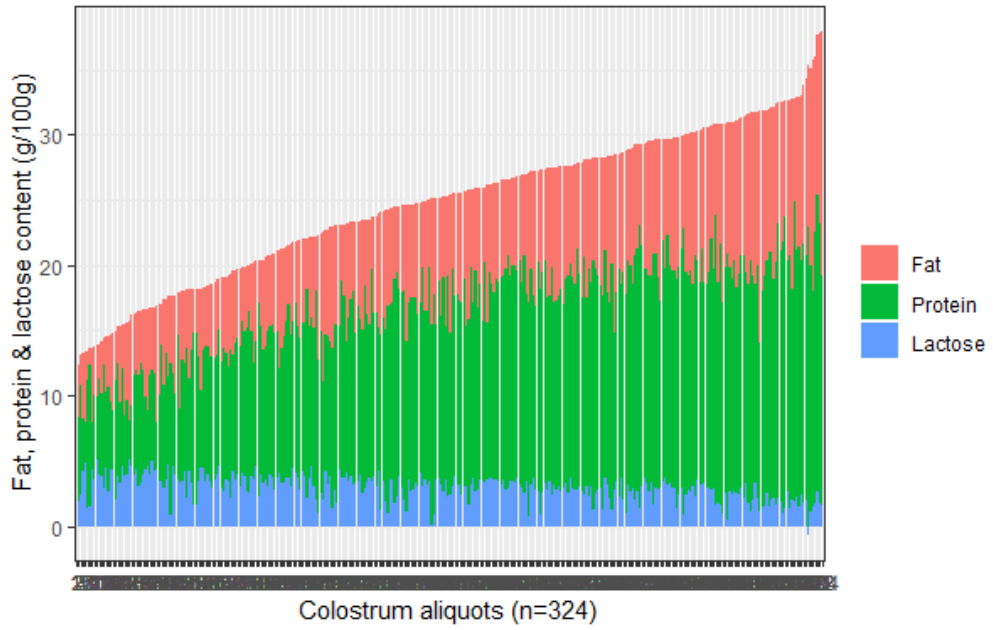

Figure 4-1 **Stacked bar plot illustrating the proportions of fat, protein, and lactose within individual colostrum samples.** The 324 aliquots on the x-axis have been ordered according to increasing total solid content.

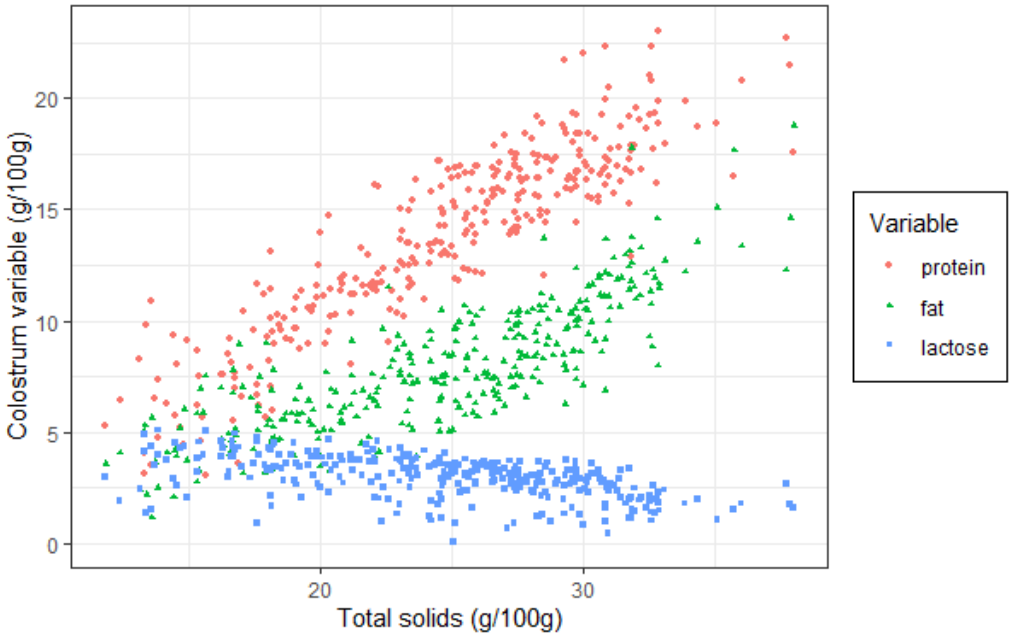

Figure 4-2 **Scatterplot illustrating the relationship between the total solid content of colostrum and each of the variables of protein, fat, and lactose (n=324).** There were significant, strong, positive linear associations between total solid content and protein content (*r*=0.901 [95% CI 0.880, 0.918], *P*<.001) and between total solid content and fat content (*r*=0.819 [95% CI 0.784, 0.852], *P*<.001). There was a moderate, negative, linear association between total solid content and lactose content (*r*=-0.512 [95% CI -0.600, -0.415], *P*<.001).

There was no significant relationship between total solid content and the protein; fat ratio (*r*=-0.109 [95% CI -0.240, 0.046], *P*=.05).

Relationship between protein content and immunoglobulin content

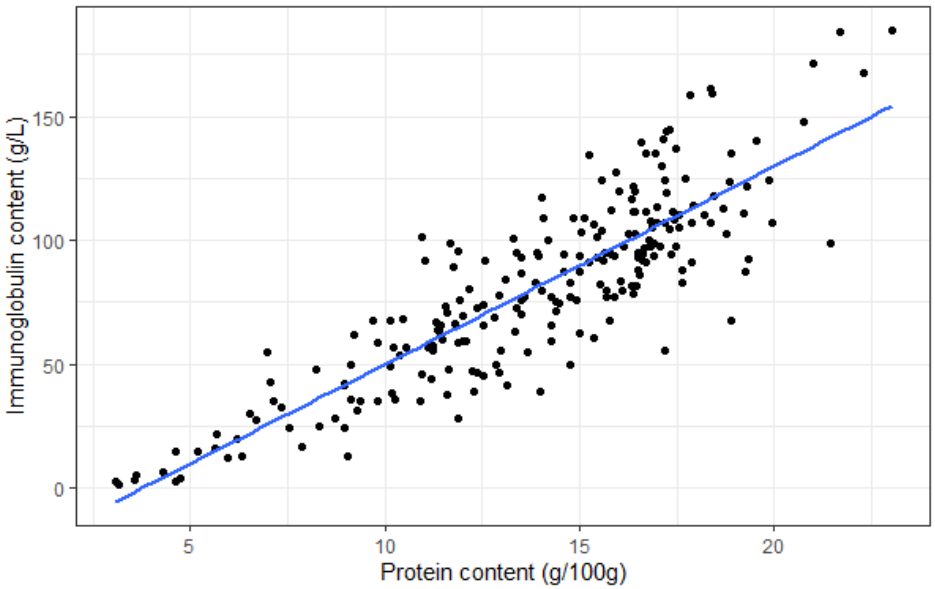

Figure 4-3 **Scatterplot showing the relationship between the protein and immunoglobulin content of colostrum (n=228).** The blue line superimposed is the regression line. There was a strong, positive, statistically significant, linear relationship between variables (*r*=0.866 [95% CI 0.823, 0.896], *P*<.001).

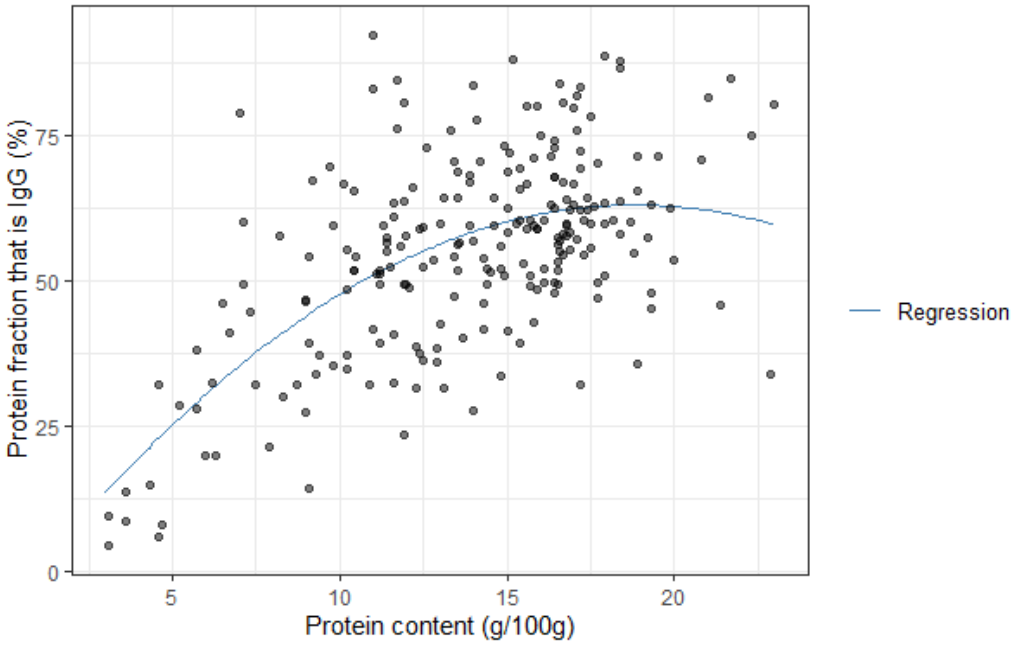

Figure 4-4 **Scatterplot showing the relationship between the protein content of colostrum and the protein fraction comprised of immunoglobulin (n=228).** The regression line is superimposed. Simple linear regression analysis showed there to be a significant curvilinear relationship between protein content and the protein fraction that was immunoglobulin (Adjusted R^2=0.378 P<.001). The regression equation was;

IgG fraction (%) = -6.847 + (7.427 x protein (g/100g)) + (-0.197 x protein^2) and summarises the relationship over the protein range of 3 g/100g – 23 g/100g. The wide dispersion of data points around this mean illustrates that colostrum of similar protein content can have very different immunoglobulin fractions.

Colostrum measures according to kidding session

Table 4-4 **Summary statistics for colostrum measures when goats are grouped according to the kidding session they are from**

n=number of goats sampled for the colostrum variable, square brackets [ ] contain 95% confidence intervals for values.

Variable	Kidding session	n	Mean	Median	Q1	Q3	Range
Brix (Brix %)	1A	116	22 [20.6, 23.5]	21 [18,23]	16 [13.9,17]	27.3 [25,29]	9 – 41
	1B	102	22 [21,23]	22 [20,22]	18 [16,19]	25 [22.7,25]	10 – 37
	2	177	26.4 [25.7,27]	26.1 [25.5,26.9]	24 [23.8,24.9]	29.3 [28,30.1]	21.1 – 39.7
	3	59	23.1 [21.7,24.4]	23 [21.3,24.1]	20.4 [18.6,21.3]	26 [24.2,28.9]	10.3 – 34.4
Total solids (g/100g)	1A	108	23.3 [22.1,24.5]	23 [20.4, 25.3]	17.9 [16.5, 19.3]	29.3 [27.2, 30.2]	11.9 – 36
	1B	89	23.9 [22.8,25]	24.2 [22.7, 25.6]	19.9 [18.2,22]	27.4 [25.9,28.4]	13.6 – 37.8
	2	92	27.2 [26.2, 28.1]	27.6 [26.6, 28.5]	24.6 [23.4, 25.8]	30.7 [29.6, 31.4]	13.4 – 38
	3	34	24.9 [23.4, 26.2]	25.9 [23.7, 27.4]	21.7 [19.3, 24.4]	27.9 [26.8, 29.3]	15.6 – 30.8
Fat (g/100g)	1A	108	7.5 [6,9.8]	7 [6.3,7.6]	5.3 [4.7,5.9]	9.7 [8.6,10.5]	2.1 – 17.8
	1B	89	7.6 [7,8.1]	7.5 [7,7.9]	5.6 [4.8,6.6]	9.1 [8.2,10.2]	1.2 – 14.6
	2	92	9.1 [8.5,9.7]	9 [8.4, 9.7]	6.8 [6.2,7.5]	10.8 [10.2,11.8]	2.2 – 18.8
	3	34	7.9 [7.3, 8.6]	7.7 [6.9,8.5]	6.2 [5.6,7.3]	9 [8.2,10.5]	4.5 – 11.9

Protein (g/100g)	1A	108	13.2 [12.3, 14.1]	13.1 [11.6,15.4]	9.2 [7.9,10.6]	16.8 [16.2,17.8]	3.1 – 23
	1B	89	13 [12.1, 13.8]	12.8 [11.8, 14.3]	10.5 [9.3,11.3]	15.9 [14.9, 16.9]	3.1 – 22.7
	2	92	15.3 [14.6, 15.9]	16.4 [15.7,16.6]	13.9 [12,15]	17.2 [16.8,17.9]	4.7 – 20
	3	27	13.7 [12.4,14.8]	14.1 [13.4,14.8]	11.7[9.9,13.5]	15.5 [14.5,17.1]	5.7 – 22.3
Lactose (g/100g)	1A	107	2.7 [2.5,2.9]	2.7 [2.5,3]	2 [1.6,2.2]	3.5 [3.1,3.6]	0.1 – 4.9
	1B	89	3.3 [3.2,3.5]	3.5 [3.2,3.6]	2.7 [2.5,3.1]	3.8 [3.7,4]	1.3 – 5.1
	2	92	2.8 [2.6,3]	2.8 [2.7,3]	2.1 [1.6,2.4]	3.4 [3.3,3.6]	0.7 – 5.1
	3	34	3.4 [3.2,3.6]	3.3 [3.1,3.6]	3.1 [3,3.2]	3.7 [3.5,4]	1.6 – 4.6
Energy (MJ/kg)	1A	108	6.4 [6.1,6.8]	6.5 [5.6,7.0]	4.8 [4.4,5.2]	8.2 [7.5,8.5]	3.1 – 10.4
	1B	89	6.5 [6.2, 6.9]	6.6 [6.1, 6.9]	5.1 [4.7,5.2]	7.5 [7.1,7.9]	3.3 – 11.0
	2	92	7.6 [7.3,7.9]	7.7 [7.2,7.8]	6.7 [6.3,7.1]	8.6 [8.2,9.1]	3.4 – 11.7
	3	34	6.8 [6.4,7.2]	7 [6.3,7.7]	5.7 [6.3,6.6]	7.8 [7.2,8.2]	4.2 – 8.8
IgG (g/L)	1A	60	79.4 [67.8,92.1]	75.1 [56.7,94.3]	37.4 [27.6,55.1]	113.1 [97.9,126.3]	1.4 – 184.9
	1B	73	72.7 [63.9,80.9]	69.6 [57.4,82.2]	49.5 [34.7,56.5]	98.6 [86.6, 112]	2.8 – 144.6
	2	88	87.8 [81.8,93.7]	92.6 [81.7,94.5]	70.1 [59.6, 78.2]	105.4 [97.7, 110]	3.9 – 161.5
	3	45	83.5 [72.9,94]	82.8 [72.5,94.8]	63.2 [44.3,74.6]	107.3 [94.1,124.5]	12.3 – 157.9
Protein fraction that is IgG (%)	1A	57	54.1 [48.7,59.3]	55.6 [43.3,63.2]	36.4 [32.3,41.3]	70.4 [60.3,70.9]	4.5 – 88.9
	1B	60	51.9 [46.5,56.5]	54.8 [49.4,59.8]	41 [31.8,48.9]	65.7 [60.3,70.9]	6.1 – 88.1
	2	81	55.7 [52.9,58.3]	56.3 [52.1,58.1]	49.6 [47.3,52]	60.4 [58.7,62]	8.2 – 92.4
	3	30	61.9 [56.9,66.7]	62.2 [56.5,67.1]	54.7 [45.3,60]	71 [64.4,79.6]	28 – 84.6

Table 4-5 **Statistically significant differences in colostrum variables when comparing the four kidding sessions.**

Results are for one-way analysis of variance (ANOVA) with Games Howell post hoc tests. Square brackets [ ] contain 95% confidence intervals for values.

Variable	***P***	**Kidding sessions where mean values differed**	**Mean difference in values**
Brix value (Brix %)	<.001	2>1A	4.2 [1.4, 7.1]
		2>1B	5 [2.7, 7.3]
		2>3	4.1 [1.3, 6.8]
Fat content (g/100g)	<.001	2>1A	1.7 [0.5, 3]
		2>1B	1.7 [0.5, 2.9]
		2>3	1.4 [0.1,2.6]
Protein content g/100g)	<.001	2>1A	2 [0.1, 3.9]
		2>1B	3 [1.3,4.6]
		2>3	2 [1.4,3.9]
Lactose (g/100g)	<.001	3>1A	0.8 [0.4, 1.1]
		3>2	0.6 [0.3, 1]
		1B>1A	0.7 [0.3, 1]
		1B>2	0.5 [0.2, 0.9]
Total solids (g/100g)	<.001	2>1A	3.8 [1.4,6.3]
		2>1B	4.1 [2, 6.1]
		2>3	2.7 [0.3, 5.1]
Energy (MJ/kg)	<.001	2>1A	1.2 [0.4, 1.9]
		2>1B	1.3 [0.6, 1.9]
		2>3	0.9 [0.2, 1.6]

Kidding session 2 had significantly higher mean values for total solids, fat, protein, energy content, and Brix values than kidding sessions 1A, 1B and 3. Both kidding sessions 3 and 1B had significantly higher lactose values than kidding sessions 2 and 1A, but sessions 3 and 1B did not differ significantly.

There were no significant differences in means when comparing immunoglobulin content and the protein fraction that was immunoglobulin. There were no significant differences in means when comparing the proportions of total solids that were fat or protein or the protein; fat ratio.

Simple linear regression with Brix as the independent variable and total solids, energy, and immunoglobulin as the outcome variables

Three linear regressions were run to understand how well Brix values predict the total solids, energy, and immunoglobulin content respectively. Relationships are illustrated by scatterplots (Figures 4-5, 4-6 and 4-7). Numeric values for prediction intervals for each outcome variable are provided in Table 4-6, for quick reference for practical usage.

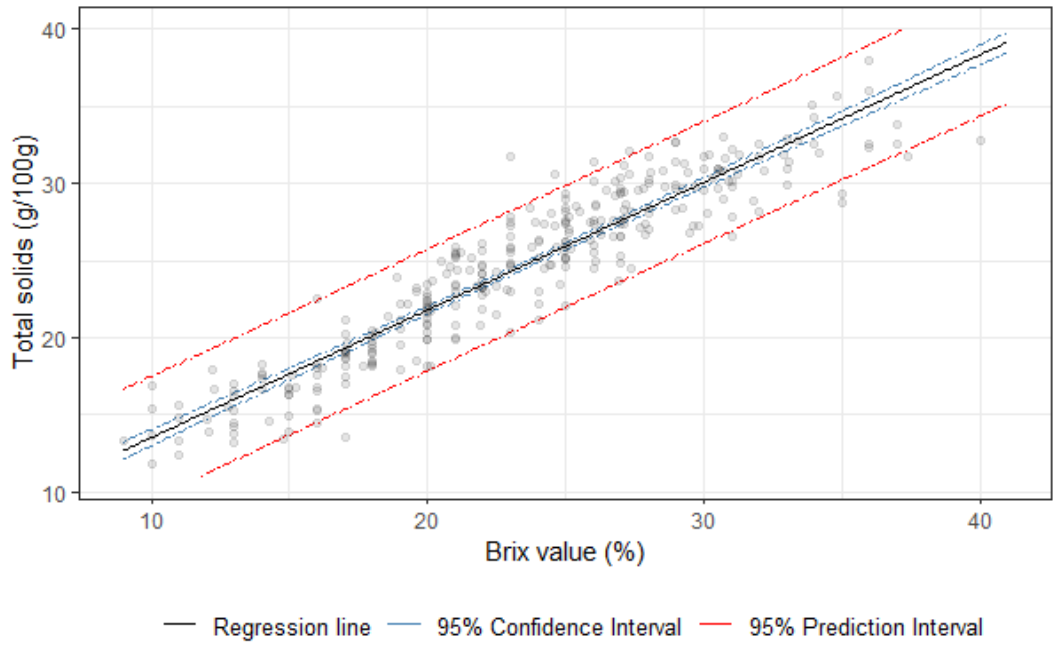

Figure 4-5 **Scatterplot illustrating the relationship between the Brix value and the total solid content of colostrum (n=313).** Following the examination of standardised residual plots, linear regression analysis could be confidently applied over the full range of Brix values of 9% – 41%. Brix value significantly (*P*<.001) predicted total solids, accounting for 86% of the variation in total solids (adjusted R^2=0.86). The regression equation was; total solids (g/100g) = 5.351 + (Brix (%) x 0.821). An extra 1% Brix led to a 0.821 [95% CI 0.786, 0.856] g/L increase in mean total solids. The standard error of the residuals was 1.97 g/100g.

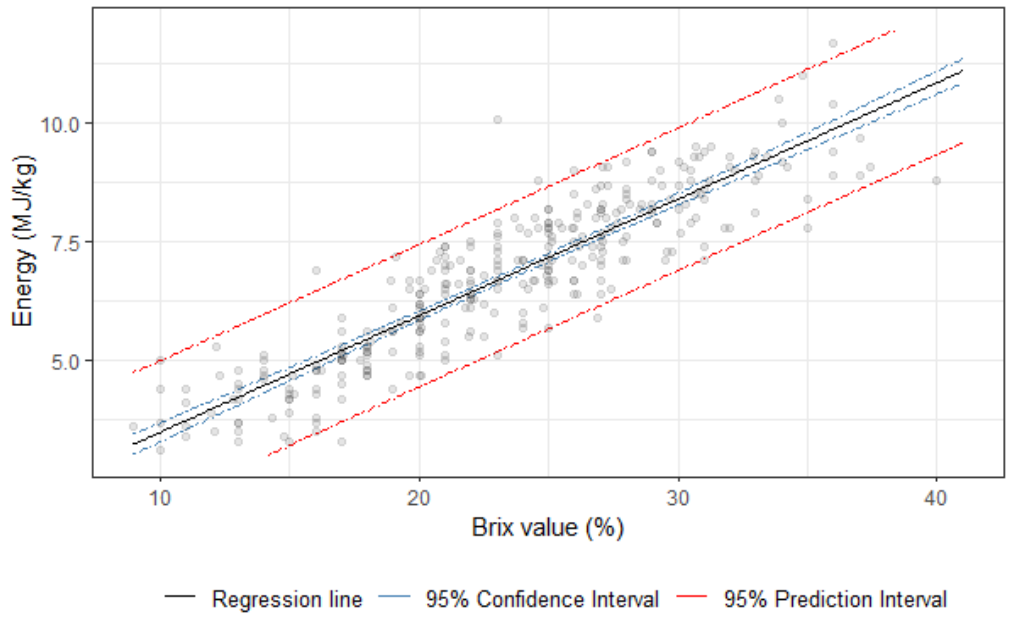

Figure 4-6 **Scatterplot illustrating the relationship between the Brix value and the energy content of goat colostrum (n=313).** Following examination of standardised residual plots, linear regression analysis could be confidently applied over the full range of Brix values of 9% – 41%. Brix value significantly (*P*<.001) predicted energy content accounting for 81.3% of the variation in energy (adjusted R^2=0.813). The regression equation was; energy (MJ/kg) = 1.039 + (Brix (%) x 0.245). An extra 1% Brix led to a 0.245 [95% CI 0.232, 0.248] MJ/kg increase in mean energy. The standard error of the residuals was 0.736 MJ/kg.

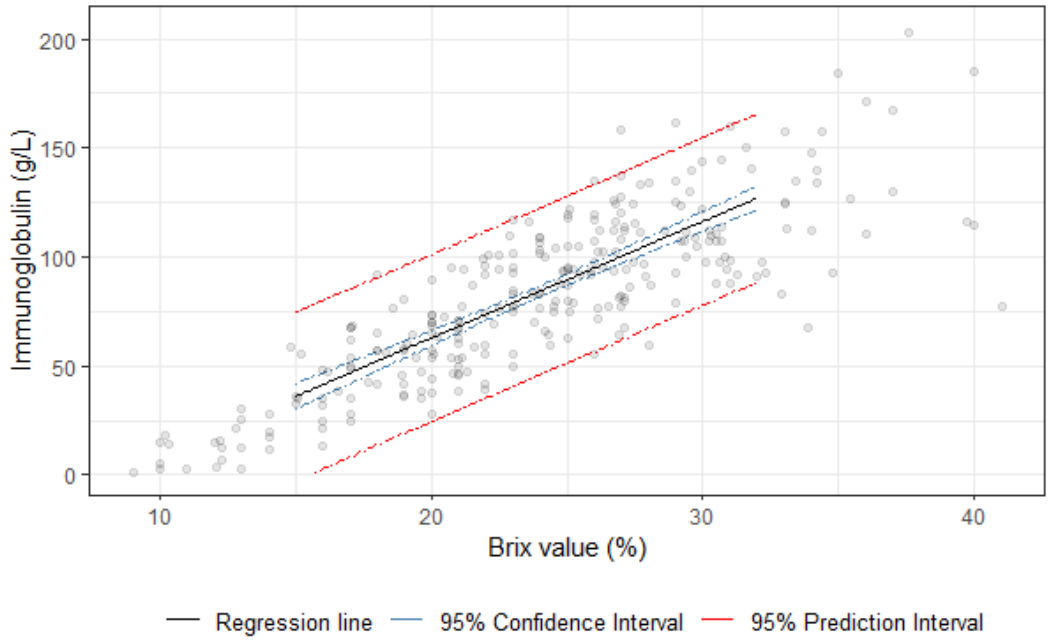

Figure 4-7 **Scatterplot illustrating the relationship between the Brix value and the IgG content of colostrum (n=272).** Following examination of standardised residual plots, linear regression analysis could be confidently applied only over the range of Brix values of 15% – 32%. Brix value significantly (*P*<.001) predicted immunoglobulin content, accounting for 58% of the variation in immunoglobulin (adjusted R^2=0.58). The regression equation was; IgG (g/L) = -44.3 + (Brix (%) x 5.34). An extra 1% Brix led to a 5.34 [95% CI 4.76, 5.95] g/L increase in IgG content. The standard error of the residuals was 19.3 g/L.

Table 4-6 **Numerical values for the 95% prediction intervals for the IgG, energy and total solid content of colostrum with a Brix value range of 15% to 32%**

The table was created to allow values to be quickly identified for field usage. Values are derived from Figures 4-5, 4-6 and 4-7. Values for IgG are rounded to the nearest whole number. Values for total solids and energy are rounded to one decimal place.

Brix value (Brix %)	**95% Prediction Interval**		
	IgG (g/L)	**Total solids (g/100g)**	**Energy (MJ/kg)**
15	0 – 75	13.8 –21.6	3.3 – 6.2
16	3 – 80	14.6 – 22.4	3.5 – 6.4
17	8 – 85	15.4 – 23.2	3.7 – 6.7
18	14 – 90	16.2 – 24.0	4.0 – 6.9
19	19 – 96	17.1 – 24.8	4.2 – 7.1
20	25 – 101	17.9 – 25.7	4.5 – 7.4
21	30 – 106	18.7 – 26.5	4.7 – 7.7
22	35 – 112	19.7 – 27.5	5.0 – 7.9
23	41 – 117	20.4 – 28.1	5.2 – 8.1
24	46 – 122	21.2 – 28.9	5.5 – 8.4
25	51 – 128	22.0 – 29.8	5.7 – 8.6
26	57 – 133	22.8 – 30.6	5.9 – 8.9
27	62 – 139	23.6 – 31.4	6.2 – 9.1
28	67 – 144	24.5 – 32.2	6.4 – 9.3
29	73 – 149	25.3 – 33.1	6.7 – 9.6
30	78 – 155	26.0 – 33.9	6.9 – 9.8
31	83 – 160	26.9 – 34.7	7.2 – 10.1
32	89 – 166	27.7 – 35.5	7.4 – 10.5

Alternative analysis for Brix readings as a predictor of colostrum quality

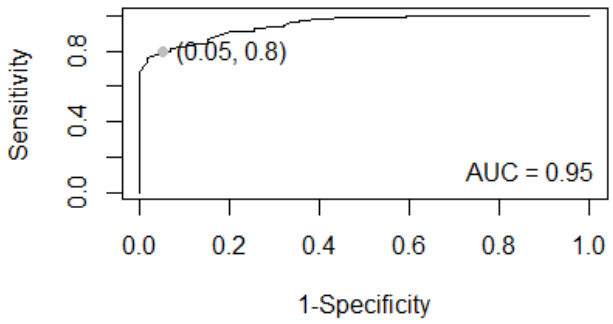

Figure 4-8 **Receiver operating characteristic (ROC) curve constructed for diagnostic test evaluation.** The false positive rate (1 - specificity) was plotted on the x-axis and the true positive rate (sensitivity) on the y-axis (n=272).[297] The threshold for good quality colostrum was set at an IgG content of ≥ 50 g/L, and the threshold for poor quality at an IgG content <50 g/L IgG. The ROC curve identified a 21.4% Brix value as the optimal test value (most true positives, least false positives) for distinguishing between good and poor-quality colostrum, located at a sensitivity value of 0.8 and 1 - specificity value of 0.05. The area under the ROC curve (AUC) was 0.95 [95% CI 0.927, 0.974], *P*<.001.

Table 4-7 **Values for sensitivity, specificity, positive and negative predictive values and likelihood ratios when a Brix value of 21.4% is used as the diagnostic threshold for identifying colostrum with IgG content of 50 g/L or greater (n=272).**

Square brackets [ ] contain 95% confidence intervals for values.

Statistic	**Definition in the context of the study**	**Value**
Sensitivity (%)	The proportion of colostrum aliquots with IgG content < 50 g/L that have a Brix reading of < 21.4%.	79.8 [74.4, 85.2]
Specificity (%)	The proportion of colostrum aliquots with IgG ≥ 50 g/L that give a Brix reading of ≥ 21.4%.	94.9 [89.3, 100]
Positive likelihood ratio (+LR)	The likelihood that a Brix reading of < 21.4% would be expected in a colostrum sample with IgG content < 50 g/L compared to the likelihood of this Brix reading for a colostrum sample with IgG content ≥ 50 g/L.	15.7 [5.2, 47.4]
Negative likelihood ratio (-LR)	The likelihood of a Brix value ≥ 21.4% when the colostrum IgG is < 50 g/L compared to the probability of this Brix reading for a colostrum sample with IgG content ≥ 50 g/L.	0.213 [0.162, 0.28]
[1]Positive predictive value (PPV) (%)	The probability that a colostrum sample measuring < 21.4% Brix has an IgG content < 50 g/L.	98.3 [96.3, 100]
[1]Negative predictive value (NPV) (%)	The probability that a colostrum sample with a Brix reading of ≥ 21.4% has an IgG content ≥ 50 g/L.	56.6 [46.8, 66.3]

[1]The predictive values apply to the sample prevalence of 59 out of 213 goats (27.7%) producing colostrum with immunoglobulin content < 50 g/L.

4.1.6 Discussion

The main findings were as follows. Values for colostrum measures varied considerably amongst goats and this level of variability persisted when goats were grouped by kidding session. Colostrum samples of similar total solid content comprised differing proportions of fat, protein, and lactose and, therefore, differing energy content. Colostrum samples of similar protein content had very variable immunoglobulin content. Linear regression analyses established that Brix measures could significantly predict total solids, energy, and immunoglobulin content. The alternative ROC identified 21.4% as the Brix value most accurate for identifying colostrum as good or poor quality according to an IgG threshold value of 50 g/L. However, wide confidence intervals for the predictive values and likelihood ratios limit the usefulness of this approach.

Variation in colostrum measures amongst goats

The large variation in the nutritional and immunoglobulin content of colostrum amongst goats is interesting, as is the persistence of this variation when goats were grouped according to kidding session.

Many of the goats sampled in our study shared similar qualities; they were of the similarly young age of one to two years, similar breed, and mostly in good physical body condition. In other ways they were quite different being from three different farms and four different kidding sessions that took place at differing times of the year, exposing them to a range of different factors related to husbandry, feeding, breeding, and the environment. It is likely that a combination of these factors affects colostrum quality, though this has been little studied in goats. The small number of studies considering parity,[175,180,190,200] breed,[180,205] and age[170] are likely unpowered given the large variability in colostrum measures amongst goats evident from our study. Where studies are underpowered there is an increased risk they will fail to detect an effect present in the population. Where the effect is correctly detected then the size of the effect will be exaggerated.[298]

It is logical that the length of the dry, or non-lactating, period before parturition would impact colostrum quality, as for dairy cattle,[160] and this would be relevant for the 65 multiparous goats from kidding session 1A. This has been little studied in goats. Caja et al. (2006)[174] found that goats that had a dry period of 27 days (n=5) and 56 days (n=9) had similar colostrum quality whereas goats that omitted the dry period (n=3) had greatly reduced colostrum quality, but only 17 goats were sampled during this study. It is also interesting that some primiparous goats (n=3) produced colostrum of very low total solid content (13.2%, 13.4%, and 13.8%), only a little higher than that of milk, despite never

having lactated. The cause was not known but again, reasons are likely multifactorial including genetics, environment, general husbandry, vaccination schedules, and responses to vaccines.

In this study, descriptive statistics for goats categorised by parity and gravidity and for statistical tests comparing means of groups gave very wide confidence intervals (Appendix B). A scatterplot of dry period length against the Brix value of colostrum showed a weak relationship (Appendix B). Much larger sample sizes than those used in our study will be needed to undertake reliable generalized linear model (GLM) analyses for assessing the impact of different factors on colostrum quality.

Fat, protein, and lactose

Several studies have measured the fat, protein, and lactose content of goat colostrum. However, on summarising the findings (Table 2-1, Chapter 2) there is little with which to compare our results, largely due to the different purposes and methodology of these studies, the relatively small sample sizes and data often presented as mean values only. Kessler et al. (2019, 2021)[180,181] studied 116 commercially farmed goats of 10 different breeds from 28 different farms, finding not dissimilar mean and standard deviation values for protein and fat content. Forty-seven of these goats (18 Saanen, 21 Toggenburg, eight Anglo Nubian) are breeds commonly found on UK farms.[228]

Other studies do not appear to have investigated the proportions of fat, protein, and lactose within samples. As colostrum samples of similar total solids contain differing proportions of fat, protein, and lactose, they will provide different amounts of energy. The nutritional and energy content of colostrum has received little research attention in other species, even dairy cattle, despite the importance of good nutrition and high energy intakes for neonates.[164,290]

Goats from kidding session 2, farm 2, had significantly higher mean values for total solids, fat, and protein than goats from kidding sessions on the other two farms (Table 4-5). However, wide confidence intervals mean the practical importance of this difference cannot be determined. It is interesting that the milk from farm 2 was produced with the sole purpose of producing cheese whereas farms 1 and 3 mainly supplied the liquid milk market. Feeding as well as genetics plays an important role in determining the composition of milk from dairy goats.[299] Further research is needed to establish the extent to which these factors affect colostrum composition.

Immunoglobulin

Throughout this paper the term immunoglobulin refers to subclass IgG, as this is the main immunoglobulin in ruminant colostrum, comprising between 85% and 90% of the total immunoglobulin in cattle[160] and goat[183] colostrum. IgG is usually the reference value when discussing immunoglobulin content[300] as it is a good indicator of other immunoglobulins.

Many studies of goat colostrum have measured immunoglobulin content using enzyme-linked immunoassay (ELISA) tests[180–186] rather than the 'gold standard' method of radial immunodiffusion (RID).[170–173,178] However, there has been little investigation of the agreement between RID and ELISA measures of colostral immunoglobulin. Where studied, the agreement was poor[170] (Appendix D), making this an area of urgent research attention. Results from the two methods should not be compared,[170] which further limits the evidence base available for comparison with our results.

Zobel et al. (2020)[170] provided the most useful data for comparison, having studied 300 goats of Saanen and Saanen cross breeds over two kidding sessions on two large commercial farms in New Zealand, measuring the immunoglobulin content using RID and the same laboratory as in our study.

Zobel et al. (2020)[170] found a lower mean immunoglobulin content than in our study (63.4 g/L compared to 82.7 [95% CI 77, 91.6] g/L) but a similar amount of dispersion (standard deviation of 35.4 g/L and range 1.8 g/L – 186.1 g/L, compared to a standard deviation of 38.1 [95% CI 35.1,41.5] g/L and range of 1.4 g/L – 203 g/L in our study). Zobel et al. (2020)[170] hypothesised that the large variation in immunoglobulin content amongst goats, even those with colostrum of very similar Brix values, may in part be due to the sampling strategy, such as samples being collected at differing times within a 24-hour period postpartum, and goat kids sometimes having suckled their mothers prior to collection. However, in our study all samples from goats within kidding sessions 1A and 1B were collected within 20 minutes postpartum and before the kids suckled. Therefore, the large variability occurs irrespective of these factors and is likely due to individual goat differences, as well as goats within large groups receiving slightly different management and access to resources, despite husbandry appearing consistent at the group level.[134,135,278,301,302]

Yang et al. (2009)[178] also measured immunoglobulin using RID, reporting a mean value of 72 g/L with very little dispersion (SD 4.13 g/L) but only ten goats were sampled. Also, all animals were from a research facility where more standardised breeding and management, age, and parity could have produced less variability.

Relationship between protein and immunoglobulin content

Immunoglobulin is a type of protein. The relationship between protein and immunoglobulin content has been little studied, even in dairy cattle. As expected, there was a strong positive correlation between protein content and the IgG content, similar to that found by Quigley et al. (2002)[164] in a study of 146 Jersey cows (r=0.71) and Argüello et al. (2006)[175] in a study of 60 Majorera dairy goats (r=0.695). Colostrum samples of quite similar protein content had a quite variable immunoglobulin

content. The reasons are likely multifactorial including genetics, environment, general husbandry, vaccination schedules, and responses to vaccines, and warrant further investigation.

Whilst the calculated immunoglobulin fractions are slightly overestimated, the figures will be close enough to the true value to be informative. There is little evidence base for comparison, even in dairy cattle. Quigley et al. (2002)[164] reported the immunoglobulin fraction of protein in colostrum from Jersey heifers in units of milligrammes of immunoglobulin divided by grammes of protein, finding a range of 223 mg/g – 869 mg/g, a mean value of 488 mg/g and standard deviation of 111 mg/g. These values translate into a mean of 48.8% of the protein fraction being IgG and a standard deviation of 11.1%, which are smaller than our values for goats.

Relationship between Brix values and nutritional content

Given that Brix refractometers are designed specifically for measuring the total solid content of liquids, it is interesting that the R-squared value (R^2=0.86) describing the relationship between Brix values and total solids (Figure 4-5) was not higher. It is also interesting that the Brix value of samples was not consistently higher than the corresponding total solids value, as in reality, colostrum contains 0.7% – 1.8% of additional solid content, or ash,[178,192] which has been excluded from the calculation of total solids. This could largely be due to colostrum refracting light less consistently than the sucrose solutions against which refractometers are calibrated, making Brix values a less accurate estimate of the total solid content of colostrum than of sucrose solutions. Sucrose molecules readily dissolve and evenly disperse when mixed in water whereas colostrum contains many different types of solids; water-soluble proteins such as immunoglobulins, poorly water-soluble caseins, insoluble substances such as lipids that are suspended, and numerous cells.

A one-unit change in the Brix value explained only 76% of the change in energy content (Figure 4-6), despite the value for energy being calculated directly from the total solids content. This lower R-squared value can only be due to the differing proportions of fat, protein, and lactose within samples of similar total solids content, with fat being approximately twice as energy dense as protein. The energy content of colostrum has received little research attention despite high energy intakes being vital for thermoregulation in neonates.[160,290] From the regression equation (Figure 4-6), the mean energy content of 31% Brix colostrum is 35% greater than that of 22% Brix colostrum and it is 83% greater than that of 15% Brix colostrum. Kids consuming similar quantities of such differing colostrum will receive very different amounts of energy. The relationship between Brix measures, total solid content, and energy content of colostrum does not appear to have been studied elsewhere. It must be noted that predicted energy values are based on figures of ME derived from calf nutrition, derived from the National Research Council nutrition guidelines[295] due to a lack of goat

specific evidence. These figures are useful as broad approximations of the energy available to kids from colostrum. However, there is likely to be some difference in ME values amongst species. Research into goat kids is needed.

Zobel et al. (2020)[170] and Kessler et al. (2019, 2021)[180,181] reported Brix values, and these can be considered a reasonable guide to the total solids and energy content. The values reported by Zobel et al. (2020)[170] (mean Brix value of 20% and standard deviation of 4.3%) and Kessler et al. (2021)[181] (mean Brix value of 21.6% and standard deviation of 5.3%), are not vastly different to those found in the goats in our study (mean Brix value of 24.5% and standard deviation of 6.1%).

Relationship between Brix values and immunoglobulin content

Whilst linear regression analysis of the relationship between Brix value and IgG content could only be confidently applied over a Brix range of 15% to 32% (Figure 4-7), this more limited range is still practically useful. The loss of homoscedasticity of residuals outside this Brix range might be due to less data being available here or there may be a real deviation from a linear relationship.

It is unsurprising that a one-unit change in Brix value explained only 58% of the change in immunoglobulin content as the immunoglobulin fraction of the protein content (Figure 4-3), and therefore of the total solids content, was highly variable (Figure 4-5). Values are not dissimilar to those found by Zobel et al. (2020)[170] who reported an R-squared value of between 0.51 and 0.57 depending on whether optical or digital refractometers were used and whether colostrum was fresh or thawed.

Knowledge of prediction intervals is useful when selecting colostrum to feed to kids (Figures 4-5, 4-6, 4-7 and Table 4-6). For example, colostrum of Brix value 17.4% would contain a mean immunoglobulin content of 50 g/L according to the regression equation but the prediction interval would be between approximately 9 g/L and 90 g/L. Colostrum of Brix value 25% or greater would be required for 95% certainty of immunoglobulin content over 50 g/L.

Alternative analysis when using Brix as a predictor of colostrum quality

Other studies have analysed the relationship between Brix refractometer values and immunoglobulin content by dichotomising data, according to a threshold value of immunoglobulin above which colostrum is considered good quality and below which it is regarded as poor quality.[170,291,303–307] The most common threshold value in dairy cattle is 50 g/L,[170,291,303–307] derived from studies of passive transfer of immunity in dairy calves when fed colostrum of differing immunoglobulin content.[160] In dairy cattle, colostrum of Brix value between 20% and 22% or greater is usually considered good quality.[227,308] Similar studies of passive transfer are lacking in goats.[170]

Finding a single value above which colostrum should be retained for use is appealing as it is straightforward for use in the field. In our study, the ROC curve identified 21.4% Brix as the optimal value for correctly identifying colostrum as good or poor quality according to a 50 g/L threshold immunoglobulin content, which is slightly higher than the value of 19% found by Zobel et al. (2020).[170] However, this approach to analysis also has limitations.

Firstly, this approach reduces the statistical power of analyses. When continuous data are dichotomised there is a major loss of statistical power[309] meaning that much larger sample sizes are needed for reliable results compared to continuous data, especially given the high variability in immunoglobulin content of different colostrum of similar Brix values. This is often overlooked and values for sensitivity, specificity, and positive and negative predictive values are provided without confidence intervals.

Secondly, there are limitations beyond statistical power. In an ideal world, values for both sensitivity and specificity would be very high. In the real world, there is usually a 'trade-off' with one value increasing as the corresponding value decreases. This is reflected in a similar 'trade-off' between positive and negative predictive values. Our high positive predictive value of 98.3 [95% CI 96.3, 100]% gives good assurances that most colostrum assigned to the poor-quality category is actually poor quality. However, the low negative predictive value (56.6 [95% CI 46.8, 66.3]%) would result in a considerable proportion of colostrum wrongly classified as being of high quality.

In addition, predictive values vary with prevalence, only applying to populations with the same prevalence, as in the research study population. In our study, 27% of goats produced low quality colostrum, but in the field the prevalence may not be known.[310,311]

Lastly, dichotomising data leads to much loss of detail around an arbitrary 'cut-off' point. For example, a colostrum sample of 48 g/L immunoglobulin content would be considered inadequate quality alongside one that measures 30 g/L but the former would be much more beneficial for the goat kid and could be fed if there was a shortage of higher quality colostrum.

Retaining data in a continuous format and providing prediction intervals (Table 4-6), allows the range of possible immunoglobulin values to be quickly identified and allows for a more nuanced approach.

The use of this evidence base could depend on the logistics of the individual farm, their aims, and the level of certainty required. For some farms, a simple 'keep' or 'discard' decision based on a single Brix measure of colostrum, such as the 21.4% value derived from the ROC curve, might be appropriate. Examples are where colostrum is saved for emergency situations, where a farm has a high prevalence of poor-quality colostrum, or where stockpersons are new to, and adjusting, to the

use of the refractometer. For other farms, a more nuanced approach may be possible and desirable. Removing kids from their mothers at birth and artificially feeding them colostrum has become routine practice on a number of UK farms.[228] Here all colostrum collected could be measured and split into 300 ml aliquots for pasteurisation and storage with the Brix value written in marker pen on the bag. Aliquots can be stored on a shelf in the fridge or freezer in order of increasing quality, so the highest quality colostrum can be readily located. Stockpersons could aim to feed over 25% Brix value colostrum to all kids, dropping down to between 23% and 25% if this is in short supply but there should be an aim to never drop below 22%. If there is a need to go below 22% then colostrum as close to this value as possible should be used and larger, more frequent quantities fed to try and offset the impact of poorer quality.

Sampling of goats

Convenience sampling was used, both when selecting farms and goats, and will have introduced biases related to goat parity, age, and breed. Inferences will be relevant mainly for primiparous goats, as only kidding session 1A comprised multiparous goats. The youngest primiparous goats were estimated to be approximately one year age and the oldest between 18 months and two years of age, according to farm records and farmer knowledge.

All goats sampled were of the breed Saanen or Saanen crosses, which is the predominant breed used in UK dairy goat farming.[228] The results may not accurately represent other breeds less commonly farmed, such as Anglo Nubians.[228]

Goats were observed mostly in good physical body condition. Some 309 goats were individually scored by palpation and approximately 50% of these were close to the ideal recommended range for parturition of between 2.75 and 3 scores (IQR 2.5 – 3). There were no extremely fat goats (BCS > 4), though some were heavier than desirable. Nine goats were particularly thin (BCS < 2).

Regarding sample size, as many goats as possible were sampled whilst maintaining the quality of data collected.

Sampling took place over between one and three weeks of a kidding session rather than throughout the full duration. It is possible that the colostrum quality from goats kidding outside these time periods could differ due to differing times of vaccination in relation to kidding and differing dry period nutrition, and this warrants further investigation. On farms 1 and 2, colostrum samples were collected from the first 500 ml volume of the first milking and on farm 3, from the first full milking. The extent to which values for the first full milking differ from those of the first 300 ml to 500 ml is not known.

All samples were handled and stored in a consistent manner. Each individual goat sample was split into multiple aliquots so that all tests could be performed after a single thawing, avoiding repeat freeze-thaw cycles that could damage immunoglobulin[173] and potentially alter other constituents. One area of variation was the duration that samples were stored frozen prior to analysis. Samples were stored frozen for between two and nine months prior to export for radial immunodiffusion analysis. Current evidence indicates that colostrum samples can be stored for extended periods of time at minus 20°C without damage to immunoglobulins[173] and these differences in time periods should have minimal effects. However, evidence is sparse and further investigation is warranted.

4.1.7 Conclusion

This study has provided initial valuable information on the nutritional and immunoglobulin content of colostrum from dairy goats commercially farmed in the UK. However, it only concerns three farms and four kidding sessions with their associated biases and further studies of more farms and goats are needed. The Brix refractometer is a useful tool for assessing colostrum quality in goats and guidance is provided as to how this might be used in practice.

5 Chapter 5

5.1 Repeatability of Brix refractometer measures of goat colostrum

5.1.1 Abstract

Brix refractometers have been used to assess the quality of colostrum in a range of species. They use the principle of refraction to estimate the total solid content of liquids. However, colostrum can be considered a novel substance, structurally quite different from the sucrose solutions against which refractometers are calibrated. Therefore, this study quantifies agreement between repeat Brix measures of colostrum. The primary reason for the study was to inform the methodology of a goat colostrum quality study but comment is also made about implications for routine Brix measurements of colostrum on farms. Colostrum samples were collected from 107 dairy goats on a commercial dairy goat farm. Repeat Brix measures of samples were performed under controlled laboratory and farm conditions and using an optical and a digital Brix refractometer. Agreement between repeat measures of colostrum samples was evaluated using Bland Altman plots, establishing the lower and upper limits of agreements, denoted as LLA and ULA respectively. The greatest agreement was between paired optical measures (LLA -0.56, ULA 0.62 Brix %) and paired digital measures (LLA -0.75, ULA 0.61 Brix %) performed under controlled laboratory conditions. Agreement lessened slightly when comparing optical and digital measures (LLA -1.09, ULA 0.82 Brix %), and further still when optical and digital measures were performed under farm conditions (LLA -1.62, ULA 1.19 Brix %). The least agreement was found when comparing measures performed on fresh colostrum on the farm with those on thawed colostrum at a subsequent date (LLA -2.37, ULA 1.99 Brix % for digital measures, and LLA -2.05, ULA 1.46 Brix % for optical measures).

5.1.2 Introduction

Ideal methods of measurement are valid, accurate, and repeatable (reliable); they measure the variable they are supposed to measure, they give the true value of that variable, and repeat measures of the same subject give the same result.[230,312] In real life, methods of measurement rarely achieve such high standards as there is often natural variation in the subject, variation in measurement processes, or both.[313] Measurement error has been defined as the difference between the 'true' value and the measured value of a variable.[312] It can rarely be eliminated but it can be minimised by good practice in sample handling and measurement technique, and by choosing the measurement method considered most accurate. Knowledge of the size of measurement error is important for informing research methodology and improving inferences made from results.[312] Often the 'true' value of a variable cannot be known, making evaluations of accuracy difficult. Here evaluating the repeatability of measures can be[312] helpful because, whilst good repeatability does not guarantee good accuracy, poor repeatability does indicate poor accuracy.[312]

This study evaluates the repeatability of Brix refractometer measures of goat colostrum, with the primary purpose of using the results to inform the methodology of subsequent goat colostrum quality studies. Comment is also made about the implications of findings for routine Brix measurements on farms. Brix refractometers were developed as a low-cost tool for rapidly estimating the sugar content of liquids, primarily for use in the food industry. They work by measuring the change in direction of light when it passes between substances of different densities[257] and are calibrated to accurately measure the content of sucrose in pure water, with one Brix percent (Brix %) equal to 1 gramme of sucrose in 100 grammes of solution following an approximately linear relationship. Both optical and digital instruments are available. Brix refractometers have now been used to measure colostrum in a range of species, including cattle,[291,305–307,314–318] equines,[264] pigs,[265–267] sheep,[268] dogs,[319] and goats.[170,181] They are practical on farm because they are handheld and portable, low-cost, easy to use, require only two to three drops of colostrum per reading, and no additional reagents. Many instruments have an automatic temperature control (ATC) function that prevents the environmental temperature from confounding results.

However, it is possible that repeat Brix refractometer readings of the colostrum may be less reliable than would be expected for sucrose solutions against which these refractometers have been calibrated. Colostrum contains differing types of solids to the simpler sugar solutions for which the Brix refractometers are calibrated, including water-soluble proteins such as immunoglobulins, poorly water-soluble caseins, insoluble substances such as lipids that are suspended, and numerous cells.

To date, the repeatability of Brix refractometer measures of colostrum has received little research attention for any species and, when considered, analyses have not always been appropriate. There appear to be only two published studies robustly evaluating repeatability. These are Balzani et al. (2016)[266] who evaluated repeat Brix measures of sow colostrum using intra-class correlation coefficient and Zobel et al. (2020)[170] who evaluated dairy goat colostrum using Lins concordance correlation coefficients. Both reported good reproducibility.

Correlation coefficients have limited practical use as they provide a dimensionless figure for the size of the agreement. Therefore, Bland Altman analyses[320] were used in our study to quantify agreement, in absolute units (Brix %). Pairs of measures obtained using an optical and a digital refractometer and performed in several different contexts were analysed. Bland Altman plots were created for the following pairs of measures.

Measures performed under controlled conditions in the laboratory:

- Two digital measures
- Two optical measures
- One optical and one digital measure (first optical and first digital measure taken)

Measures performed on farm:

- One digital and one optical measure

Measures performed both on farm and in the laboratory:

- One digital measure on farm and the first digital measure in the laboratory
- One optical measure on farm and the first optical measure in the laboratory

5.1.3 Materials and methods

Colostrum samples were obtained from goats on a commercial dairy goat farm located in the UK, housing 2,400 adult milking goats of breed Saanen or Saanen crosses.

The collection of colostrum samples was designed to fit around the normal kidding routine. Pregnant goats were housed in groups of approximately 200 goats, where they gave birth. Shortly after giving birth the goat was caught and restrained. The operator wore clean gloves (TouchNTuff®, 92-660, Ansell), and the teats were thoroughly cleaned with a fresh udder wipe. The first two to three ejections of colostrum were hand milked from each teat and discarded, to clear any debris from the teat canals. Then 400 ml to 500 ml of colostrum were hand milked into a clean, plastic container. A single researcher collected all colostrum.

Brix refractometer instruments

A digital refractometer (PAL-1 Digital Hand-held "Pocket" Refractometer, 0 - 53.0% Brix, ATC, Atago®, Atago Co. Ltd, Japan) and an optical refractometer (HHTEC®, ATC, 10°C to 30°C, 0% – 32% Brix Refractometer) were used for all colostrum measures. Both refractometers were used according to the manufacturer's instructions.

A single researcher performed all Brix measures. Optical readings were always done before digital readings because optical readings require some operator interpretation and prior knowledge of the digital reading could influence this. For the optical refractometer, distinguishing between the top reading of the scale (32 Brix %) and readings above the scale could be difficult due to colostrum samples with higher Brix values often being much more viscous than those of lower Brix values, and as a result producing a wider, blurred line rather than a sharply defined line on the scale. Therefore, readings where either some or all the blue demarcation line was observed to lie above 32% were recorded as being "off scale".

Brix measures of colostrum performed on the farm

All colostrum was collected within 20 minutes of the goat giving birth and before the kids had a chance to suckle. One optical and one digital Brix reading were performed on the farm within 10 minutes of the colostrum being collected. Colostrum tested was from the first 400 ml to 500 ml milked. Prior to testing, colostrum was thoroughly mixed in the collecting jug.

Colostrum was removed from the jug with a clean 1 ml syringe (Terumo® HT-SLWC-0R2W 1 ml Syringe). When using the optical refractometer, two to three drops were applied to the prism, ensuring it was completely covered with a thin layer of colostrum when the flap was closed. When

using the digital refractometer, colostrum was applied to the well to a depth of between one-third and one-half, completely covering the prism. The digital measure was done immediately after the optical measure. After each measure, the refractometer prisms were washed thoroughly with running tap water and dried with a paper towel. The prism of the instrument was also then visually inspected to check no traces of residue remained.

Samples were collected and tested over a period of seven days according to when the goats gave birth. The refractometer was calibrated with distilled water at the start of each day and calibration was checked after every four to five samples.

After performing the Brix readings for a sample, the colostrum in the jug was then thoroughly remixed before decanting into multiple sample pots, either screw-top polystyrene containers (7 ml or 30 ml, Thermoscientific™ Sterilin™ Universal containers) or microcentrifuge tubes (2 ml Eppendorf®, Thomas Scientific). Each pot was labelled with the goat's individual ear tag number and date of collection. Colostrum samples were placed in a freezer within 30 minutes of collection and stored frozen at minus 20°C until further analysis.

Brix measures performed in the laboratory

Two months later, the samples were remeasured under controlled conditions in the laboratory at Bristol University, where they could be handled in a nearly identical manner, with more consistent attention to detail than was possible in the farm environment. An additional four Brix readings, two digital and two optical, were performed on each sample over the course of a single day.

The samples were slowly thawed to room temperature. Once thawed and immediately prior to testing, the colostrum in the sample pot was vortexed for 10 seconds to ensure thorough mixing. Colostrum was removed from the sample pot using a 1 ml clean syringe (Terumo® HT-SLWC-0R2W 1 ml Syringe).

For the optical refractometer, two drops from the syringe were placed on the prism, ensuring that the colostrum thoroughly and evenly covered the prism when the flap was fully closed. For the digital refractometer, 0.3 ml of colostrum was placed in the well and the reading was performed 20 seconds later.

All four readings (two optical and two digital) were done in quick succession, with the prism or well washed after each individual reading by holding it under running tap water and then thoroughly dried with a paper towel. The prism was then visually inspected to check no traces of residue remained. For each sample, the optical reading was performed immediately before the digital

measure. The calibration of the instruments was checked using distilled water prior to testing each new aliquot, that is, every four Brix readings.

5.1.4 Data handling and statistics

Data were entered into an Excel spreadsheet and analysed using R studio (RStudio Team (2021) RStudio: Integrated Development Environment for R. RStudio, PBC, Boston, MA URL http://www.rstudio.com/.), libraries tidyverse and boot. Bootstrapping techniques, 10,000 replicates with replacement, were used in all analyses. All confidence intervals are at the 95% threshold and denoted by square brackets after the relevant statistic.

Bland Altman plots were created to quantify the level of agreement between pairs of measures in absolute units (Brix %).[320] First scatterplots were constructed to check for strong, linear relationships between pairs of measures, and the distribution of differences in pairs of measures was checked for normality. To create Bland Altman plots, the means of each pair of measures were plotted on the x-axis, against the difference between each pair of measures on the y-axis. When comparing paired optical and digital measures, the digital measures were subtracted from optical measures. When comparing paired optical or paired digital measures the second reading was subtracted from the first reading. The mean of the difference in measures, or bias, indicates the extent to which the first measure is systematically greater or smaller than the second measure. The upper and lower limits of agreement, denoted as ULA and LLA respectively, define the interval where repeat measures can confidently be expected to lie in 95% of cases. When evaluating the agreement between pairs of the measures, then the second reading is unlikely (probability of 0.05 or less) to exceed the first reading by more than the value for the upper level of agreement (ULA) and to be reduced by a value smaller than that of the lower limit of agreement limit (LLA). Bland Altman plots were created for differing pairs of measures.

5.1.5 Results

A total of 107 unique colostrum samples were collected, with mean Brix values ranging from 10.1% to 41.5% (mean 22.5%, median 22.1%, IQR 16.5% – 27.7%).

Figures 5-1 through 5-6 are a series of Bland Altman plots illustrating the bias values and the level of agreement between repeat measures.

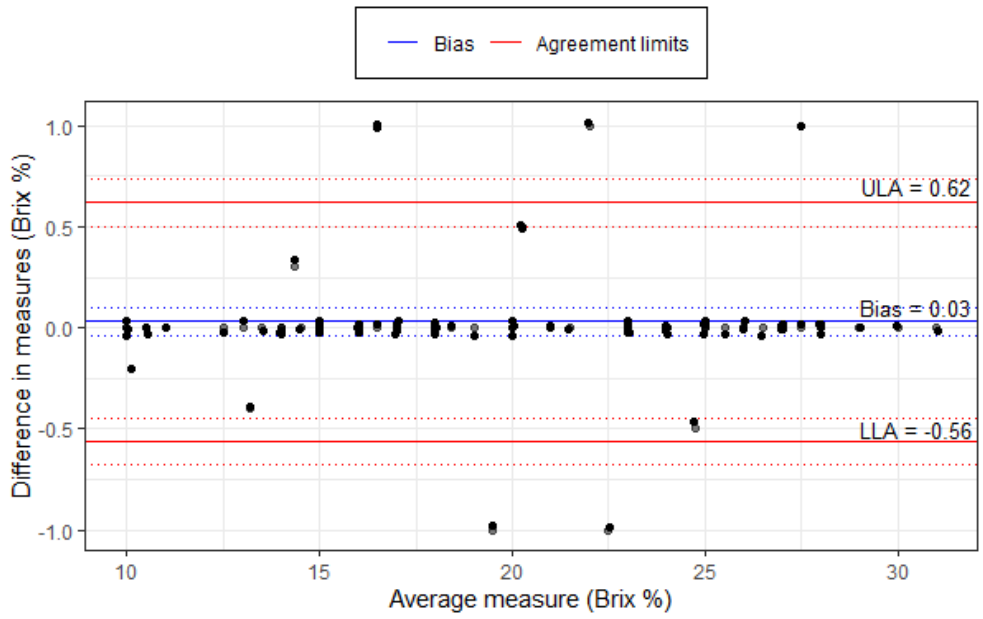

Figure 5-1 **Bland Altman plot showing agreement between repeat measures of colostrum performed using the optical Brix refractometer under laboratory conditions (n=[1]78).**

Two optical measures were performed for each sample, under laboratory conditions and using thawed colostrum. The mean optical Brix values for the samples were plotted on the x-axis. The differences in measures were plotted on the y-axis, with the second measure subtracted from the first measure. The bias value, or mean difference, shows the extent to which the first and second measures differ systematically and was 0.03 [95% CI -0.04, 0.1] Brix %. The agreement limits show the interval where pairs of measures can confidently be expected to lie in 95% of cases. The upper limit of agreement (ULA) was 0.62 [95% CI 0.5, 0.74] Brix %, and the lower limit of agreement (LLA) was -0.56 [95% CI -0.68, -0.45] Brix %. The dotted lines on the plot represent 95% confidence intervals for values.

[1] Some 78 pairs of the 107 samples collected were included in the analysis. This was because only 95 of the 107 samples collected were tested with the optical refractometer due to it being dropped and damaged. Fifteen of these 95 samples gave readings "off scale" for both measures and were not included in the plot. Two of the 107 samples tested on the farm could not be located during the laboratory analysis.

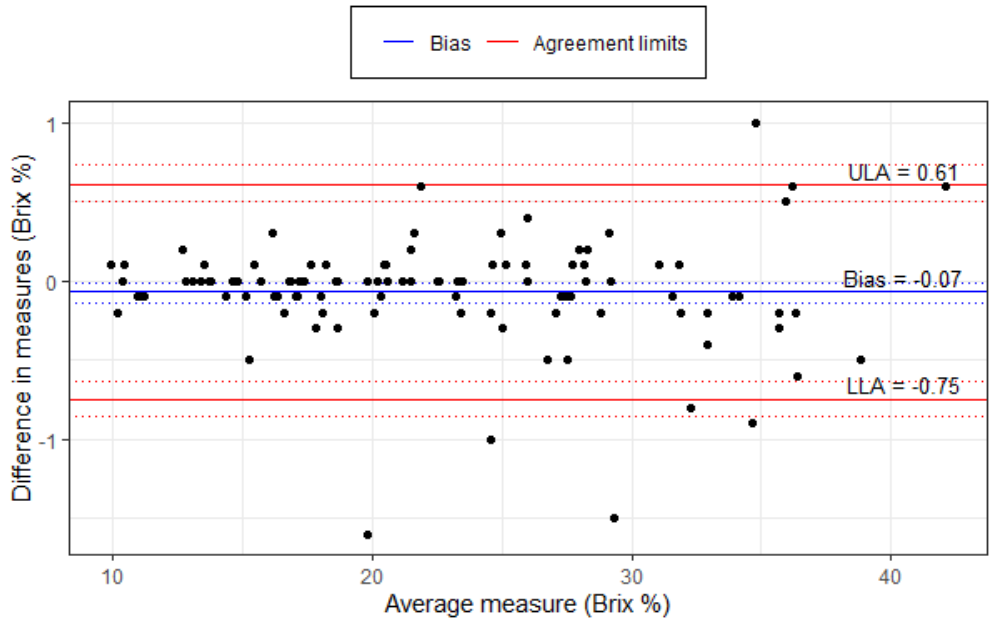

Figure 5-2 **Bland Altman plot showing agreement between repeat measures of colostrum performed using the digital Brix refractometer under laboratory conditions (n=[1]105).**

Two digital measures were performed for each colostrum sample, under laboratory conditions and using thawed colostrum. The mean digital Brix values for the samples were plotted on the x-axis. The differences in measures were plotted on the y-axis, with the second measure subtracted from the first measure. The bias value, or mean difference, shows the extent to which the first and second measures differ systematically and was -0.07 [95% CI -0.14, -0.01] Brix %. The agreement limits show the interval where pairs of measures can confidently be expected to lie in 95% of cases. The upper limit of agreement (ULA) was 0.61 [95% CI 0.5, 0.73] Brix %, and the lower limit of agreement was -0.75 [95% CI -0.86, -0.63] Brix %. The dotted lines on the plot represent 95% confidence intervals for values.

[1] A total of 105 pairs of samples were analysed, as two of the 107 samples collected could not be located during the laboratory analysis.

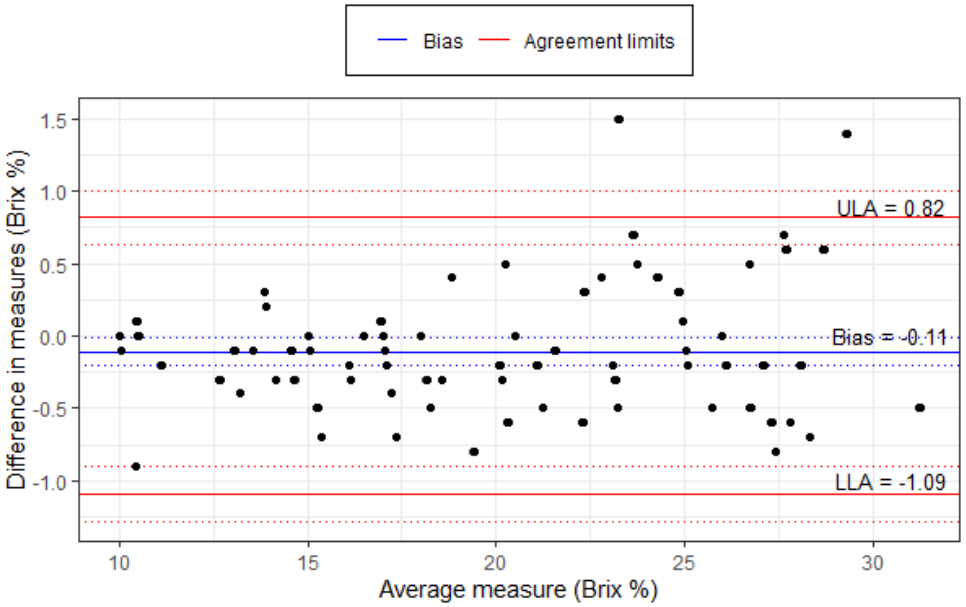

Figure 5-3 **Bland Altman plot showing agreement between repeat measures of colostrum performed using the optical Brix refractometer and digital Brix refractometer under laboratory conditions (n=[1]78).**

One optical and one digital measure were performed for each sample, under laboratory conditions and using thawed colostrum. The mean Brix values for the samples were plotted on the x-axis. The differences in measures were plotted on the y-axis, with the digital measures subtracted from optical measures. The bias value, or mean difference, shows the extent to which the optical and digital measures differ systematically and was -0.11 [95% CI -0.01, -0.2] Brix %. The agreement limits show the interval where pairs of measures can confidently be expected to lie in 95% of cases. The upper limit of agreement (ULA) was 0.82 [95% CI 0.63, 1.00] Brix %, and the lower limit of agreement was -1.09 [95% CI -1.28, -0.90] Brix %. The dotted lines on the plot represent 95% confidence intervals for values.

[1] Only 7 of the 105 samples were used in the analysis as only digital readings of less than 32%, the maximum on the optical scale, could be compared with optical measures on the plot. There were 15 additional optical measures giving readings "off scale". The corresponding digital measures all recorded >32%.

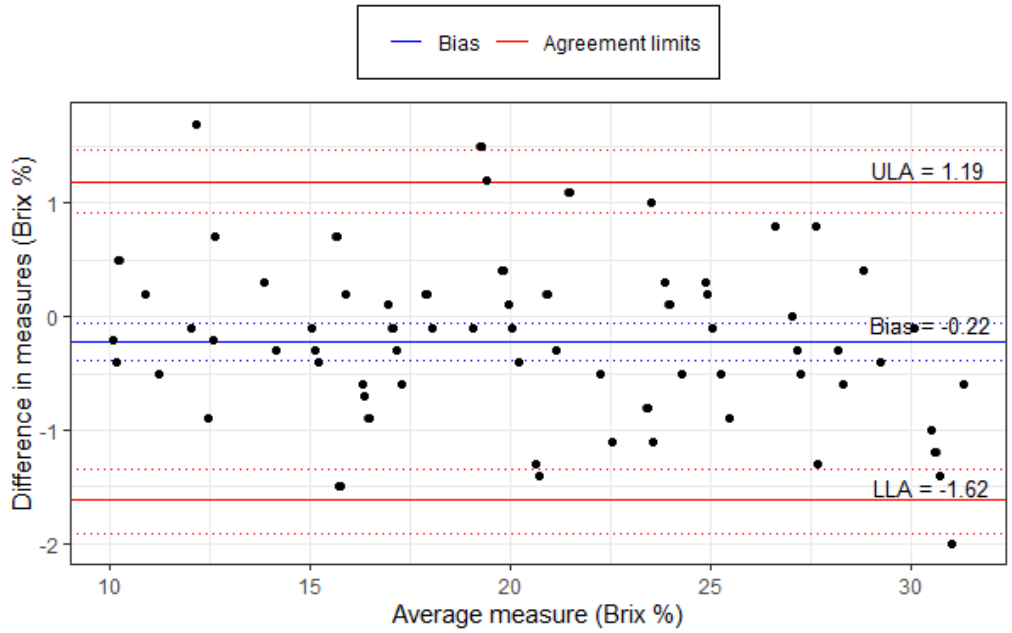

Figure 5-4 **Bland Altman plot showing agreement between repeat measures of colostrum performed using the optical Brix refractometer and digital Brix refractometer under farm conditions (n=[1]75).**

One digital and one optical measure were performed for each sample, under farm conditions and on freshly collected colostrum. The mean Brix values for the samples were plotted on the x-axis. The differences in measures were plotted on the y-axis, with the digital measures subtracted from the optical measures. The bias value, or mean difference, shows the extent to which the optical and digital measures differ systematically and was -0.22 [95% CI -0.38, 0.05] Brix %. The agreement limits show the interval where pairs of measures can confidently be expected to lie in 95% of cases. The upper limit of agreement (ULA) is 1.19 [95% CI 0.91, 1.47] Brix %, and the lower limit of agreement (LLA) is -1.67 [95% CI -1.91, -1.34] Brix %. The dotted lines on the plot represent 95% confidence intervals for values.

[1] The plot comprised 75 paired samples, as 12 of the 87 samples measured "off scale" for optical readings and were considered separately. These 12 samples had corresponding digital Brix readings also >32%.

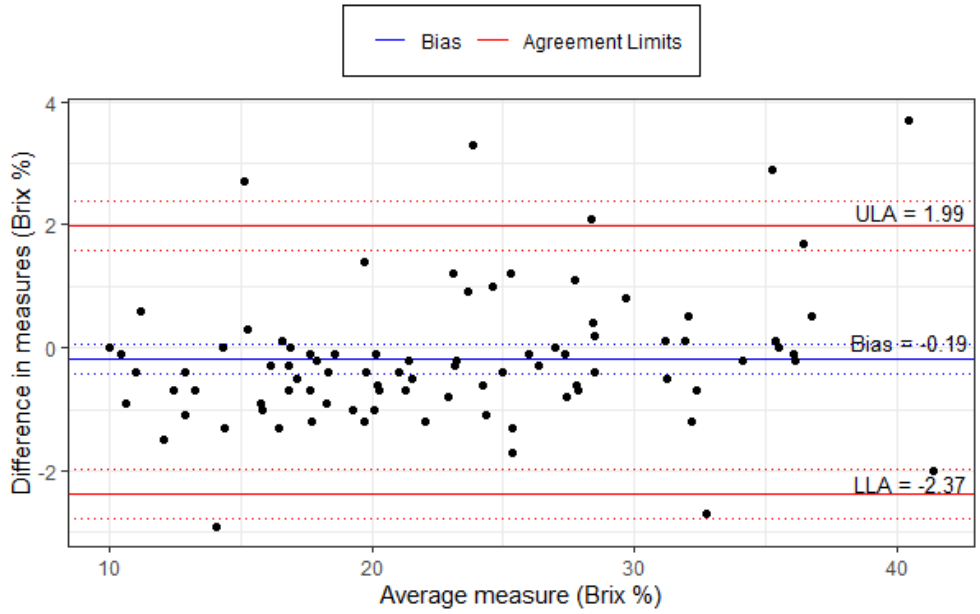

Figure 5-5 **Bland Altman plot showing agreement between repeat measures of colostrum performed using the digital Brix refractometer under both farm and laboratory conditions (n=[1]87).** Two digital measures were performed on each sample, with one measure performed on freshly collected colostrum on the farm and the second measure performed on thawed colostrum in the laboratory. The mean Brix values for the samples were plotted on the x-axis. The differences between measures were plotted on the y-axis, with the laboratory measures subtracted from the farm measures. The bias value, or mean difference, shows the extent to which the farm and laboratory measures differ systematically and was -0.19 [95% CI -0.43, 0.05] Brix %. The agreement limits show the interval where pairs of measures can confidently be expected to lie in 95% of cases. The upper limit of agreement (ULA) was 1.99 [95% CI 1.58, 2.39] Brix %, and the lower limit of agreement (LLA) was -2.37 [95% CI -2.78, -1.97] Brix %. The dotted lines on the plot represent 95% confidence intervals for values.

[1] Digital measures were performed both on the farm and in the laboratory for 87 colostrum samples.

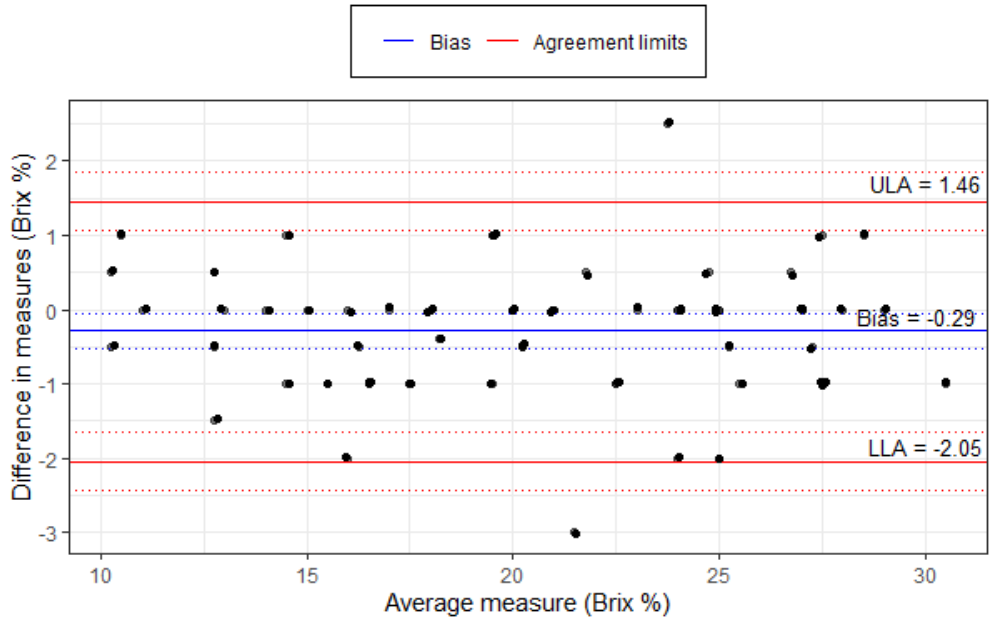

Figure 5-6 **Bland Altman plot showing agreement between repeat measures of colostrum performed using the optical Brix refractometer under laboratory and farm conditions (n=[1]62).** Two optical Brix measures were performed on each sample, with one measure performed on freshly collected colostrum on the farm and the second measure performed on thawed colostrum in the laboratory. The mean Brix values for the samples were plotted on the x-axis. The differences in measures were plotted on the y-axis, with the laboratory measures subtracted from the farm measures. The bias value, or mean difference, shows the extent to which pairs of optical measures differ systematically and was -0.29 [95% CI -0.06, -0.52] Brix %. The agreement limits show the interval where pairs of measures can confidently be expected to lie in 95% of cases. The upper limit of agreement (ULA) was 1.46 [95% CI 1.07, 1.86] Brix %, and the lower limit of agreement (LLA) was -2.05 [95% CI -2.44, -1.66] Brix %. The dotted lines on the plot represent 95% confidence intervals for values.

[1] For 16 of the 78 samples tested with the optical refractometer on the farm, the values for both optical measures were "off scale". They were not included in the Bland Altman plot, leaving 62 samples for the analysis.

Summary of main findings

For all pairs of measures the biases were either negligible or too small to be of any practical significance, indicating the first measure was not systematically higher or lower than the second measure in any practically meaningful way. The values for the upper and lower limits of agreement in Figures 5-1 through to 5-6 translate into the following general statements for practical usage. Values have been rounded to one decimal place.

For paired optical measures performed under laboratory conditions, it is unlikely (a probability of 0.05 or less) that the two measures would differ by more than 0.6 [95% CI 0.5, 0.7] Brix %.

For paired digital measures performed under laboratory conditions, it is unlikely (a probability of 0.05 or less) that the two measures would differ by more than 0.7 [95% CI 0.6, 0.8] Brix %.

When the first optical and first digital measure performed under laboratory conditions are compared, the agreement limits indicate that it is unlikely (a probability of 0.05 or less) that the two measures would differ by more than 1 [95% CI 0.8, 1.1] Brix %.

For paired optical and digital measures performed under farm conditions it is unlikely (a probability of 0.05 or less) that the two measures will differ by more than 1.4 [95% CI 1.1, 1.7] Brix %. Only one digital and one optical measure were performed on fresh colostrum on farm, so paired optical and paired digital measures could not be compared under farm conditions.

Bland Altman analyses comparing one measure performed under farm conditions with one measure performed under laboratory conditions at a later date indicate that, in this context, repeat digital readings are unlikely (a probability of 0.05 or less) to differ by more than 2.2 [95% CI -1.8, 2.6] Brix % and that repeat optical readings are unlikely (a probability of 0.05 or less) to differ by more than 1.8 [95% CI 1.4, 2.2] Brix %.

5.1.6 Discussion

It was thought important to evaluate the repeatability of Brix measures of colostrum, as colostrum has a very different physical composition to the sucrose solutions against which Brix refractometers are calibrated. Sucrose molecules readily dissolve and evenly disperse when mixed in water whereas colostrum contains many different types of solids including water-soluble proteins such as immunoglobulins, poorly soluble caseins, insoluble substances such as lipids, and numerous cells. Not only is colostrum likely to refract light somewhat differently to sucrose solutions, but repeat measures of the same colostrum samples may also refract light differently, possibly due to differing dispersion of solids when colostrum is applied to the prism.

The greatest agreements were between paired optical measures (Figure 5-1) and between paired digital measures (Figure 5-2) when performed under controlled laboratory conditions, at ± 0.6 [95% CI 0.5, 0.7] Brix % and ± 0.7 [95% CI 0.6, 0.8] Brix % respectively. Agreement lessened slightly to ± 1 [95% CI 0.8, 1.1] Brix % when comparing optical and digital measures (Figure 5-3), and further still to ± 1.4 [95% CI 1.1, 1.7] Brix % when optical and digital measures were performed under farm conditions (Figure 5-4). The least agreement was found when comparing measures performed on fresh colostrum on the farm with those on the same aliquots of thawed colostrum at a subsequent date, providing values of ± 2.2 [95% CI 1.8, 2.6] Brix % for digital measures (Figure 5-5) and ± 1.8 [95% CI 1.4, 2.2] Brix % for optical measures (Figure 5-6). For all pairs of measures, the biases were either negligible or too small to be of any practical significance, indicating that the first measure was not systematically higher or lower than the second measure in any practically meaningful way.

Evaluating measures performed under controlled laboratory conditions provides some useful insights as why measures might differ. Under laboratory conditions, repeat measures could be performed in a nearly identical manner, free of the small variations in colostrum handling and measurement technique inevitable when working on the farm, for example slightly different amounts of colostrum applied to the prism compared to the precise amounts measured when working in the laboratory, precluding these as a major source of measurement error.

When comparing the Bland Altman plots for the repeat optical measures (Figure 5-1) and repeat digital measures (Figure 5-2), the distribution of data points between the agreement limits was observed to differ. Data points for optical measures were more consistent, with 74 (88.1%) pairs of measures having identical values, and four (4.8%) pairs of measures differing by 0.5 Brix %. This is probably because the optical scale limits the values that the operator can assign to increments of one Brix %, with the possibility of assigning a half score where the measure appears to sit between two whole units. In contrast, the digital scale can vary by 0.1 Brix % increments. Also, optical readings require some interpretation of the scale by the operator and many of the higher Brix colostrum samples produced a blurred line on the scale. Knowledge of the first optical reading could have influenced the second optical readings unless there was an obvious difference of 1% Brix or greater between measures.

It is unsurprising there was less agreement between pairs of optical measures and between pairs of digital measures than between pairs comprising one optical and one digital measure. Whilst manufacturers meet certain regulatory standards, there will be small differences between instruments, such as those due to the use of slightly different conversion factors.

It is unsurprising that agreement worsened when the same measures were performed on the farm, as measurements will have been done in a less standardised way than in the laboratory. It is also possible that storing colostrum frozen and subjecting it to one freeze-thaw cycle introduced further measurement error. Logically a freeze-thaw cycle should not change the quantity of total solids in colostrum, but it might change the physical structure of some of the solids, thereby affecting how they refract light.

To date, there appear to be only two other published studies evaluating the repeatability of colostrum Brix measures using an appropriate measure of agreement.

Balzani et al. (2016)[266] divided 124 sow colostrum samples into three aliquots and then subjected each aliquot to a different treatment. Post-treatment each aliquot was measured twice in quick succession using the same refractometer; one aliquot was measured twice when fresh, one aliquot was measured twice after a period of refrigeration and one aliquot was measured twice after one freeze-thaw cycle. This study reported good levels of agreement for pairs measures in each group, with intra-class correlation coefficient values of 0.98, 0.88 and 0.98 respectively.

Zobel et al. (2020)[170] performed three Brix readings on each of 300 dairy goat colostrum samples. One optical and one digital reading of fresh colostrum were performed shortly after collection and in quick succession and a third reading was performed later for thawed colostrum using a different digital refractometer. Good reproducibility was reported, with Lins concordance correlation coefficients of between 0.93 and 0.98.

Intra-class correlation coefficients[321] and Lins concordance coefficients can provide an index of repeatability when comparing measures performed using the same method. However, they provide a single dimensionless figure which is of limited practical usefulness. In contrast, Bland Altman plots are more useful for our purposes as they provide agreement levels in units of the variable being measured, they separate the systematic error from the random error, values for measurement error are independent of the range of values in the colostrum samples and they enable the distribution of data points between the agreement limits to be observed.[320]

Other studies have presented relationships between pairs of Brix measures, performed using different instruments or performed on colostrum after different handling and storage conditions, in the form of Pearson's product-moment correlations and simple linear regression.[166,291,305,307] Whilst strong positive linear correlations are prerequisites for good agreement they are not in themselves a measure of agreement.[320] High correlation values can be obtained in situations where measures

disagree, either due to a consistent size difference between repeat measures or even where there is simply a wide range of possible true values for the variable being measured.[320]

Elsohaby et al. (2017)[307] additionally used Kappa statistics to assess how well optical and digital Brix measures agreed in their classification of colostrum as good or poor quality and Bielmann et al. (2010)[305] used t-tests to compare the means of optical and digital measures of pairs of samples. Neither of these statistical tests provide a measure of agreement between repeated measures of the same samples.

The key questions of our study were whether repeat measures agreed sufficiently for the digital and optical refractometers to be used interchangeably and the impact the size of measurement error might have on results. These questions were considered in relation to collecting data in the goat colostrum quality study (Chapter 4), and also the routine use of Brix refractometers in colostrum management on farms.

The repeatability study tested aliquots with a Brix range of 10% to 40%, representing the full range expected to the found on the dairy goat farm, keeping the agreement limits relevant.

During the colostrum quality study (Chapter 4), it was decided that fresh colostrum would be tested shortly after collection as this is the context in which a farmer would undertake Brix readings when deciding which colostrum to feed to kids. Therefore, the agreement limits for measures performed on the farm (± 1.4 Brix %) are most relevant for decision making and considered adequate, provided accuracy was improved by using the means of at least two measures performed on the fresh colostrum as the data point for that sample. This is not dissimilar to the approach taken by a number of colostrum quality studies in other species, where means of multiple measures were used to improve accuracy.[264–266,305,307,314] Other studies have performed one Brix measure per colostrum sample or are presumed to have done so through not specifying otherwise.[267,268,304,306,316–319]

For the purposes of the colostrum quality study (Chapter 4) there was considered to be close enough agreement between the optical and digital measures for them to be used interchangeably (in place of each other), except where readings were classed as “off scale” on the optical refractometer, in which case the digital refractometer would be used to assign a specific value for that sample.

During extremely busy periods, such as when large numbers of goats give birth during a very short time period, then it was considered reasonable to make an adjustment to measurements, optimising the amount of data collected without compromising the quality of measures. Here one Brix measure only would be performed on fresh goat colostrum and then the sample would be stored frozen at minus 20°C for later thawing and retesting at a more convenient time, where a further two to four

Brix readings could be performed under farm type conditions. The means of these measures could be used as the data point for that sample. The repeatability of all measures would then be assessed again on completion of all data collection to check that it had stayed within the expected limits.

It is useful to consider the implications of our findings for routine usage of Brix refractometers on farms as part of general colostrum management. Single measures should still be appropriate because the extra work involved in taking two readings and finding the average is unlikely to be offset by any practical gains from a small increase in accuracy. Consider a farm selecting colostrum to retain for feeding if it meets a Brix value threshold of 22% or greater, taking one Brix measure only. In the worst-case scenario, a sample measuring 22% on the first reading would read 20% on a second reading. In this scenario, single sampling would lead to a sample that had an average Brix value of 21% being retained for feeding. Many samples would be closer in value to each other than this. Rather than performing more than one Brix reading per sample, stockperson time and energy are better invested in ensuring good practice in measuring colostrum, for example, proper maintenance and calibration of the refractometer, proper cleaning of the prism between readings, and ensuring colostrum is well mixed so solids are evenly distributed before testing.

It is useful to know that digital and optical instruments can be used interchangeably as optical instruments are more affordable. Also, farmers do not need to assign a specific value to colostrum over 32%, automatically regarding anything “off scale” as good quality.

5.1.7 Conclusion

In conclusion, quantifying measurement error is valuable, especially when measuring relatively novel substances such as colostrum with an instrument designed for other purposes. Analysis is preferable to presumption. There were limits to the combinations of measures that could be tested with these samples, for example, paired digital and paired optical readings on the farm were not evaluated, but sufficient information was obtained from the measures evaluated to make necessary decisions. The cause of differences in agreement limits for different combinations of refractometers and conditions could not be established with certainty but knowledge of the size of measurement error was valuable irrespective of this. Brix refractometer measures of colostrum are sufficiently precise for them to be a useful measure of goat colostrum.

6 Chapter 6

6.1 Colostrum intakes and serum total protein values of goat kids routinely bottle-fed colostrum on a commercial dairy goat farm in the UK

6.1.1 Abstract

To the author's knowledge, there are no studies measuring the voluntary colostrum intakes of goat kids on commercial dairy goat farms, whether suckled naturally or artificially fed. Observational studies on farms are helpful in providing baseline data for what is achievable when real-world factors are in play. Where done on farms working to high standards or best practices, such data has the potential for use in benchmarking and informing guidelines. Therefore, this study measured the quantity and timings of colostrum intakes of kids on a large commercial dairy goat farm in the UK during the first 13 hours of life, where the routine practice was to remove kids at birth and feed them artificially from a nipple bottle. It describes the husbandry practices instigated by the farm to maximise intake. The main findings of interest were the timings and quantities of the first and second colostrum feeds and the total colostrum intakes. Stockpersons managed to offer all kids their first colostrum feed within two hours of birth. First feed quantities were very variable, ranging from 50 ml – 430 ml in volume (IQR 152.5 ml – 273.8 ml). The first feed quantity expressed as a proportion of birthweight ranged from 1.2% –11.5% (IQR 4.3% – 7.3%). Second feed quantities varied greatly (range 0 ml – 450 ml, or 0% – 11.3% of birthweight). Some 69.6% (48/69) of kids consumed their second feed and therefore their total colostrum within 360 minutes of birth, which is the time period where the efficacy of absorption of immunoglobulins is greatest. Most kids (72.5%) achieved total colostrum intakes of at least 10% of birthweight during the 13-hour data collection period but did so over two separate feeds rather than in a single feed.

The study farm worked closely with their veterinary surgeon to implement best practices, and routinely monitored kid outcomes in terms of morbidity, mortality, and the serum total protein values as an indirect measure of passive transfer of immunity. The serum total protein values of the kids that were measured whilst assisting the farm's vet to address a clinical query are presented, along with an evaluation of the level of agreement between biuret and refractometer measures of serum total protein.

6.1.2 Introduction

Dairy goat farmers must balance a variety of factors when deciding how best to rear their goat kids. One main decision is whether to leave neonatal kids with their mothers to suckle colostrum naturally or to remove them immediately after birth and feed them colostrum artificially. There are advantages and disadvantages to both systems.

The likely advantages of removing kids at birth include minimising disease transmission from adult to kids;[197,322–324] reducing stress on the doe by preventing her from forming a bond with her kids before separation;[325,326] kids anecdotally being easier to train to drink from an artificial teat if they have never suckled naturally; stockpersons finding it easier to ensure that all kids from multiple births or of small body size feed well and avoiding the difficulties that some kids have latching onto teats of pendulous udders.

The likely disadvantages of removing kids at birth include the kid being unable to feed colostrum *ad libitum* according to their individual behavioural and nutritional needs and the loss of maternal care, resulting in considerable extra workload for stockpersons. The doe may also experience discomfort from a distended udder where the first milking is delayed.

Each dairy goat farm has a unique combination of resources, personnel, goats, and priorities, and different systems of husbandry will suit different farms. There is a role for industry guidelines that assist farmers in choosing the best system for their farm and then operating optimally within that system. However, in contrast to dairy cattle, there is currently little research to inform such guidelines.

Whichever system is used the quantity, quality, and timing of colostrum feed remain vitally important. These combine to determine the level of nutrition, immunity, and other beneficial components the kid receives, which in turn impacts their subsequent health, welfare, and productivity, both in the short and long term.[108]

There are far fewer studies of goat kids than of dairy calves. In goat kids, several studies have aimed to evaluate the impact of different colostrum feeding methods on circulating immunoglobulin levels. Included are different lengths of time spent naturally suckling,[225] bottle suckling versus natural suckling,[222] *ad libitum* feeding versus restricted meals,[222] and feeding colostrum that has undergone different treatments including refrigeration,[256] freeze-thaw cycles,[256] heat treatment,[182] and lyophilisation.[213,221] Some studies have measured the circulating immunoglobulin levels achieved in goat kids on commercial dairy goat farms. However, for many studies, the small sample sizes and

methodologies limit inferences that can be confidently made,[108,216,217] and further research is needed for all areas.

To the author's knowledge, there are no studies measuring the voluntary colostrum intakes of goat kids on commercial dairy goat farms, whether suckled naturally or artificially fed. Observational studies on farms are helpful in providing baseline data for what is achievable when real-world factors are in play. Where done on farms working to high standards or best practices, such data has the potential for use in benchmarking and informing guidelines.

Therefore, this case study measured the quantity and timings of colostrum intakes of kids on a large commercial dairy goat farm in the UK, where the routine practice was to remove kids at birth and feed them artificially from a nipple bottle. Removing kids from mothers at birth is increasingly common practice in the UK, with 10 out of 46 farms that completed a postal survey indicating they routinely undertook this practice.[228] This contrasts with kidding practices 15 years ago where all 25 farms visited allowed kids to suckle their mothers (K.Anzuino, unpublished data collected during a survey of 25 UK farms)[7].

The study farm worked closely with their veterinary surgeon to implement best practices, and routinely monitored kid outcomes in terms of morbidity, mortality, and the serum total protein values as an indirect measure of passive transfer of immunity. The researcher assisted the farm's vet with a query regarding the serum total protein (STP) values that had been observed during this routine monitoring. During the study period, it was possible to routinely blood sample kids at the ideal, though less practical, age of one to two days instead of at routine disbudding, and to measure serum total protein using the reference biuret method as well as the refractometer, providing some evaluation of the normal blood sampling protocol.

Therefore, this study describes the volume and timings of colostrum feeds during the first 13 hours of life for goat kids fed by nipple bottles on this commercial dairy goat farm, along with the husbandry practices instigated by the farm to maximise intakes. It also describes the serum total protein values of the kids that were measured to assist the farm's vet, along with the level of agreement between biuret and refractometer measures of serum total protein.

6.1.3 Materials and methods

Details of normal farm husbandry for the care and feeding of neonatal kids are provided. Data collection was designed to fit around normal practice. Some modifications for the purposes of data collection were required.

Normal farm husbandry

The farm was a commercial dairy goat farm in the UK, holding approximately 1200 adult female milking goats, mostly Saanen and Saanen crossbreeds. There were usually three kidding sessions per year, with the number of goats giving birth each session varying from 150 to 400. All goats were scanned to confirm pregnancy and the number of kids expected. Kids were removed from their mothers at birth, primarily to minimise any disease transmission from adults to kids. The farmers also found this system more practical than penning does and newborn kids together and removing kids at birth seemed less stressful for the does. Kids were routinely fed colostrum using a nipple bottle, as opposed to a stomach tube, to avoid delays in teaching the kid to suckle an artificial teat and because suckling behaviour stimulates closure of the oesophageal groove.

Observations of the pen of pregnant goats

Pregnant goats were housed in a straw-bedded barn at an initial group size of approximately 150 animals. The group size gradually decreased as goats gave birth and were moved to the freshly kidded group. Stockpersons frequently observed the group of pregnant goats for any signs of parturition between the hours of 6 am through to 7 pm. Goats were checked two or three times between 7 pm and 11 pm, during the night at approximately 2 am, and again at 4 am just prior to the morning milking session.

Removal of kids from mothers

The farm aimed to remove kids from their mothers within 10 minutes of birth, and before they had suckled. They were taken to housing devoted to newborn kids where they remained for the first one to three days of their life. They were towel dried and their navels were dipped in a 10% iodine solution. Each kid was assigned a small pen, made from an intermediate bulk container (IBC), and grouped with one or two kids of the same age. They were bedded on shavings with a rubber mat underneath, both for added insulation and to prevent the kid from slipping when trying to stand. Pens were thoroughly disinfected between batches of kids. The farm routinely weighed all kids at two days.

Whiteboard recording system

A whiteboard and paper book adjacent to the kid pens was used to record the birth date, the mother's ear tag number, sex, gravidity, pen location, and any individual identification marks applied to the kid, such as coloured spray markings. Kids were not ear tagged with their official individual identification until they had drunk both colostrum feeds. They were routinely offered two colostrum

feeds before being fed artificial milk replacer. After the first feed, a blue dot was marked on the whiteboard next to the kid's details. After the second colostrum feed a second blue dot was added.

Colostrum handling

After giving birth the goat was taken to the milking parlour and machine-milked into a metal churn to obtain the full volume of the first colostrum milking. Colostrum was then tipped into a clean dry bucket. It was measured using an optical Brix refractometer (HHTEC®, ATC, 10°C to 30°C, 0% – 32% Brix Refractometer) and only that of at least 22% Brix was retained for feeding. The colostrum was divided into aliquots of approximately 200 ml to 300 ml in Ziploc® bags (manufacturer S. C. Johnson & Son, Inc.) and the date and Brix value were written on the bag using a permanent marker pen.

Colostrum was then pasteurised at 60°C for 60 minutes using a purpose-designed batch pasteuriser for dairy cattle. These values were derived from dairy cattle industry guidelines. Following heat treatment, bags containing colostrum were left to cool to room temperature and then placed in the fridge at 4°C, where they would be used within two days, or placed in the freezer at minus 20°C and stored for a period not exceeding six months.

Colostrum that had been stored frozen was thawed by placing it in a water bath at 37°C temperature for up to one hour before it was required for feeding. Hotter water was used if a faster thaw was required, but never too hot to comfortably place a hand in. All colostrum was fed warm judged by the temperature on the hand. After every feeding session, the bottles and teats were washed thoroughly with hot soapy water, rinsed, and left to soak in dilute sterilising fluid (Milton®, Laboratoire RIVADIS) until next required. They were rinsed with fresh water before use.

Bottle-feeding colostrum to kids

Latex teats (Ritchey™ lamb teats) were used on 500 ml plastic feed bottles. Kids were offered their first bottle feed as soon as practical after birth. The time of the second feed depended on when the kid was first fed. It would be the next routine feed session for all kids, which would be either between 5 am and 6 am, between 11 am and 12 noon, or between 4 pm to 5 pm. However, kids that consumed a particularly small first feed, defined as 100 ml or less, were recorded on the whiteboard, and stockpersons aimed to provide them a second feed within two hours of the first, irrespective of the next routine feeding time for all kids.

Unused thawed colostrum was discarded at the end of the feeding session, not left to stand in the warmer for later use. After kids consumed two substantial colostrum feeds, they were bottle-fed artificial milk replacers (Lamlac, Volac International Limited). The target minimum total colostrum intake was 250 ml per kid.

Blood sampling kids

The farm's veterinary surgeon routinely monitored the serum total protein (STP) of female kids by blood sampling them during the first week of life at the time they were anesthetized for routine disbudding, generally between two and seven days of age. Male kids were not disbudded and therefore, not blood sampled.

Approximately six to 10 kids would be sampled out of 30 to 40 kids being disbudded on a particular day. An optical total protein refractometer was used (HHTEC®, ATC, clinical refractometer RHS – 300, scale 0 – 12 g/dL). Approximately 2 ml of blood was obtained by jugular venipuncture using a 21 gauge needle and a plain vacutainer tube ((BD VS368609 Vacutainer Eclipse 21g needle, BD VS368975 Vacutainer® Blood Plastic Serum Tube, 4ml, Becton, Dickinson U.K. Limited).

Blood samples were left to clot in the vacutainer tubes at room temperature for between one and two hours until disbudding of all kids was complete. Serum was then removed from the vacutainer using a clean pipette and applied to the refractometer prism and measured according to the manufacturer's instructions. The refractometer was calibrated with distilled water at the start of each disbudding session. In the absence of goat-specific evidence, a dairy calf guideline for adequate passive transfer was used, requiring at least 80% of animals to have a serum total protein value of 5.2 g/dL or greater.

Data collection

Data were collected from a convenience sample of kids born between mid-May and mid-June. The same researcher was present on the farm for the full data collection period and worked alongside the same two stockpersons throughout.

The following data were recorded for each kid using a combination of paper and digital Dictaphone: the date and time the kid was born; whether the kid could have suckled its mother prior to removal; kid sex; whether the kid was a single, twin or triplet; birthweight; times that colostrum feeds were offered and the volume of each colostrum feed consumed; Brix values of any colostrum fed; and any interventions such as assisted kidding due to dystocia or emergency feed via stomach tube.

The volumes consumed at each feed were measured using the scale (millilitres) printed on the side of the feed bottle, calibrated so that volume could be measured to the nearest 10 ml. The quantity of colostrum consumed was also estimated as a proportion of birthweight (%) with 1 ml of colostrum equating to 1 gramme in weight in the calculation.

The following modifications to normal farm husbandry were made for the purposes of data collection. Kids were weighed shortly after birth by placing them on a veterinary platform scales (Veterinary Scale LCVS180K – 180KG x 0.05KG Large Lightweight Vet Scale with "Hold" function, Brand: LW Measurements Europe Ltd) after they had been towel dried. Calibration of the scales was checked prior to each weighing using dumbbells of known weight.

Brix measures were performed on colostrum in feed bottles just prior to feeding kids, in addition to the routine farm measures at the time of colostrum collection. The colostrum was thoroughly mixed in the feed bottle and then removed using a clean 1 ml syringe (Terumo® HT-SLWC-0R2W 1 ml Syringe). Two optical and two digital Brix readings were performed for each sample. The optical refractometer ((HHTEC®, ATC, 10°C to 30°C, 0% – 32% Brix Refractometer), digital refractometer ((PAL-1 Digital Hand-held "Pocket" Refractometer, 0% – 53.0% Brix, ATC, Atago®, Atago Co. Ltd, Japan) were used according to the manufacturer's instructions, as described in Chapter 4. All Brix measures were performed by the same researcher.

To provide additional assurances that immunoglobulin levels were preserved during pasteurisation, direct measures of immunoglobulin by radial immunodiffusion were performed on a convenience sample of colostrum from the feed bottles, the number determined by logistics. A 'spot check' of the pasteuriser was also performed whereby the immunoglobulin content of five unique colostrum samples was measured immediately before and immediately after pasteurisation. Each unique sample was split into three separate aliquots by decanting them into separate Ziploc bags, clearly labelled with their unique identification number, and samples were taken from the bags before and after heat treatment. To obtain samples, the colostrum in each Ziploc bag was thoroughly mixed before decanting into 7 ml universal containers and then stored frozen at minus 20^{o}C until analysed by radial immunodiffusion at the Saskatoon Colostrum Company Limited, Saskatoon, Canada, as described in Chapter 4.

A convenience sample of kids was blood sampled at between one and two days of age and with the animal conscious, instead of during the later disbudding time. The blood sampling technique used was the same as that described by the farm's vet. Once serum total protein refractometer readings were complete then the serum samples were measured using a reference biuret method. For this, the remaining serum in the vacutainers was pipetted into plain 1.5 ml Eppendorf Tubes® (Eppendorf Gerätebau Netheler & Hinz GmbH) and labelled with a unique kid identifier. Samples were frozen at minus 20^{o}C for no longer than two weeks before being analysed using the biuret method (Total protein FS*', Manufacturer; DiaSys Diagnostic Systems GmbH, Germany) at the laboratories of Langford Vets, Bristol School of Veterinary Science.

This observational study was done according to Recognised Veterinary Practice[327] performing the minimum of testing appropriate for addressing the clinical query, and generally only one refractometer and biuret measure per sample. However, for clotted samples yielding slightly more serum (n=21) refractometer readings of fresh serum were performed in duplicate allowing for some checks on the precision of the instrument.

6.1.4 Data handling and statistics

Data were entered into Excel and analysed using R studio (RStudio Team (2021) RStudio: Integrated Development Environment for R. RStudio, PBC, Boston, MA URL http://www.rstudio.com/.); libraries tidyverse and boot. Bootstrapping techniques, 10,000 replicates with replacement, were used for all hypothesis tests and for calculating confidence intervals. All confidence intervals are at the 95% threshold and denoted by square brackets after the relevant sample statistic.

Descriptive statistics are provided for the different variables. Independent sample t-tests were used to compare the mean values of variables grouped according to different factors. Scatterplots were created to illustrate the relationships between pairs of continuous variables. Pearson's product-moment correlation coefficients quantified the strength of association for linear relationships. Boxplots were used to show how the total colostrum intakes of groups of kids altered over time.

Bland Altman analyses[320] were used to quantify the level of agreement between refractometer and biuret measures of serum total protein. First scatterplots were constructed to check for strong, linear relationships between pairs of measures, and the distribution of differences in pairs of measures was checked for normality. To create Bland Altman plots, the means of pairs of measures were plotted on the x-axis. The differences between pairs of measures were plotted on the y-axis and were calculated by subtracting the biuret from the refractometer measure. The bias shows the extent to which the refractometer measure is systematically greater or smaller than the biuret measure. The agreement limits define the intervals where repeat measures can confidently be expected to lie in 95% of cases.

6.1.5 Results

Kids sampled

Data were collected for a convenience sample of 110 kids born to 72 primiparous goats aged between 15 and 24 months. Data collection took place over 27 consecutive days, comprising the middle four weeks of a kidding session that lasted approximately six weeks where approximately 150 goats gave birth.

Therefore, approximately 48% (72/150) of goats from that kidding session were sampled. Thirty-three goats gave birth to single kids, 36 gave birth to twins and two goats gave birth to triplets. Fifty-eight (52.7%) of the kids were male and 52 (47.3%) were female. The number of kids born per day ranged from zero to 14 (median 3, IQR 2 – 6). The mean birthweight of kids (n=110) was 3.7 kg (median 3.3 kg, IQR 3.3 kg – 4.3 kg, range 2.1 kg – 5.3 kg). The mean birthweight of male kids was significantly greater than that of female kids (independent samples t-test, mean difference 0.5 [95% CI 0.3, 0.7] kg, $P<.001$).

Some 74.5% (82/110) of kids were known with certainty not to have suckled their mothers and are referred to as the NM group. The 24.5% (28/110) kids that could have suckled their mothers before removal are referred to as the M group. Some 78.6% (22/28) of the M kids were born during the night. Some 14.3% (4/28) of the M kids were born at midday and were two sets of twins. One M kid was born early morning at 6 am and another M kid was born in the evening at approximately 6 pm.

Only apparently healthy kids were included in the analysis. An additional three kids born during the study period were excluded; one kid from a set of triplets was born dead, and two kids were weak after undergoing prolonged parturitions.

Table 6-1 **Descriptive statistics for the quantities, timings and Brix values of colostrum consumed by NM kids.**

The observation period was the first 13 hours of the kid's life. NM kids are those removed from their mothers before they had suckled. F1 = first colostrum bottle feed, F2 = second colostrum bottle feed, n=number of kids in the sample, IQR = interquartile range.

Variable	n	Mean	Median	IQR	Range
Volume ingested during F1 (ml)	[1]82	218	200	152.5 – 273.8	50 – 430
Volume ingested during F1 expressed as a proportion of birthweight (%)	82	6	5.9	4.7 – 7.3	1.2 – 11.5
Time between birth and F1 (minutes)	82	31.1	29	16.3 – 40	0 – 100
Brix value of colostrum in F1 (Brix %)	82	24	24.3	22 – 26	18 – 38
Time between the F1 and F2 (minutes)	[2]69	278.8	240	160 – 355	30 – 740.0
Time between birth and F2 (minutes)	69	316	275	198 – 438	55 – 782
Volume ingested during F2 (ml)	69	198.6	200	150 – 250	0 – 450
Volume ingested during F2 expressed as a proportion of birthweight (%)	69	5.3	5.7	3.8 – 6.8	0 – 11.3
Brix value of colostrum in F2 (Brix %)	69	23	22.8	21 – 24	17 – 28
Total volume of colostrum ingested (F1 + F2) in the 13 hours after birth (ml)	69	423.1	420	320 – 500	100 – 830
Total volume of colostrum ingested in the 13 hours after birth, expressed as a proportion of birthweight (%)	69	11.3	11.4	8.8 – 14.1	2.7 – 19.8

[1]The first colostrum feed was recorded for 82 kids.

[2]Both the first and second colostrum feeds were recorded for 69 of the 82 kids.

Some 39% (32/82) of NM kids consumed their first feed within 30 minutes of birth. Some 6.1% (5/82) of NM kids consumed their first feed over 60 minutes after birth, the maximum time being 100 minutes. Some 69.6% (48/69) of kids consumed their second feed within 360 minutes of birth.

Relationship between birthweight and first feed volume in NM kids

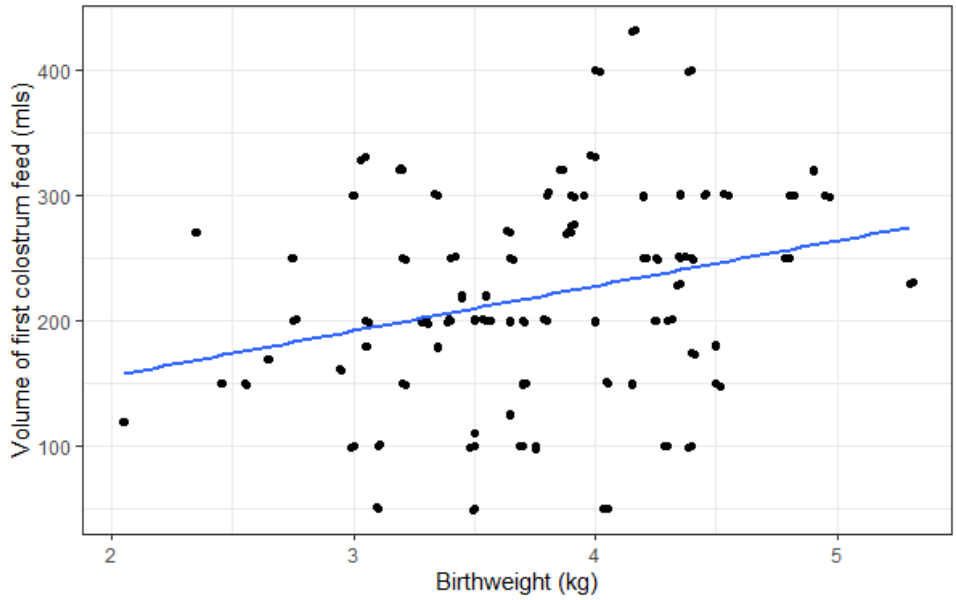

Figure 6-1 **Scatterplot illustrating the relationship between kid birthweight and the volume of colostrum consumed during the first bottle feed in the NM kids (n=82).**

NM kids = kids removed from their mothers before they had suckled.

First feed volume varied greatly amongst apparently normal healthy kids, including those of similar birthweight. The colostrum intakes of the best feeders for each birthweight show that kids of 3 kg birthweight or less did not consume more than 300 ml, those between 3 kg and 4 kg birthweight did not consume more than 350 ml and only kids of birthweight over 4 kg consumed more than 350 ml, with a maximum intake of 450 ml. The regression line is superimposed on the plot.

There was a statistically significant, weak positive correlation between birthweight and first feed volume (r=0.281 [95% CI 0.068, 0.469], P=.01). There was no significant correlation when the quantity of the first feed was expressed as a proportion of birthweight (%).

Kids consuming a particularly small first feed

Eight of the 82 (8.8%) NM kids took a particularly small first feed, defined as <100 ml, which for all eight kids was <3% of their birthweight. Feed quantities as a proportion of birthweight were 1.2%, 1.4%, 1.6%, 2.3%, 2.3%, 2.7%, 2.7% and 2.9%.

Five of these kids were born in the evening time and were offered an additional second feed before the long overnight interval. These five kids increased their total colostrum intakes as a result. Three kids had a substantial increase from 1.2%, 2.3%, and 2.7% of birthweight to 5%, 11%, and 8% of birthweight respectively and two of the kids had more marginal increases from 1.4% and 2.3% of birthweight to 1.7% to 3.4% of birthweight respectively.

Kids consuming a particularly large first feed

Seven of the 82 (8.5%) NM kids consumed a particularly large first feed, defined as 10% or more of birthweight, with values ranging from 10% to 11.5% of birthweight.

Cumulative colostrum intakes of kids over the first 13 hours of life

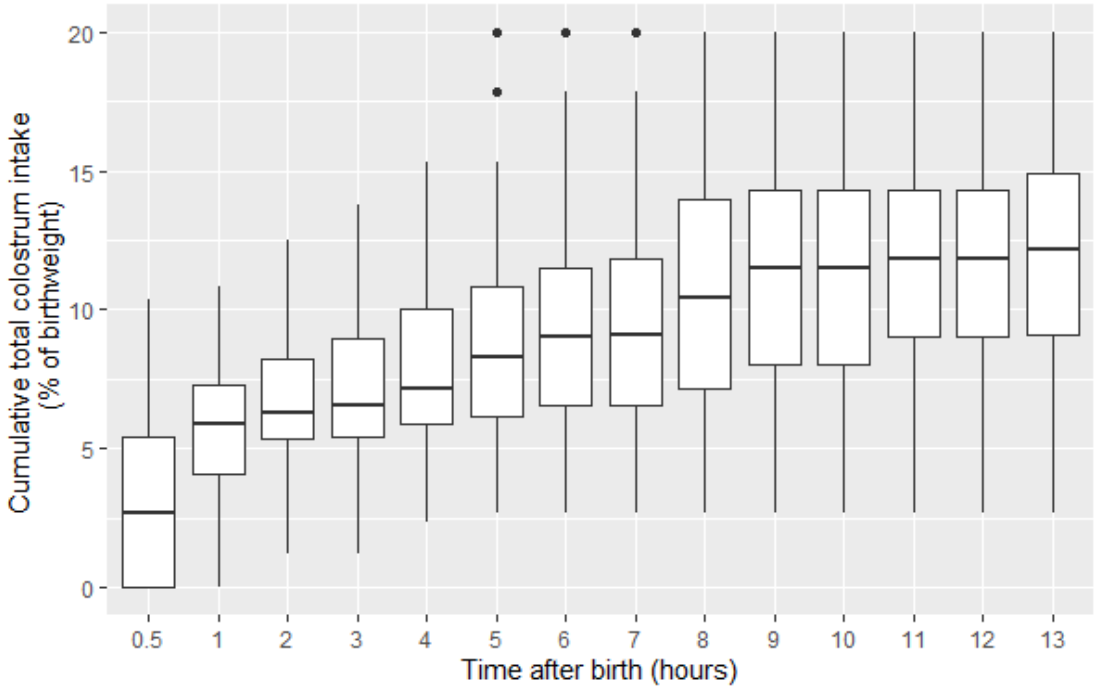

Figure 6-2 **A series of boxplots showing the cumulative total colostrum intakes of NM kids at hourly intervals following birth (n=69).**

NM kids are those removed from their mothers before they had suckled.

The observation period was the first 13 hours of the kid's life. Data are from 69 kids where both the first and second colostrum bottle feeds were recorded. The quantities of colostrum ingested are expressed as a proportion of birthweight. When interpreting each boxplot, the white box contains the 25th to 75th percentile, the central black line denotes the median values (50th percentile), the black whiskers mark the 5th and 95th percentiles and values beyond these upper bounds are considered outliers, marked as black dots.

Some 97% (67/69) of NM kids consumed at least 5% of their birthweight in colostrum and 72.5% (50/69) consumed at least 10% of their birthweight in colostrum. The 2.9% (2/69) of NM kids that had low total colostrum intakes of <5% were born in the evening time and consumed relatively small first feeds of 100 ml, followed by small second feeds of 50 ml and 0 ml respectively when offered an additional evening meal.

Some 90.2% (74/82) of NM kids met the farm's target total colostrum intake of at least 250 ml.

M kids

For M kids (those thought to have suckled their mother prior to removal) the quantity of the first feed taken from the bottle ranged from zero to 580 ml (median 400ml, IQR 295 ml – 502 ml). The quantity of first feed expressed as a proportion of birthweight ranged from 0% to 18.6% (median 10.2%, IQR 7.3% – 12.7%). Seven kids refused when first offered but consumed some colostrum during subsequent feeds. Multiple colostrum feeds were offered due to stockperson uncertainty about the quantities already suckled from their mothers; four kids were offered one feed, 10 kids were offered two feeds, 10 kids were offered three feeds and four kids were offered four feeds.

Biuret measures of serum total protein

A convenience sample of 65.5% (72/110) of the kids was blood sampled, comprising 66% (55/82) of the NM kids and 60.7% (17/28) of the M kids.

Table 6-2 **Summary statistics for biuret measures of kid serum total protein**

n=number of kids in sample, Q1 = first quartile, Q3 = third quartile, NM = kids removed from their mothers before they had suckled, M = kids that had suckled their mothers. Values are rounded to one decimal place. Square brackets [ ] contain the 95% confidence intervals for values.

Group	n	Serum total protein (g/dL)				
		Mean	Median	Q1	Q3	Range
All kids	72	5.4 [5.2, 5.7]	5.3 [5.1, 5.7]	4.7 [4.3, 5.0]	6.2 [5.8, 6.6]	3.4 – 8.7
NM	55	5.2 [4.9, 5.4]	5.2 [4.9, 5.4]	4.5 [4.0, 4.8]	5.8 [5.5, 6.2]	3.4 – 7.0
M	17	6.3 [5.7, 7]	6.4 [5.5, 6.9]	5.5 [5.0, 6.1]	7.1 [6.4, 8.3]	3.6 – 8.7

Comparison of biuret and refractometer measures of serum total protein

Table 6-3 **Descriptive statistics for the biuret and refractometer measures of serum total protein for the 69 kids where both measures were performed**.

IQR = interquartile range

	Serum total protein (g/dL)			
Measure type	**Median**	**Mean**	**IQR**	**Range**
Refractometer	5.6	5.5	5.3 – 6	3.8 – 8
Biuret	5.3	5.4	4.7 – 6.2	3.4 – 8.7

Based on these 69 samples, 42% (29/69) of kids would have been classified as having inadequate passive transfer (STP <5.2 g/dL) when serum was measured using the biuret method compared to only 23.2% (16/69) of kids when measured using the total protein refractometer.

Relationship between refractometer and biuret measures of serum total protein

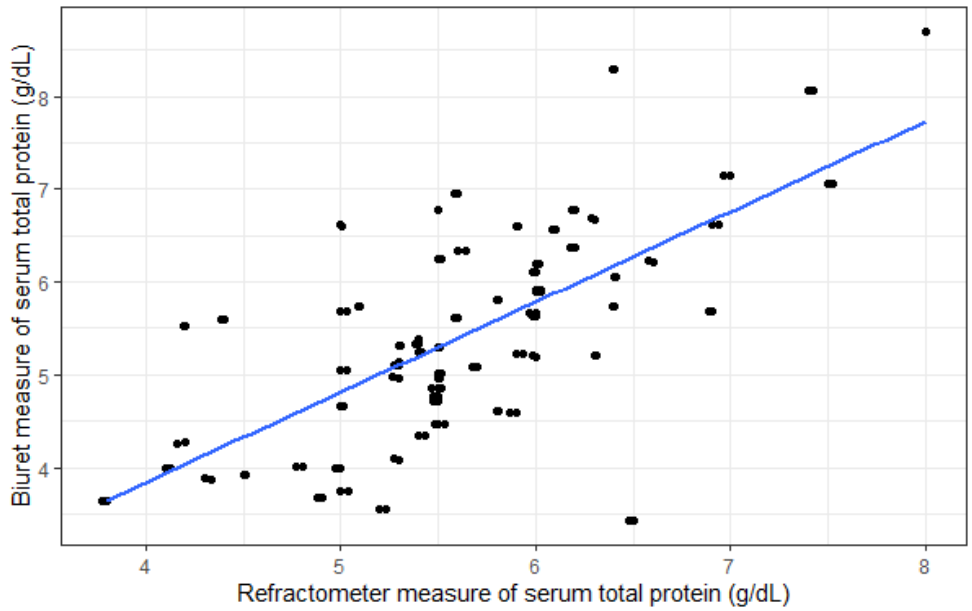

Figure 6-3 **Scatterplot illustrating the relationship between the biuret and refractometer measures of serum total protein.**

There was a significant, moderate to strong, positive correlation between measures (r=0.679 [95% CI 0.456, 0.808], P<.001), highlighted by the regression line superimposed on the plot. This relationship is weaker than would be expected for measures that agree.

Agreement between biuret and refractometer measures of serum total protein

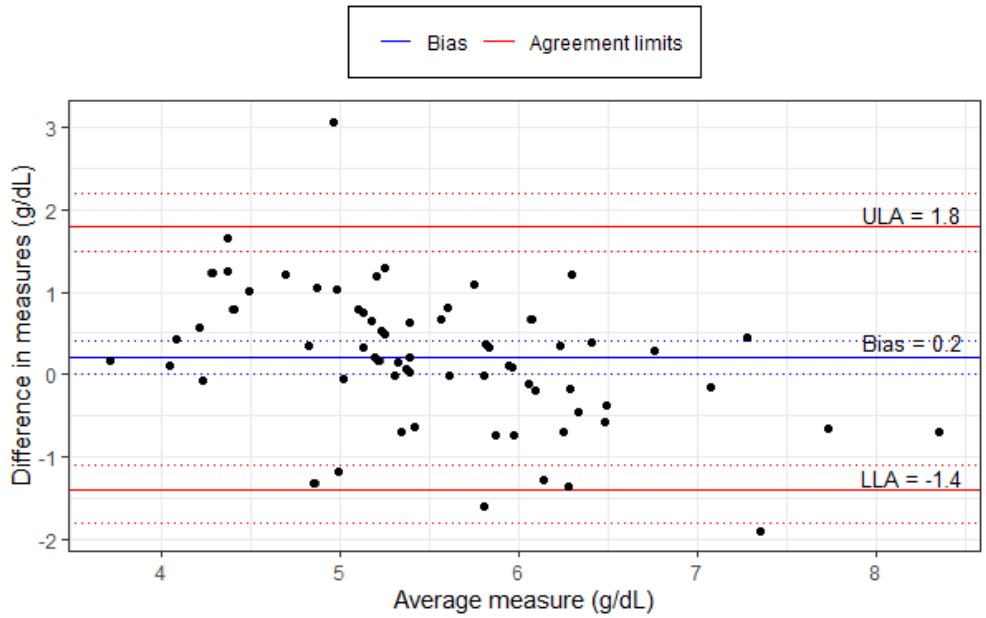

Figure 6-4 **Bland Altman plot showing the level of agreement between refractometer and biuret measures of serum total protein (n=69).** One biuret and one refractometer measure were performed for every serum sample. The mean values for each sample were plotted on the x-axis. The differences in values were plotted on the y-axis, with the biuret measures subtracted from the refractometer measures. Refractometer measures were systematically greater than biuret measures with a bias value of 0.2 [95% CI 0.01, 0.4] g/dL. The values for the upper and lower agreements were 1.8 [95% CI 1.5, 2.2] g/dL and -1.4 [95% CI -1.1, -1.8] g/dL respectively. Therefore, it is likely (probability of 0.95) that the difference between the biuret and refractometer measures of serum total protein would be as much as 1.6 g/dL.

Differences in measures expressed as a proportion of the mean value (coefficient of variation), produced a bias value of 4.6 [95% CI 1.1, 8.5] %, upper limit of agreement of 35.4 [95% CI 32.2, 38.7]% and lower level of agreement of -26.2 [95% CI -22.9, -29.4] %.

The precision of the total protein refractometer

For 67% (14/21) of the serum samples where refractometer readings were performed in duplicate, pairs of measures were identical. For the remaining 33.3% (7/21) the maximum difference was only 0.2 g/dL (the equivalent of 2 g/L). The STP values of the samples tested ranged from 4.2 g/dL – 6.9 g/dL (median 5.4 g/dL, IQR 5 g/dL – 6 g/dL).

Immunoglobulin content of colostrum

The IgG content, measured by RID, for 38 colostrum samples from 38 different nipple bottles ranged from 50 g/L to 131 g/L (median 91 g/L, mean 89 g/L, IQR 67 g/L – 108 g/L) and were within expected predictive ranges for the Brix values, as set out in Table 4-6, Chapter 4.

'Spot check' of pasteuriser

The mean immunoglobulin concentration of the five colostrum samples before pasteurisation were 94.3 g/L, 112.5 g/L, 98 g/L, 84.3 g/L, and 47.3 g/L. Measures for each sample were precise with a maximum coefficient of variation (CV) value of 5.7%. The mean immunoglobulin values of the five samples post-pasteurization were 71.3 g/L, 114.5 g/L, 93.8 g/L, 83.9 g/L, and 46 g/L respectively, with a maximum CV value of 7.9%. The mean immunoglobulin values before and after pasteurisation produced CV values of 27.8%, 1.8%, 4.4%, 0.5%, and 2.6% respectively.

6.1.6 Discussion

The main findings of interest were the timings and quantities of the first and second colostrum feeds and the total colostrum intakes in NM kids. Whilst the primary aim of the study was to measure the colostrum intakes, the serum total protein values amongst kids and the level of agreement between biuret and refractometer measures were surprising, warranting more discussion than initially anticipated.

To optimise health and welfare within a system of husbandry, the advantages of that system need to be realised and the disadvantages minimised. One disadvantage of removing kids from their mother at birth is the removal of maternal care along with the opportunity for kids to suckle colostrum *ad libitum* according to their individual behavioural and nutritional needs. For optimal outcomes, stockpersons must replicate as much work of the doe as they are able. Routine, artificial feeding of colostrum is labour-intensive, as evidenced by the description of normal farm husbandry.

Colostrum intakes will be determined by a combination of kid and stockperson factors. The study farm promoted optimal intakes by ensuring all stockpersons had good skills and motivation in feeding and caring for kids, were allocated sufficient time to do this properly and systems were put in place to easily detect and provide extra attention to kids at risk of low colostrum intakes.

Data were only collected from apparently healthy kids. Therefore, the main variables of interest – quantity and timings of colostrum intakes – should provide useful baseline data for what is achievable in this type of husbandry system.

Voluntary colostrum intakes in NM kids

NM kids had not suckled their mother prior to removal so quantities ingested were not affected by prior feeding.

Timing of first colostrum feed in NM kids

Stockpersons managed to offer all kids their first colostrum feed within two hours of birth, in line with recommended good practices for dairy calves.[160,260] Passage of immunoglobulins across the gut wall by the process of pinocytosis is a time-limited process in goat kids, as for dairy calves, with the apparent efficiency of absorption declining gradually from birth through to 'closure' of the gut at approximately 24 hours age,[213,214,222] so the sooner the kid consumes colostrum the better.

Quantity of first colostrum feed in NM kids

The very variable first feed quantities, ranging from 1.2% to 11.5% of birthweight, could be due to apparently healthy kids differing in the quantity of colostrum that satiates them and there could also be differences in how quickly individuals adapt to feeding from an artificial nipple. Subclinical problems such as anoxia or bruising during parturition, resulting in weaker suckling behaviour, and smaller first feeds in some kids cannot be ruled out.

Small first feed mitigation

Kids that ingested an overly small first feed were readily detected with the assistance of the whiteboard recording system and offered a second feed shortly after, accounting for the particularly short time of 30 to 120 minutes between feeds for some kids.

The practice of offering kids an additional evening feed if they consumed a small first feed late afternoon (n=5), proved helpful for mitigating low total colostrum intakes. Five kids increased their total colostrum intake before nightfall due to this practice; three kids substantially by 3.8%, 5.3%, and 8.7% of birthweight, and two kids more marginally by 0.4% and 1.1% of birthweight.

First feed intake according to birthweight

Voluntary intakes of first feeds (Figure 6-1) should provide reassurance as to the volumes of colostrum that can be safely administered by stomach tube, presuming that kids of similar birthweight have similar stomach capacities. Approximately 10% of birthweight should be a safe first feed quantity given that kids of 3 kg weight or less did not consume more than 300 ml, those between 3 kg and 4 kg did not consume more than 350 ml and only those over 4 kg consumed more than 350 ml with the maximum feed being 450 ml (Figure 6-1).

This is in line with dairy cattle guidelines recommending a first colostrum feed of between 10% and 12% of birthweight.[260] Most farms use a stomach tube in emergency situations and some farms adopt this as a routine feeding method. This information is important as administering too large a feed by stomach tube overly distends the stomach and risks colostrum being aspirated into the lungs, leading to pneumonia.

Quantity of second colostrum feed in NM kids

Second feed quantities varied greatly, ranging from zero to 450 ml, or zero to 11.3% of birthweight. This was most likely due to variable levels of hunger amongst kids which are determined by the quantity and quality of earlier feeds.

Some 69.6% (48/69) of kids consumed their second feed and therefore their total colostrum within 360 minutes of birth, which is the time period where the efficacy of absorption of immunoglobulins is greatest. However, colostrum still has many benefits beyond this time period and even after gut 'closure', continuing to be an excellent source of nutrition and energy, and providing local immune protection in the gut and other developmental benefits.

Total colostrum consumed over the 13-hour observation period

Most kids (72.5% or 50/69) achieved total colostrum intakes of at least 10% but did so over two separate feeds rather than in a single feed (n=8) (Figure 6-2). The only data for comparison comes from the methodology sections of controlled studies performed for a variety of reasons. Individual meals of 5% of birthweight in quantity appear to be the norm with Argüello et al. (2004)[222,256] and Morales-delaNuez et al. (2011)[195] providing 10% of birthweight split into two feeds during a 24-hour period, Fernandez et al. (2006)[182] providing 120 ml/kg split into three feeds over a 24 hours period and Moretti et al. (2012)[213] providing meals of 5% of birthweight, fed at birth, at seven hours age and at 14 hours age.

The quantity and quality of colostrum combined determine the energy available to kids. Colostrum of Brix value of 22%, the target minimum for this farm, has been estimated to contain between 5.0 MJ/kg and 7.9 MJ/kg (Table 4-6, Chapter 4). This is estimated to provide energy of between 0.25 MJ/kg of birthweight and 0.39 MJ/kg of birthweight where a kid consumes 5% of their birthweight in colostrum. A kid receives energy of between 0.50 MJ/kg of birthweight and 0.79 MJ/kg of birthweight when they consume 10% of their birthweight in colostrum. To date, studies of the energy requirements of neonatal ruminants in the first hours of life appear lacking.

Calculating the quantities of colostrum consumed as a proportion of birthweight was useful for comparing kids during this study, as it standardises the measure of colostrum intake across the

different birthweights. However, this is not a very practical measure to use in real-time on farms, due to the various time pressures on stockpersons. Therefore, straightforward targets based on volume (ml) are appropriate, aiming to set a target minimum volume intake per kid that strikes a sensible balance between protecting kids at risk of low intakes and avoiding slowing the movement of kids through the housing system and onto the next stage, which can create another set of problems.

Whilst 90.2% (74/82) of NM kids met the farm's target total colostrum intake of at least 250 ml, it must be noted that this minimum target can represent from 4.7% of birthweight to 11.9% of birthweight, estimated using the weight range of the kids in this study.

Brix values of colostrum

Despite the farm policy of measuring colostrum on collection, a small proportion (8/151 or 5.3%) of samples taken directly from the nipple bottles had Brix values less than 22%, the lowest being 17%. The most likely cause is the less accurate readings at the time of collection due to suboptimal maintenance of the refractometer, such as the prism sometimes not being properly cleaned or dried.

M kids

Colostrum intakes of the M kids will have been influenced by prior suckling. These kids were offered more than two feeds due to stockperson uncertainty over the quantity they suckled prior to removal from their mothers.

Serum total protein values

Similar principles apply when using STP as an indirect measure of passive transfer in goat kids as in dairy calves; immunoglobulin is a type of protein and the higher the circulating immunoglobulin levels then the higher the STP. A dairy cattle guideline was used due to the lack of goat-specific data.

Findings of interest were that the STP values in the convenience sample of kids did not differ greatly from those observed by the farm's vet and that the biuret and refractometer measures of STP showed less agreement than expected.

STP values were not dissimilar to those observed by the farm's vet despite the altered timing of blood sampling and the biuret method being used. During the study kids were blood sampled at 24 to 48 hours of age when circulating immunoglobulin levels should be peaking, without undergoing the disbudding procedure, and a larger proportion of kids than normal were tested. Findings suggest that the normal timing, use of the total protein refractometer and the disbudding procedure were

not radically altering values. However, inferences beyond this are not possible as testing was performed within the limits of Recognised Veterinary Practice[327] and not with a methodology designed to robustly compare different groups.

These STP values may be appropriate for kids on this farm, representing the best values that can be achieved when the husbandry system is running optimally. They may even provide benchmark values for groups of kids against which the farm could measure its performance in the future, for example during busier kidding sessions where larger numbers of kids are born over a shorter time, with stockpersons working at greater speed and levels of tiredness.

There is little other data for comparison. O'Brien et al. (1993)[217] observed similar values (mean 5.4 g/dL, median 5.12 g/dL, IQR 4.6 g/dL – 6.3 g/dL, range 3 g/dL – 7.4 g/dL) when measuring STP by refractometry for 41 newborn kids on an intensively managed commercial dairy goat farm in the USA. Kids were fed colostrum by both nipple bottles and by natural suckling, but quantities consumed were not measured.

Poor colostrum quality could lead to lower passive transfer and lower STP values but was not deemed a problem on this farm. Most of the colostrum feeds measured 22% Brix or greater. All colostrum was handled according to good practice, in a manner that should maintain its quality from first milking through to the point of feeding; it was hygienically collected; the duration and intensity of heat treatment (60 minutes at 60°C) should have killed most bacteria and many disease-causing organisms[160,196,197] without an overly detrimental effect on immunoglobulin content; it was gradually thawed and it was not left standing in the warmer for long periods of time providing minimal opportunity for bacteria to multiply to levels that would inhibit the absorption of immunoglobulin in the gut.[328] Additionally, the direct measures of immunoglobulin showed that values were within the expected prediction interval for the Brix value (Table 4-6, Chapter 4). The 'spot check' of the pasteuriser overall did not show an unexpectedly large reduction in immunoglobulin, making it unlikely that the immunoglobulin in the colostrum was greatly damaged by the heat. However, one sample did show a sizeable reduction in IgG content of 27%, from 94.3 g/L pre heat treatment down to 71.3 g/L post heat treatment. There has been limited investigation of the extent to which heat treatment affects the immunoglobulin content of goat colostrum samples. It is possible some samples may be more susceptible to degradation than others.

It is possible that the STP values that can be achieved in goat kids differ to those possible in dairy calves. Further research is required, involving both controlled studies in a research environment and observational studies on farms where there is exposure to real-world factors. The following topics would be a priority.

Firstly, there is a need to identify the serum immunoglobulin levels that can be achieved in goat kids fed optimally and the serum immunoglobulin levels below which morbidity and mortality worsen. Studies are sparse. O'Brien et al. (1993)[108] recommended a minimum circulating immunoglobulin value of 1200 mg/dL based on the mortality and morbidity data for 41 kids on a farm in the USA. Mellado et al. (1998)[216] estimated a threshold value of 800 mg/dL or greater based on the survival rates of 63 kids born on a farm in Mexico.

Secondly, a better understanding of the extent to which the apparent efficacy of absorption (AEA) varies amongst healthy kids is needed. Moretti et al. (2012)[244] demonstrated that AEA in goat kids reduced with time after birth but information about the normal variability of AEA amongst healthy kids is lacking.

Thirdly, better knowledge of the immunoglobulin fraction of STP is required for the correct interpretation of STP as an indicator of passive transfer status in goat kids. Again, studies are sparse and the methodologies limit the inferences that can be made. O'Brien et al. (1993)[217] found that an STP by refractometry of 5.4 g/dL suggested immunoglobulin levels of 1200 mg/dL or greater in the 41 kids studied. Several studies have used electrophoresis to provide information on the protein types comprising STP.[182,204,220,223,224] However, they do not evaluate the STP fractions comprised of immunoglobulin at the level of the individual.

Finally, there are other considerations unique to the context of dairy goat farming. Regarding blood sampling, the most efficient time for the vet, least stressful time for the kid, and most cost-effective time for the farmer is when the kid is unconscious under anaesthetic at the time of routine disbudding. Therefore, studies establishing how circulating immunoglobulin and STP values alter during the first seven to 10 days of life are required. Current studies evaluating changes in circulating total protein and immunoglobulin with time[182,204,222,255] present data as mean values only, and sample sizes are small, limiting inferences that can be made. The impact of anaesthesia, drug administration, and other aspects of the disbudding also needs evaluation.

Aside of whether the dairy calf STP threshold is appropriate for goat kids, any threshold value should be used as a guide only. The distribution of the STP values, including their proximity to the threshold value, should be considered. Small differences in values can lead to very different passive transfer classifications, as evidenced by the similar descriptive statistics obtained for both the biuret and refractometer methods but the very differing passive transfer classifications derived from these results.

Level of agreement between biuret and refractometer measures of serum total protein

The vet and researcher had presumed that biuret and refractometer measures of the STP would closely agree, a view likely shared by many veterinary practitioners. Whilst group-level STP values were similar for the biuret and the refractometer methods, the agreement was poorer than expected at the level of the individual (± 1.6 g/dL). This difference was clinically important, as it is probable (probability 0.95) that a biuret measure of 5.2 g/dL could have a corresponding refractometer measure as low as 3.6 g/dL or as high as 6.8 g/dL. The former indicates failed passive transfer and the latter very good passive transfer.

On reflection, this difference should not have been so surprising because the two measurement methods are based on different principles. The biuret method enolizes the peptide bonds of proteins to provide a direct and accurate measure of STP. The STP refractometer measures the angle of refraction of light as it passes through serum, which is determined by the total solid content of serum.[257] Whilst protein is the main solute, there are other non-protein solutes in serum. Estimates of STP assume that the non-protein components of serum are constant among individuals. However, it is logical to assume that biological variables will differ amongst individuals unless demonstrated otherwise. Solutes such as cholesterol, urea, lipoproteins, and glucose are known to add recognisable error of between 0.5 g/dL to 1 g/dL to total protein estimates.[257]

If accurate measures of STP were an accurate predictor of immunoglobulin content, then the agreement between methods would be too poor for the total protein refractometer to be used in place of the biuret method. However, this is not the case. Whilst there is a clinically useful relationship between STP level and immunoglobulin this relationship is limited, as it is very likely that the STP fraction comprised of immunoglobulin will vary considerably between kids.[217] [108] Similarly, there will be a clinically useful but limited relationship between the total solid content of serum and the immunoglobulin content, with the proportion of total solids comprised of immunoglobulin varying. O'Brien et al. (1993)[217] listed the values for STP measured by refractometry and serum immunoglobulin measured by zinc sulphate turbidity assay for the 41 kids sampled. From their data, the proportion of STP that is immunoglobulin can be calculated and ranged from zero to 59.9% (median 22.4%, IQR 5% – 30.4%). This was for estimated STP values ranging from 3 g/dL to 7.4 g/dL (median 5.2 g/dL, IQR 4.6 g/dL – 6.3 g/dL).

Even the very extensive studies performed on calves do not fully capture the relationship between STP measures and immunoglobulin. Where analyses have retained data in a continuous format, they have explored correlations and regression which focus on the mean immunoglobulin content for a given STP value but have not described the variability in immunoglobulin values around this mean in

the form of a prediction interval. Analyses omit this step, choosing to dichotomise data and analyse values for sensitivity, specificity, and the predictive values of STP for classifying serum as containing 10 g/dL or more. Whilst this approach has its uses, it is less effective at capturing the variability in the proportions of STP that comprise immunoglobulin, especially given that confidence intervals for point estimates are often omitted. It must be noted that in dairy calves there have now been numerous studies providing sufficient evidence for a good assessment of the replicability of results and meta-analyses, which can compensate for more limited inferences that otherwise could be made.

To summarise, both the biuret and refractometer methods provide helpful information about the IgG content of the serum, as evidenced by numerous studies in dairy calf serum, but they do it in slightly different ways. They will be useful for assessing passive transfer status at the level of the group but not at the level of the individual animal.

The distinction between methods is rarely emphasised in the literature or in practical settings. George (2001)[257] made the useful suggestion of using the term 'total protein by refractometry' throughout papers where refractometry has been used to avoid conflation with a reference method. The total protein refractometer measures of serum probably have a much closer relationship with Brix refractometer measures of serum than with that measured using a reference method. Most studies in dairy calves have used the refractometry estimates of STP as the predictor, due to its lower cost and greater ease of use on farms.[264,292,329–333] Far fewer have used a reference method of measuring STP.[334,335]

Few other studies have analysed the agreement between biuret and refractometer measures of STP and there are no other data for goat kid serum. Agreement between measures has been evaluated for beef calf serum (n=108),[336] dairy calf serum (n=101),[337] and the serum of adult goats (n=58), sheep (n=67) and cattle (n=120)[338] using Bland Altman analyses.

Bias values were small for all studies, at 0.44 g/dL,[336] 0.75 g/dL,[337] and 0.5%, 6%, and 5.2% respectively,[338] and not dissimilar to that found in the goat kids (0.2 [95% CI 0.01, 0.4] g/dL or CV value of 4.6 [95% CI 1.1, 8.5] %). However, the direction of bias differed in the goat kids, with the refractometer reading systematically higher than the biuret measures. Possible explanations are the use of different instruments, sampling error, and aspects of goat kid serum. Different laboratories undertaking the biuret measures may calibrate their equipment slightly differently, enough to contribute to a small difference in bias values amongst studies.

The agreement limits define the size of the difference between biuret and refractometer measures that is unlikely to be exceeded (probability 0.95). However, Denholm et al. (2021)[337]and Katsoulos et al. (2017)[338]did not report agreement limit values, appearing to have mistakenly referred to the bias value in their place. Agreement limits can be estimated by observing the published plots. Those of Denholm et al. (2021)[337] suggest it is unlikely that the biuret and refractometer measures would differ by more than approximately 2 g/dL (equates to 20 g/L), which is not dissimilar to those in goat kid serum (± 1.6 g/dL). Those of Katsoulos et al. (2017)[338] suggest it is unlikely that measures would differ by more than 16%, 13%, and 18% for sheep, cattle, and goats respectively, which are lower values than found for goat kid serum (± 31 [95% CI 27.5, 34.1]%). Vandeputte et al. **(**2011)[336] did not report agreement limits values or display the Bland Altman plots, instead reporting strong, positive, linear associations between measures (r=0.961, r=0.953 and r=0.964 respectively). Whilst a strong correlation is a prerequisite for good agreement, it is not a measure of agreement and can often be found even where there is poor agreement.

The precision of refractometer measures of serum total protein

The high precision of the duplicate measures (n=21) provided some reassurance as to the accuracy of the refractometer when measuring fresh goat kid serum. Whilst good precision does not guarantee accuracy, poor precision would indicate a problem with accuracy. Katsoulos et al. (2017)[338] also found precise values (CV values of 1% or less) when measuring the serum of adult goats, sheep, and cattle. However, Denholm et al. (2021)[337] found lower precision when measuring dairy calf serum with a median CV value of 5.4% (range 0% – 88.7%). The reasons are unclear. Further studies that investigate the precision of measures for goat kid serum after different treatments, for example comparing values of fresh serum with those after a freeze-thaw cycle, would be useful for informing the use of the instrument in a wider range of settings.

STP values in the M kids

The STP values for the M group of kids were as high as those for the NM group of kids, strongly suggesting these particular kids coped when left with their mothers for a period of time amongst the other adult goats in the pen, managing to suckle adequately and not mismother. This is important as 20% (22/110) of the kids were born during the night and it is impractical for them to be removed within 10 minutes. There were insufficient data to make more general inferences about kids left with their mothers alongside other adult goats or to compare natural suckling with artificial feeding.

6.1.7 Conclusion

This study has provided helpful information about the colostrum intakes that can be achieved in goat kids fed artificially by nipple bottles when a commercial dairy goat farm is operating its husbandry system optimally with the various real-world constraints.

However, it represents one kidding only and was performed within the limitations of Recognised Veterinary Practice. Measures were also taken during what can be regarded as a quiet to moderately busy kidding session, in terms of the numbers of kids born per day. More studies of this type would be useful.

Areas that are priorities for further research have been highlighted, many of which will fall outside of Recognised Veterinary Practice, requiring a Home Office licence under the Animals (Scientific Procedures) Act 1986[339] to perform in the UK. These should provide the evidence needed to properly interpret STP values in goat kids. Studies should also aim to determine whether there are sufficient health and production benefits to feeding higher quality, quantity, and frequency of colostrum as routine, or whether overall the current use of resources achieves the best balance for the overall running of the farm.

7 Chapter 7

7.1 Discussion

This section summarises the studies outlined in this thesis, outlining their original contributions to research and practice in the field. The overarching principles that shaped this research are discussed. The various strengths and limitations are identified now that the research is complete. Proposals for the direction of future research are made.

7.1.1 Summary of research chapters

Current practices and concerns within the UK dairy goat industry needed to be better understood for research to have optimal value, which resulted in an initial postal survey of the farmer membership of the Milking Goat Association (Chapter 3).

Farmers were asked questions about their husbandry practices, their goats, and their priorities for further research. Seventy-three percent of Milking Goat Association members responded, representing 38% of commercial dairy goat farms and 53% of the commercial dairy goat population in England and Wales at the time of the survey.

The findings were comprehensive and showed extensive variation in farm practices. Farmers reported pneumonia and scours (diarrhoea) as the most prevalent illnesses of their kids. Pneumonia, diarrhoea, failure to conceive, and poor growth were the most prevalent observations of youngstock. Overly fat body condition, assisted kidding, failure to conceive, and difficulty drying off were the most prevalent observations of adult milking goats. Farmers' top priorities for further research were kid health (79.5% of farmers), Johne's disease (69.5%), tuberculosis (59%), and nutrition (47.7%).

Three interrelated studies relevant to kid health, focusing on colostrum quality and colostrum feeding of kids, were then undertaken.

Chapter 4 described an observational study undertaken on UK farms with the aim of providing information on the nutritional and immunoglobulin content of colostrum from commercially farmed dairy goats and the usefulness of the Brix refractometer as a predictor of goat colostrum quality.

Colostrum samples were obtained from a total of 461 Saanen and Saanen cross-breed goats from four different kidding sessions that took place on three different commercial farms. Immunoglobulin levels were measured using radial immunodiffusion, the fat, protein, and lactose content were

measured using infrared spectroscopy and the energy content was calculated from the nutritional analysis results.

The main findings were that values for colostrum measures varied considerably amongst goats and this level of variability persisted when goats were grouped by kidding session. Colostrum samples of similar total solid content comprised differing proportions of fat, protein, and lactose and therefore differing energy content. Colostrum samples of similar protein content had very variable immunoglobulin content.

Linear regression analyses established that Brix measures could significantly predict the mean total solids, energy, and immunoglobulin content. Numerical values for the prediction intervals for these variables were provided over a Brix range of 15% to 32%.

Chapter 5 described a study of the reliability of Brix measures of goat colostrum. This study was undertaken because colostrum is structurally quite different from the sucrose solutions against which Brix refractometers are calibrated. Quantifying agreement between repeat Brix measures of colostrum was useful for both informing the methodology of the goat colostrum quality study (Chapter 4) and for informing the routine usage of Brix measures on dairy goat farms.

Repeat Brix measures of unique colostrum samples (n=107) were performed under controlled laboratory and farm conditions using an optical and a digital Brix refractometer. Agreement between repeat measures of colostrum samples was evaluated using Bland Altman plots, establishing the lower and upper level of agreements, denoted as LLA and ULA respectively.

The greatest agreement was between paired optical measures (LLA -0.56, ULA 0.62 Brix %) and paired digital measures (LLA -0.75, ULA 0.61 Brix %) performed under controlled laboratory conditions. Agreement lessened slightly when comparing optical and digital measures (LLA -1.09, ULA 0.82 Brix %) and further still when optical and digital measures were performed under farm conditions (LLA -1.62, ULA 1.19 Brix %). The least agreement was found when comparing measures performed on fresh colostrum on farm with those on thawed colostrum at a subsequent date (LLA -2.37, ULA 1.99 Brix % for digital measures, and LLA -2.05, ULA 1.46 Brix % for optical measures).

Chapter 6 described a case study measuring the colostrum intakes of farmed dairy goat kids where the routine practice was to remove kids at birth and bottle feed them colostrum. Removing kids at birth and artificially feeding them colostrum used to be uncommon practice in the UK but this is no longer the case. Chapter 6 also described the serum total protein values of the kids measured using the biuret method as well as a serum total protein refractometer when assisting the farm's veterinary surgeon with a clinical query.

The main findings of interest were the timings and quantities of the first and second colostrum feeds and the total colostrum intakes over the observation period of the first 13 hours of life. Stockpersons managed to offer all kids their first colostrum feed within two hours of birth. The quantities of first feeds consumed were very variable (range 1.2% – 11.5% of birthweight, IQR 4.3% – 7.3% of birthweight). Some 69.6% (48/69) of kids consumed their second feed and therefore their total colostrum within 360 minutes of birth. Most kids (50/69 or 72.5%) achieved total colostrum intakes of at least 10% over the 13-hour observation period but did so over two separate feeds rather than in a single feed.

There was considerable variation in serum total protein values amongst kids. Summary statistics for the serum total protein values for the groups of kids were similar when measures were performed using the biuret and refractometer techniques. However, measures showed relatively poor agreement at the level of the individual kid when analysed using Bland Altman plots.

7.1.2 Original contributions to research

Several original contributions to research have been made. The postal survey of the MGA farmer membership (Chapter 3) established key husbandry practices on MGA farms at the start of the project in 2017/2018 and farmer priorities for future research. The findings provided crucial context for shaping the Ph.D. research and will also be useful for others undertaking goat-related research.

Chapter 4 established baseline data for some important colostrum quality variables; immunoglobulin, fat, protein, lactose, and energy estimates. To date, there have been no published studies of colostrum for goats in the UK and few robust studies globally.

The results highlight the extensive variation in colostrum quality amongst goats, which persists across farms and kidding sessions. It also persists where goats share similar qualities relating to age, breed, and body condition, and were from the same kidding session. It is likely that a combination of factors, such as parity, breed, age, and nutrition affect colostrum quality. However, these are yet to be thoroughly investigated in goats. To date, the small number of studies considering these factors[170,175,180,190] are likely unpowered given the large variability in colostrum measures amongst goats evident from our study.

Zobel et al. (2020)[170] found a similar dispersion in values for immunoglobulin content in farmed goats in New Zealand as in our study and hypothesised that the large variation in immunoglobulin content amongst goats, even those with colostrum of very similar Brix value, may in part be due to the sampling strategy, such as samples being collected at differing times within a 24-hour period postpartum and goat kids sometimes having suckled their mothers prior to collection. However, the

design of the study of colostrum quality (Chapter 4) ensured that all goats from kidding sessions 1A and 1B were sampled within 20 minutes of birth and prior to any suckling. Therefore, additional factors will be responsible for this variability, for example, individual goat differences, as well as goats within large groups receiving slightly different management and access to resources,[134,135,278,301,302] despite husbandry appearing consistent at the group level. Extensive variability in colostrum quality persisted amongst primiparous goats, where the length of the dry period could not have had an impact.[174]

There has been little study of the nutritional and energy content of colostrum, even in dairy cattle, despite the importance of good nutrition and high energy intakes for neonates.[160,164,289,290] As a result, there is little data with which to compare the baseline values for energy and nutrition produced by the thesis research (Chapter 4). Some helpful comparisons can be made with the findings of Kessler et al. (2019, 2021)[180,181] who studied 116 commercially farmed goats of mixed breeds from 10 different farms, finding the not dissimilar mean and standard deviation values for protein and fat content. Forty-seven of these goats (18 Saanen, 21 Toggenburg, eight Anglo Nubian) are breeds commonly found on UK farms.[228]

The findings of this thesis (Chapter 4) are that colostrum samples of similar total solid content comprised differing proportions of fat, protein, and lactose and, therefore, differing energy content. Other studies do not appear to have undertaken similar investigations. Both feeding and genetics play important roles in determining the composition of milk from dairy goats.[299] Further research is needed to establish the extent to which these factors affect colostrum composition.

As expected, analyses of the relationship between protein content and immunoglobulin content found a strong, positive correlation, not dissimilar to that found by Quigley et al. (2002)[164] in a study of 146 Jersey cows (r =0.71) and Argüello et al. (2006)[175] in a study of 60 Majorera dairy goats where (r =0.695). This thesis research demonstrated that colostrum samples of quite similar protein content had a quite variable immunoglobulin content. The reasons are likely to be multifactorial including genetics, the environment, general husbandry,[190] vaccination schedules, responses to vaccines, and warrant further investigation. Other studies of the relationship between protein and immunoglobulin content of colostrum are sparse, even in dairy cattle.

This research has produced new information about the Brix refractometer as a predictor of goat colostrum quality. Linear regression analyses show that Brix measures significantly predict mean total solids, energy, and immunoglobulin content. The findings are reproducible with Zobel et al. (2020), who found a similar size relationship between Brix values and immunoglobulin content measured using RID. The relationship between Brix values and the fat, protein, and lactose of

colostrum are not dissimilar to those found by Kessler et al. (2019, 2021).[180,181] This reproducibility increases confidence in inferences.

Chapter 4 also provided prediction intervals for colostrum measures for the range of Brix values from 15% to 32%. This type of analysis has not been observed in other studies of colostrum.

In Chapter 5, the reliability of Brix readings of colostrum was tested rather than presumed. This was thought necessary as colostrum has a very different physical composition to the sucrose solutions against which Brix refractometers are calibrated. To date, there appear to be only two other published studies evaluating the repeatability of colostrum Brix measures that use appropriate measures of agreement.[321] Balzani et al. (2016)[266] measured sow colostrum (n=124) and Zobel et al. (2020)[170] measured goat colostrum (n=300). Both studies found good agreement between measures when analysing data using the intra-class correlation coefficient and Lins concordance coefficient respectively. This research adds to current evidence by expressing the level of agreement in absolute units (Brix %), using Bland Altman analyses, which is more practically useful than a correlation coefficient value.

To the author's knowledge, there are no other published studies measuring the voluntary colostrum intakes of goat kids on commercial dairy goat farms, whether suckled naturally or artificially fed. In Chapter 6, the study farm promoted optimal intakes by ensuring all stock persons had good skills and motivation in feeding and caring for kids, were allocated sufficient time to do this properly and systems were put in place to easily detect and provide extra attention to kids at risk of low colostrum intakes. Therefore, the main variables of interest – quantity and timings of colostrum intakes – should provide valuable baseline data for what is achievable in this type of system. Whilst the primary aim of the study was to measure the colostrum intakes, the serum total protein values for the group of kids and the level of agreement between biuret and refractometer measures were surprising, warranting more discussion than initially anticipated.

The vet and researcher had presumed that biuret and refractometer measures of the STP would closely agree, a view likely shared by many veterinary practitioners. Whilst group-level STP values were similar for the biuret and the refractometer methods, the agreement was poorer than expected at the level of the individual (agreement limits ±1.6 g/dL). This difference was clinically important, as it is probable (probability 0.95) that a biuret measure of 5.2 g/dL could have a corresponding refractometer measure as low as 3.6 g/dL or as high as or as high as 6.8 g/dL. The former indicates failed passive transfer and the latter indicates very good passive transfer. To the author's knowledge, this is the first information on the agreement between biuret and serum total protein refractometer measures of goat kid serum.

7.1.3 Practical applications

This research has provided evidence useful for guiding colostrum feeding practices on farms. Providing prediction intervals for immunoglobulin, total solids, and energy in a quick reference table (Table 4-6, Chapter 4) is a useful approach not used by other studies. Values for a given Brix value can be quickly identified. Prediction interval values allow for a more nuanced approach to practical colostrum management than is possible with the single value of 21.4%, derived from the ROC curve analysis, above which colostrum can be categorised as good quality.

The approach could depend on the logistics of the individual farm, their aims, and the level of certainty required. For some farms, a simple 'keep' or 'discard' decision, based on a single Brix measure of colostrum, such as the 21.4% value derived from the ROC curve, might be appropriate. Examples are where colostrum is saved for emergency situations, where a farm has a high prevalence of poor-quality colostrum, or where stockpersons are new, and adjusting, to the use of the refractometer. For other farms, a more nuanced approach may be possible and desirable. An example would be when kids are removed from their mothers at birth and artificially fed colostrum. Here the colostrum collected from the first milking of does could be measured, and split into 300 ml aliquots for pasteurisation and storage with the Brix value written in marker pen on the bag. Stockpersons could aim to feed over 25% Brix value colostrum to all kids, dropping down to between 23% and 25% if this is in short supply but they should aim to never to drop below 22%. If there is a need to go below 22% then colostrum as close to this value as possible should be used and larger, more frequent quantities fed to try and offset the impact of poorer quality. Aliquots could be stored on a shelf in the fridge or freezer in order of increasing quality, so the highest quality colostrum can be readily located.

Evidence for the repeatability (reliability) of Brix measures of colostrum (Chapter 5) is suitable for making informed decisions about how data collection could be modified during research. The findings show there is close enough agreement between the optical and digital measures for them to be used interchangeably, except where readings are classed as "off scale" on the optical refractometer, in which case the digital refractometer would be used to assign a specific value for that sample.

The measurement error was not overly large (± 1.4 Brix % for fresh colostrum) and accuracy could be improved using the means of at least two measures for each sample as the data point for that sample. During extremely busy periods, such as when large numbers of goats give birth during a very short time period, then it was considered reasonable to make adjustments to measurements, optimising the amount of data collected without compromising the quality of measures. Here one

Brix measure only would be performed on fresh goat colostrum and then the sample would be stored frozen at minus 20°C for later thawing and retesting at a more convenient time, where a further two to four Brix readings could be performed under farm type conditions. The means of these measures could be used as the data point for that sample.

The results were also useful for informing routine usage of Brix refractometers on farms as part of general colostrum management. Single measures should still be appropriate because the extra work involved in taking two readings and finding the average is unlikely to be offset by any practical gains from a small increase in accuracy. Rather than performing more than one Brix reading per sample, stockperson time and energy are better invested in ensuring good practice in measuring colostrum, for example, proper maintenance and calibration of the refractometer, proper cleaning of the prism between readings, and ensuring colostrum is well mixed so solids are evenly distributed before testing.

It is helpful to know that digital and optical instruments can be used interchangeably as optical instruments are more affordable. There is no need for farmers to assign a specific value to colostrum of over 32%, something that only the digital refractometer can do, as they confidently regard anything “off scale” as being good quality.

The case study in Chapter 6 provides useful new information about the colostrum intakes that can be achieved in goat kids fed artificially by nipple bottles when a commercial dairy goat farm is operating its husbandry system optimally with various real-world constraints.

This is useful baseline information about the timings and quantities of colostrum intakes in kids, and with further development has potential for use in benchmarking. It describes some useful, practical working practices that this farm uses to mitigate low feed intakes. Examples include the use of the whiteboard to track colostrum intakes.

Voluntary intakes of first feeds (Figure 6-1) should provide reassurance as to the volumes of colostrum that can be safely administered by stomach tube, presuming that kids of similar birthweight have similar stomach capacities. Approximately 10% of birthweight should be a safe first feed quantity given that kids of 3 kg weight or less did not consume more than 300 ml, those between 3 kg and 4 kg did not consume more than 350 ml and only those over 4 kg consumed more than 350 ml, with the maximum feed being 450 ml.

However, it must be borne in mind this is a case study of a single kidding session on one farm. This kidding session could be regarded as a quiet to moderately busy kidding session. Repetition is needed to build a body of baseline data.

7.1.4 Overarching principles

Several overarching principles shaped the choice of research topics and the design of studies in this thesis.

Firstly, the research was an iterative process, with the findings of each research chapter informing the findings of other chapters. This was necessary due to the scarcity of published, robust goat-specific evidence available for consultation when interpreting results. Secondly, whilst the large body of colostrum research in dairy cattle provided helpful guidance on appropriate studies, goats are likely to differ in important ways. Thirdly, it was desirable for research findings to provide immediate practical benefits on farms in addition to contributing to the research evidence base. Fourthly, decisions were needed as to the level of evidence most appropriate for further developing the goat colostrum evidence base. Finally, all studies needed to be feasible with the resources available, which in turn would determine the various strengths and limitations of the research. Each of these principles is discussed in turn below, along with reflections on the outcomes now that the research is complete.

Research as an iterative process, with the findings of each research chapter informing the findings of other chapters

The findings of the different research chapters were interrelated, with the findings of one study useful for informing and interpreting the findings of other studies.

The main reason for choosing the Brix reliability study (Chapter 5) was so that findings could be used to inform the data collection process and interpretation during the main colostrum quality study. This proved useful with the findings guiding the number of measures taken per sample and how measurement protocols could be altered during particularly busy data collection periods without compromising the quality of the data.

Another example is where the energy and immunoglobulin content of the colostrum consumed by kids in the kid feeding case study were estimated, using the prediction intervals for these variables calculated for different Brix values in the main colostrum quality study (Chapter 4).

Goats are likely to differ from cattle in important ways

Whilst the extensive studies of dairy cattle colostrum research were useful for guiding goat research, it was recognised there would likely be important species-specific differences. Firstly, goats have their unique biology meaning areas such as the physiology of colostrogenesis and values of important colostrum variables may well differ from those in cattle. Secondly, certain husbandry

practices will be unique to commercial dairy goat farming, creating differing practical challenges, which in turn leads to differing emphases when planning applied research. To illustrate, commercial dairy goat farms differ from dairy cattle farms in that often several hundred goats give birth within a short time period, often to multiple offspring, giving rise to a very large number of neonates requiring care simultaneously. It was important that any research was viewed through the lens of the challenges unique to dairy goat farmers.

Research findings with immediate, practical benefits

The studies were intended to have an applied focus, producing evidence that could have an immediate practical use for farmers in improving the health of kids on their farms in addition to contributing to the research evidence base.

To illustrate, the Brix refractometer was evaluated as a predictor of goat colostrum quality so that this affordable, practical tool could be used with reference to goat-specific values rather than extrapolating from the dairy cattle guidelines as is currently often the case. The postal survey had already highlighted the small number of farmers currently using a Brix refractometer, indicating that there was considerable scope to make practical improvements on farms by expanding its usage. This instrument would be particularly useful for the increasing number of farms removing kids at or shortly after birth and artificially feeding kids colostrum, often with the control of diseases such as Johne's in mind.

The desire to make a practical impact was also considered when presenting results. For example, data for the prediction intervals for colostrum variables for different Brix values were presented in a quick reference table so they could be readily accessed by veterinary practitioners wanting to advise farmers, and suggestions were made as to how this information might be used on farms.

Decisions about the level of evidence most appropriate

Decisions were needed as to the level of evidence most appropriate for developing the goat colostrum evidence base.[340] Different experimental designs produce different strengths of evidence,[340] for example, a well-executed, randomised control trial can often be used to determine causation whereas most observational studies cannot.

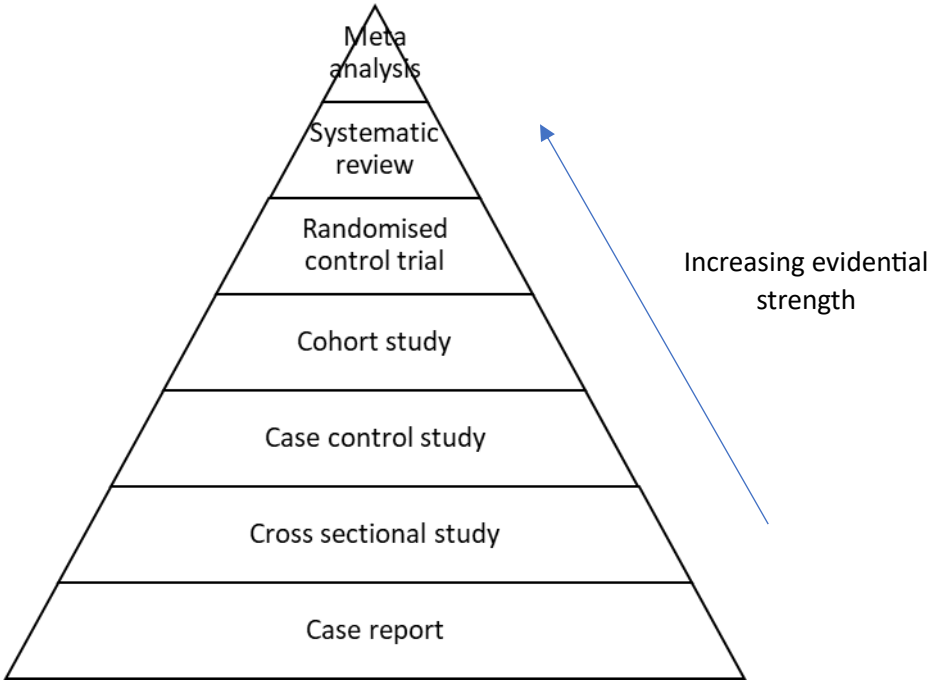

Figure 7-1 **Strength of evidence pyramid**, adapted from Wallace et al. 2022, [340] ordering the different types of scientific study according to the strength of evidence they can provide.

It is helpful if research develops logically in increments. "Consideration of the hierarchy of evidence can aid researchers in designing new studies by helping them determine the next level of evidence needed to improve upon the quality of currently available evidence."[340] Levels of evidence are illustrated in Figure 7-1. When compiling the goat colostrum literature review the author found that studies of goat colostrum often progressed to evaluating the impact of different factors on colostrum quality or on goat kids consuming colostrum without first developing a strong foundation of baseline information, and as a result overstated some inferences.

A need for robust 'baseline' data was identified. Here baseline data is defined as valid, reliable, and unbiased estimates of population parameters for important colostrum variables and a clear description of the relationship between these variables. Baseline data generated by observational, cross-sectional studies are low in the hierarchy of strength of evidence but very important nonetheless. Baseline data establishes current parameters for important variables, which in turn determines which lines of inquiry are important to pursue, and starts to generate hypotheses. Baseline data provides a strong foundation on which to build future studies. For example, the variability amongst goats of different variable values is useful for informing sample sizes, appropriate for different studies, avoiding underpowering by using too small a sample, and avoiding the

additional unnecessary expense of an overly large sample. Therefore, the Ph.D. research was pitched at this level of knowledge.

Data were collected for commercially farmed goats, as opposed to goats in a research environment, meaning that the findings had high external validity, representing real-world situations with goats subject to the multitude of real-world factors found on commercial farms. There is usually a "trade-off" between external validity and internal validity. However, controlled experiments with high internal validity were not necessary for obtaining robust baseline data.

Finally, all studies needed to be feasible and able to be completed with the resources available. Resource and logistical constraints led to varying strengths and limitations that qualified the inferences made.

7.1.5 Strengths and weaknesses of the thesis research

Weaknesses of the research

- *Convenience sampling*

A key limitation in all studies in this thesis was the need to use convenience sampling, as representative sampling techniques such as simple random sampling were not practical. Data came from a convenience sample of three farms and four kidding sessions only. Although a roster of goats due to give birth in a particular kidding session could be obtained from farm records, it could not be known in advance the exact dates, times, and order in which goats would give birth. Whilst the researcher could be present on the farm for full days when collecting data, the duration of data collection periods was between one and three weeks for each full kidding session only.

Convenience sampling is very likely to have introduced selection biases. To mitigate this, samples were described as closely as possible, hopefully identifying key biases. For example, the goats sampled were described as closely as practicable including their body condition score, parity, gravidity, and the length of the dry period. However, there are other potential unidentified biases.

The Brix reliability study was reliant on the samples collected during convenience sampling in kidding session 1A. However, this convenience sampling produced colostrum aliquots with a Brix range of 10% to 40%, representing the full range expected to the found on the dairy goat farm, keeping the agreement limits relevant. The convenience sample of 107 colostrum samples from kidding session 1 of the main colostrum quality study, used to evaluate the reliability of Brix measures (Chapter 5), was sufficiently diverse for meaningful Bland Altman analyses.

Again, during the kid feeding case study it was only practical to observe a convenience sample of consecutively born kids.

- *Potential bias in measures*

Optical readings require some interpretation of the scale by the operator and many of the higher Brix colostrum samples produced a blurred line on the scale. Knowledge of the first optical reading could have influenced the second optical readings unless there was an obvious difference of 1% Brix or greater between measures.

Strengths of the research

- *Consistency in data collection and recording*

A single researcher was present on the farm during the data collection process, undertaking the majority of the data collection, which should lead to consistency in sample collection and handling. This should remove a source of uncertainty. To illustrate, there were some results, such as where primiparous goats produced colostrum with Brix readings similar to those of normal milk, that the researcher would have queried as a mistake had they not been collecting the data themselves. However, consistency cannot be guaranteed and where there was additional help with data collection it would have been helpful to undertake inter-observer reliability studies.

- *Confidence in the measures used*

Data validity was generally not of concern. Measurement techniques for variables were chosen based on published studies, in conversation with laboratories experienced in using these measures, and with the knowledge of principles underpinning measures which made it logical to trust them as valid and reliable. However, it must be noted that the measurement techniques had been used much less for testing colostrum than in normal milk, and much less in goats than in cattle.

One potential improvement would have been to perform more than one measure per sample for each variable. This would have enabled a thorough assessment of the reliability of measures, minimised the impact of any measurement error by allowing the mean value of measures for each sample to be the data point for each colostrum sample, and supported the detection of occasional spurious values. Logistics prevented this. However, the reliability of measures for subsets of samples was evaluated instead, both during and on completion of the studies, providing a less thorough but sufficient assessment of reliability.

Poor reliability of measures would have alerted potential problems somewhere in the chain of events from data collection, handling, and storage through to testing. Concerns over the accuracy of the ELISA tests when measuring colostral immunoglobulin developed during the research, resulting in changes to the traditional RID technique. On completion of the study, preliminary results showing the level of agreement between ELISA and RID measures (n=20) (Appendix D) supported these concerns, suggesting this area to be a research priority.

- *Testing the reliability of measures*

Quantifying measurement error is valuable, especially when measuring relatively novel substances such as colostrum with an instrument designed for other purposes. Analysis is always better than presumption. There were limits to the combinations of measures that could be tested with these samples, for example, paired digital and paired optical readings on the farm were not evaluated, but sufficient information was obtained from the measures evaluated to make necessary decisions. The cause of differences in agreement limits for different combinations of refractometers and conditions could not be established with certainty but knowledge of the size of measurement error was valuable irrespective of this. Brix refractometer measures of colostrum are sufficiently precise for them to be a useful measure of goat colostrum.

- *Confidence intervals were provided*

All inferential statistical analyses included confidence intervals so that the precisions of estimates could be understood, rather than relying solely on reports of statistical significance (p-values) which can only inform whether the effect seen in the sample is likely to also exist in the wider population. Confidence intervals have generally been omitted from published studies of goat colostrum to date.

The use of the bootstrapping technique when calculating confidence intervals was helpful. Bootstrapping differs from traditional statistical techniques that use mathematical formulae by using computer programming to resample the original dataset with replacement many thousands of times, producing simulated datasets that create sampling distributions from which confidence intervals are derived. It has advantages over the traditional approach, including confidence interval calculations being possible for a wider range of statistics such as the median and inter-quartile range values.

- *Sample sizes were fit for purpose*

In advance of the research, the researcher was unsure how much data it would be possible to collect whilst accommodating the normal kidding routine on the farm, and there was also uncertainty as to

the size of the sample that would be useful. Hence, the approach was to collect as much data as possible whilst maintaining the quality of that data.

During the study, not all colostrum samples collected could be tested for all the variables of interest, due to a combination of logistical constraints and unexpected findings. When the decision was made to change to RID testing, some colostrum samples had already been thawed, tested using the ELISA technique, and discarded, so immunoglobulin measures were not available for those samples. There were also limits to the number of samples that could be exported for testing using the RID method. There were some limits to the number of samples that could be tested for fat, protein, and lactose content, as many samples were very viscous and create handling problems for the laboratory.

However, statistical analysis of data showed that confidence intervals for all variable estimates were narrow enough to be practically helpful, indicating sample sizes for all variables were fit for purpose, having provided sufficient statistical power.

- *Data were optimised*

Data were optimised by introducing additional helpful statistical analyses to those commonly used in published studies when evaluating predictors or evaluating the agreement between measures. Prediction intervals were calculated for the outcome variables at different Brix values, retaining the data in a continuous format and thereby retaining statistical power. Other studies of Brix or serum total protein refractometers as predictors have tended to use regression analyses to produce equations calculating the mean immunoglobulin value of colostrum or serum for different refractometer values but then progressing immediately to dichotomising the data and using epidemiological techniques with much lower statistical power, missing out what seems the logical next step of calculating prediction intervals. Bland Altman analyses were used to assess agreement between measures in the research as they quantify the agreement in absolute units, which is helpful for practical decision-making.

- *Statistical analyses were appropriate for the study type*

The kid feeding case study (Chapter 6) was analysed using descriptive statistics because the combination of convenience sampling, small sample sizes, and the combination of multiple factors likely unique to this farm meant that inferential statistics and generalising to the broader population was unlikely to be appropriate. Blood sampling of kids during the kid feeding case study was performed within the bounds of recognised veterinary practice, as required by the Royal College of Veterinary Surgeons Code of Professional Conduct for Veterinary Surgeons, and the Animals (Scientific Procedures) Act 1986, restricting any sampling to that required to address the clinical

question of the farm's veterinary surgeon to ensure the health and welfare of the animals in their veterinary care. Despite having low evidential strength, this case study proved very useful in providing preliminary new information and generating hypotheses that should be further investigated.

Overall, the study designs were suitable for meeting the aims of the different studies. The inferences were appropriately qualified, taking account of the various strengths and limitations, and avoiding overstating or overgeneralising findings.

7.1.6 Direction of future research

The research could be usefully progressed as follows.

Husbandry practices change with time according to different challenges faced by individual farms and by the industry generally. Therefore, periodically repeating the postal survey of the MGA membership to update on key husbandry practices and farmer concerns would be useful for informing future studies.

The evolving circumstances surrounding goat farming, will impact the direction of research. For example, one notable change in recent years is the increasing practice of separating goat kids from their mothers soon after birth, which is discussed in Chapter 3 and Chapter 5, with Ph.D. research geared towards this practice. However, if consumer attitudes and market demand change, there may be a move towards keeping newborns with their mothers for longer periods of time, which should be informed by research. This is becoming a topic of interest in the UK dairy cattle industry. Many consumers have limited knowledge of farming and of animal welfare, and certain ethical issues will hold more significance for them than others. The duration that newborns spend with their mothers is likely to be an issue that particularly resonates. An additional difficulty for large-scale commercial goat farming over dairy cattle farming is that consumers of goat milk may already perceive dairy goat farming to be more "natural", welfare and environmentally friendly, and assume such practices are already in place.

The postal survey was a rapid, user-friendly way of reaching farmers. However, combining a postal survey with farm visits to undertake semi-structured interviews with farmers would be helpful to capture some of the nuances that cannot be learned during a postal survey.

The reasons why colostrum quality was so variable amongst goats should be investigated. The reasons are likely to be multifactorial, including goat factors such as genetics, parity, breed, age, responses to vaccines, and management factors such as the environment, feeding, and vaccination schedules. For multiparous goats, the impact of the length of the dry period on colostrum quality

should be investigated. It is likely that many prior published studies of these factors were underpowered, and this should be addressed in the future.

The receiver operating characteristic (ROC) curve analysis identified 21.4% as the Brix value most accurate for identifying colostrum as good or poor quality according to a 50 g/L threshold of IgG content (Chapter 4). However, the wide confidence intervals for sensitivity, specificity, likelihood ratios, and predictive values demonstrated that this estimate was very imprecise and that much larger scale trials with increased statistical power are required in the future. These could prove expensive and logistically difficult, so an alternative may be many repetitions of smaller-scale studies where the findings can be used in meta-analyses.

Whilst the Ph.D. research focused on the main immunological and nutritional variables of colostrum, it would be important to investigate the presence and role of other components likely to benefit kids. The other main categories of colostrum quality – hygiene and the presence of disease-causing pathogens – also require further study. Investigation of methods that sanitise colostrum whilst preserving its immune, nutritional, and development functions, such as the durations and intensities of different heat treatments, would be particularly useful.

Studies focusing on the level of agreement between RID and ELISA measures of the immunoglobulin content of colostrum are a priority. Should ELISA measures of immunoglobulin be misleading then this would invalidate certain studies and have implications for how these tests are used in the future. The preliminary findings (Appendix D) showing wide disagreement between these measures are in line with the findings of Zobel et al. (2020).

The reasons why voluntary colostrum intakes were so variable amongst kids in the case study (Chapter 6) should be investigated, for example, whether kids have different natural suckling patterns that impact their intakes or whether there are natural differences in how soon after birth kids are ready to suckle. Such information could be used to guide stockpersons in achieving the best possible colostrum intakes.

The implications of the poor agreement between biuret and serum total protein refractometer measures of serum total protein in goat kids need evaluation. Based on the case study findings, it was hypothesised that the biuret and refractometer measures of serum total protein are likely to be useful for assessing passive transfer status at the level of the group but not at the level of the individual goat kid. This requires testing. The reasons for the poor agreement between measures could also be investigated by measuring other serum variables. The extent to which solutes such as

cholesterol, urea, lipoproteins, and glucose add recognisable errors when estimating serum total protein using refractometry could be evaluated.

Generally, further studies are needed for evaluating the usefulness of serum total protein measures in estimating the passive transfer of immunity in goat kids. Better knowledge of the immunoglobulin fraction of STP is required. In addition, further studies are needed as to the levels of circulating immunoglobulin that can be regarded as successful passive transfer in goat kids. There is a need to identify the serum immunoglobulin levels that can be achieved in goat kids fed optimally and the serum immunoglobulin levels below which morbidity and mortality worsen. A better understanding of the extent to which the apparent efficacy of absorption (AEA) varies amongst healthy kids would be useful.

Other considerations unique to the context of dairy goat farming in the UK are as follows. Regarding blood sampling, the most efficient time for the vet, least stressful time for the kid, and most cost-effective time for the farmer is when the kid is unconscious under anaesthetic at the time of routine disbudding. Therefore, studies establishing how circulating immunoglobulin and STP values alter during the first seven to 10 days of life are required. The impact of anaesthesia, drug administration, and other aspects of the disbudding also need evaluation.

It would be important also to evaluate the quality of different artificial colostrum replacers and the impact on kids fed these replacers, as they are increasingly being used as an alternative to natural goat colostrum by some farmers to mitigate against the risks of feeding kids disease-causing pathogens that can survive in maternal colostrum, including CAEV and MAP.

Finally, replication of research undertaken to see if results are reproducible is an essential, but often undervalued, part of developing a robust evidence base. One study alone will never be enough, even for a well-designed study with a high strength of evidence, as it is always possible that findings are due to a chance pattern in the sample.

In summary, the studies were fit for their intended purposes and the inferences made have been qualified and kept within proper limits. Original contributions to research and practice have been made. Hypotheses have been developed and the direction of future research proposed.

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9 Appendices

Appendix A Repeatability of Brix and RID measures of colostrum

Appendix A contains supplementary materials for the main colostrum quality study (Chapter 4). As part of quality control for data collected, the precision of Brix measures and RID measures of colostrum were reassessed on completion of the study.

Repeatability of Brix measures of colostrum

The repeatability of Brix measures of colostrum from kidding sessions 1B, 2 and 3, performed under farm type conditions, was assessed on completion of the study, to check that it had stayed within expected parameters, that is, repeat Brix measures of a sample were unlikely to differ (probability 0.05) by more than 2 Brix %.

The approach to analysing measures was that described by Bland and Altman (1996), appropriate where there are more than two measures for each sample.[1] Analyses involved calculating the within-subject standard deviation (Sw)[1] and the within-subject coefficient of variation (CVw)[1] using the mean square approach. Samples where a minimum of three Brix readings had been performed were used in the analysis. There were 55 samples with three Brix readings, 33 with four readings, 67 with five readings, 31 with six readings, and four more than six readings (maximum nine readings).

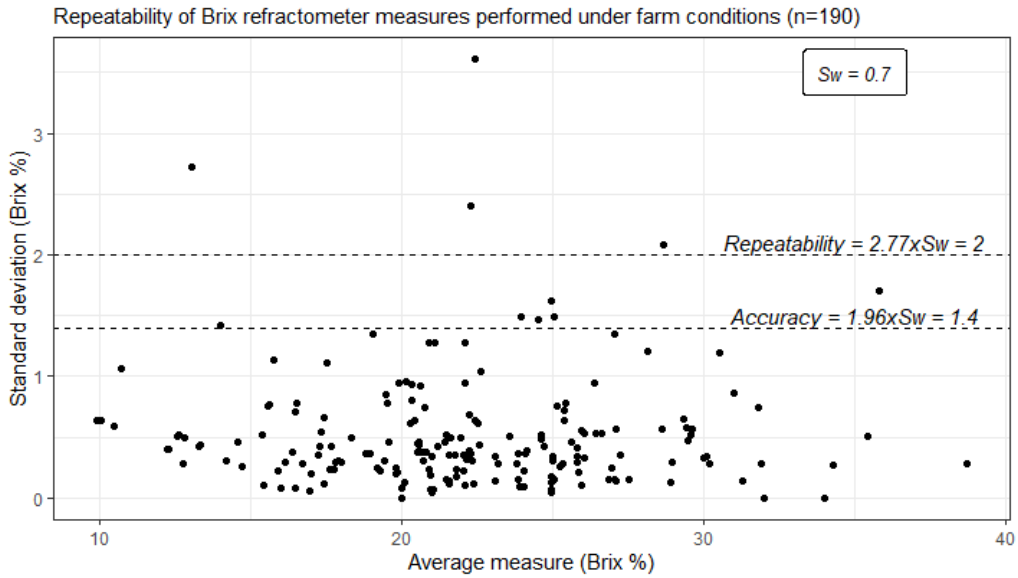

Figure A-1 **Plot illustrating the repeatability of Brix refractometer measures of fresh colostrum performed under farm conditions (n=190).** The mean Brix values for samples were plotted on the x-axis, and corresponding standard deviations were plotted on the y-axis. The within-subject standard deviation (Sw)[1] was calculated using the mean square approach. Accuracy is defined as the difference between the 'true value' and measured value and is calculated as 1.96 multiplied by Sw. Repeatability was defined as the difference between repeated measures of the same subject and is calculated as 2.77 multiplied by Sw. The within-subject standard deviation (Sw) was 0.7 Brix %. Therefore, it is likely (probability 0.95) that repeated Brix refractometer measures of a sample would differ by up to 2.1 Brix %.

Therefore, measurement error had remained within the expected range.

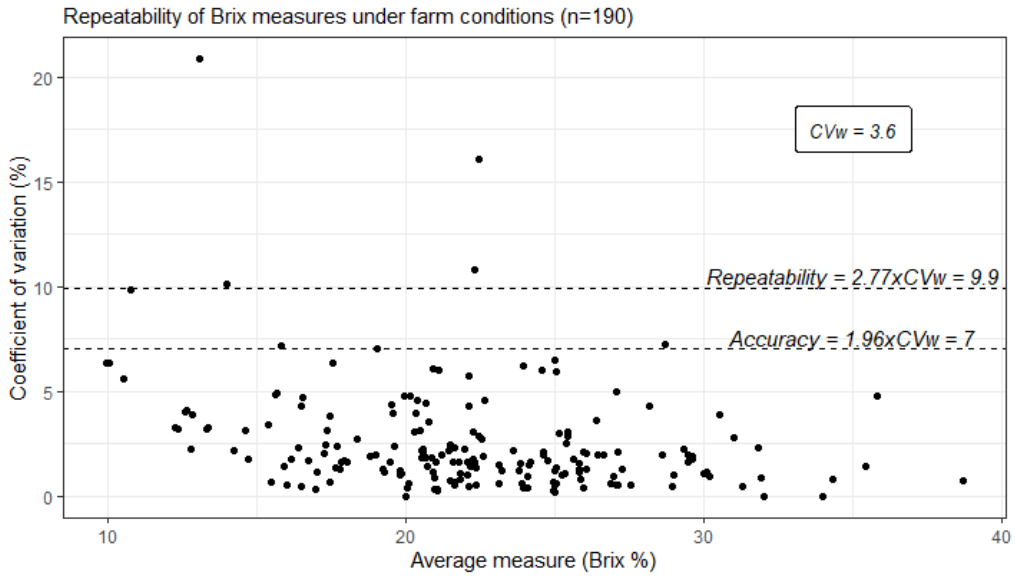

Figure A-2 **Plot illustrating the repeatability of Brix refractometer measures of fresh colostrum performed under farm conditions (n=190), with the difference in measures expressed as a coefficient of variation.** The mean Brix values for samples were plotted on the x-axis and the coefficient of variation values were plotted on the y-axis. The within-subject coefficient of variation (CVw) was calculated using the mean square approach. Accuracy was defined as the difference between the 'true value' and measured value and was calculated as 1.96 multiplied by CVw. Repeatability was defined as the difference between repeated measures of the same subject and calculated as 2.77 multiplied by CVw. The within-subject coefficient of variation was 3.6%. Therefore, it is likely (probability 0.95) that repeated Brix measures of a sample would differ by up to 9.9%.

Often laboratory tests are set a maximum acceptable coefficient of variation (CV) value of between 10% and 15%. The result provides a CV value of 9.9% which is close to, but within, this maximum value.

Measurement error for immunoglobulin measured by RID

Some 82 individual goat aliquots, where multiple RID measures had been performed, were used in the analysis. Of these aliquots, there were two readings for 63 subjects, three readings for 16 subjects, four readings for two subjects and five readings for one subject. Samples were from three different kidding sessions.

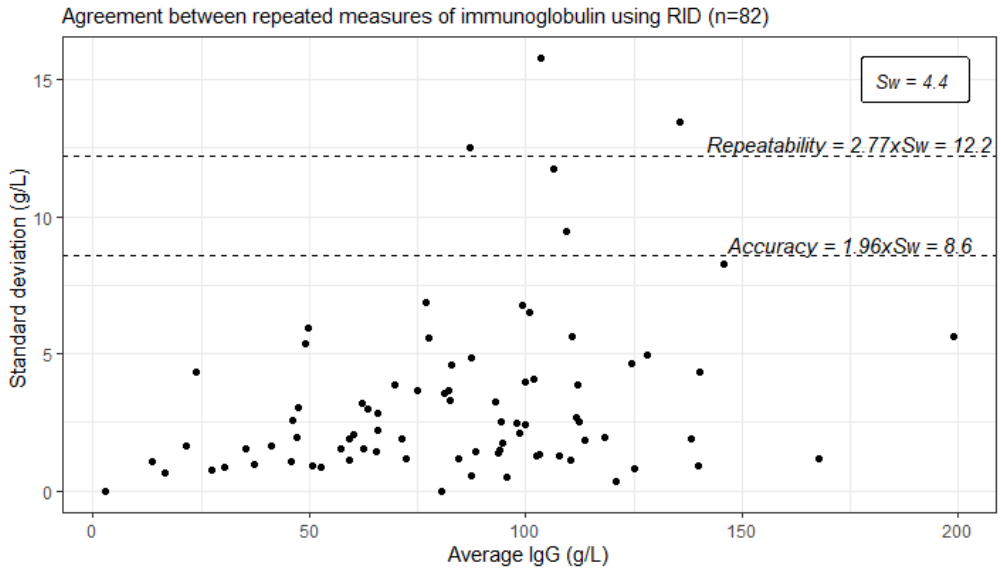

Figure A-3 **Plot illustrating the repeatability of RID measures of colostrum (n=82).** The mean IgG contents for samples were plotted on the x-axis and the standard deviations were plotted on the y-axis. Accuracy was defined as the difference between the 'true value' and measured value and is calculated as 1.96 multiplied by Sw. Repeatability was defined as the difference between repeated measures of the same subject and calculated as 2.77 multiplied by Sw. The within-subject standard deviation (Sw) was 4.4 g/L, meaning that repeat measures were unlikely (probability 0.05) to differ by more than 12.2 g/L.

There was very little difference in Sw between pasteurised (n=27) and non-pasteurised samples (n=55); 4.417 g/L and 4.385 g/L respectively.

In Figure A-3, there appeared to be a 'fan shaped' distribution to the data points. This fan shaped distribution, where the standard deviation increases as the mean value increases, is likely a consequence of the large possible range of IgG values within colostrum samples. Therefore, repeatability of measures was also calculated as a coefficient of variation value (%). The within-subject coefficient of variation (CVw) was calculated using the mean square approach. Accuracy was

defined as the difference between the ‘true value’ and measured value and is calculated as 1.96 multiplied by CVw. Repeatability was defined as the difference between repeated measures of the same subject and calculated as 2.77 multiplied by CVw. The within subject coefficient of variation (CVw) was 5.4%, so repeated measures were unlikely (probability 0.05) to differ by more than a coefficient of variation value of 14.9%, which is often quoted as a threshold value for interassay CV values and an acceptable value for the purposes of our study.

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Appendix B Colostrum quality according to parity, gravidity and dry period length

Appendix B contains material that supplements Chapter 4. Due to the scarcity of goat research, a short description of how certain colostrum measures varied according parity, gravidity and dry period length is provided as this should be useful for informing the methodology and sample sizes of future studies that focus on these factors.

It must be stressed that the data are insufficient to make robust inferences. They show sample patterns only. To progress the research, the study design would need to be appropriate for undertaking general linear model (GLM) analyses, allowing the contribution of different factors to be properly evaluated.

Table B-1 **Summary statistics for goats categorised by parity and gravidity.**

n=number of unique colostrum samples, Q1 = first quartile. Q3 = third quartile.

Subset of goats	**Colostrum measure**	**n**	**Median**	**Mean**	**Q1**	**Q3**	**Range**
Gravidity							
Single	total solids (g/100g)	145	25.4 [24.4, 26.1]	24.4 [23.6,25.2]	21 [18.2,22]	27.4 [27,28.5]	11 – 34.5
Twins		124	24 [22, 25]	24.3 [23.2,25.4]	20.2 [19, 21.1]	29.1 [26.6, 30.5]	10 – 40
Triplets		29	20 [18,22]	20.5 [18.7, 23.2]	17 [14,20]	23 [20,25]	13 – 41
Single	IgG (g/L)	76	91.6 [79.3, 95.3]	87.5 [81, 94]	66.9 [56.8, 76.5]	105.5 [98.4, 111.8]	21.7 – 159.6
Twins		78	76.5 [62.5, 86.6]	74.1 [65.8, 82.3]	46.6 [32.4, 57.8]	104.7 [91.9, 113]	2.8 – 140.6
Triplets		15	65.5 [45.6, 77.6]	68.8 [56.1, 82.8]	49.8 [31.1, 63.9]	86.2 [65.5, 106.9]	20.1 – 124.6
[1]**Parity (kidding session 1A only)**							
Primiparous	total solids (g/100g)	43	26 [23, 27]	25.3 [23.1, 27.4]	21.5 [14, 24]	29.2 [27.5, 34]	10 – 40
Multiparous		65	18 [17, 20]	20.2 [18.6, 22.1]	15 [13,16]	23 [20, 25]	10 – 41
Primiparous	IgG (g/L)	26	110.3 [72.3, 119.6]	103.2 [82.9, 121.2]	66.5 [25.7, 102.7]	133 [115.5, 167.4]	14.9 – 184.9
Multiparous		30	54.5 [37.9, 73]	62.3 [51.2, 76.2]	35.9 [28.1, 46.6]	82.3 [62.9, 110.2]	12.7 – 147.6

[1]Only kidding 1A had multiparous goats. Therefore, multiparous and primiparous goats from kidding session 1A only were compared.

Independent samples t-test showed that the mean Brix values and mean IgG values were significantly greater for primiparous than multiparous goats, though wide confidence intervals limit inferences. The mean difference in Brix value was 4.3 [95% CI 1.5, 7] Brix %, *P*=.003 and mean difference in IgG was 22 [95% CI 8.1,35.9] g/L, *P*=.003. It must be stressed this is association only and does not determine parity to be the reason for the differences.

Relationship between dry period length and Brix values (kidding 1A only)

The only multiparous goats were in kidding 1A (n=65) and the dry period was available for 58 of these goats. The dry period length ranged from 13 days to 71 days (median 32 days, mean 32.5 days, IQR 28 – 39 days). This is a relatively small sample of does and from one kidding session only.

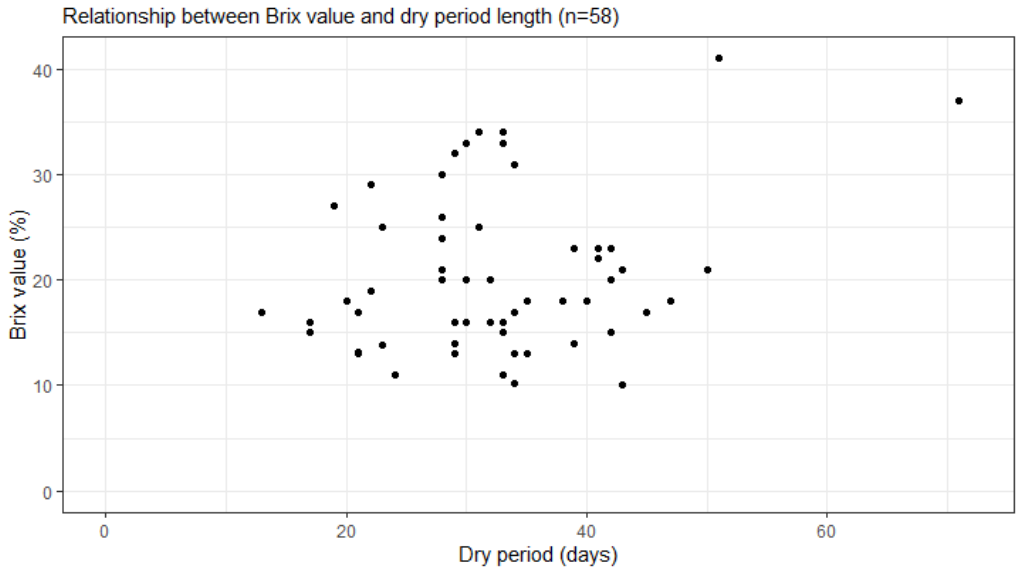

Figure B-1 **Scatterplot illustrating the relationship between dry period length and colostrum Brix value (n=58)**

Brix values varied greatly amongst goats that underwent similar dry periods. For example, there are does with dry period lengths of between three weeks and six weeks that have Brix readings under 20%, yet other does with Brix values approaching 30%.

There was only a very small number of goats with a dry period under 20 days and all, except one, had a Brix value of less than 20%.

Initial analysis shows a lack of correlation between dry period length and Brix values for these goats but this does not rule out the relationship. Larger sample sizes with a wider spread of dry period lengths, including more goats where the dry period was under 20 days, would be useful. Also, a

combination of factors will be affecting colostrum quality so sufficient sample sizes for performing GLM, examining different predictors such as gravidity, feeding, time of year and so on are needed before inferences can be made about the impact of dry period length.

Dry period and immunoglobulin content

Immunoglobulin values were only available for 29/58 (50%) colostrum samples where the dry period length was known. All 29 samples had a Brix value > 20%. The IgG content ranged from 18.3 g/L to 147.6 g/L (median 55 g/L, mean 64 g/L, IQR 36 g/L – 83.6 g/L). It must be noted that only five goats had a dry period of 20 days or less and none omitted the dry period.

Appendix C Intra-observer repeatability when scoring the body condition of goats

Appendix C presents a study evaluating intra-observer repeatability when body condition scoring farmed dairy goats. The study was undertaken with the aim of using the findings to improve the inferences made in the main colostrum quality study (Chapter 4) where body condition scoring was included as a variable.

Introduction

Body condition scoring provides a non-invasive way of assessing the energy reserves of farmed goats[1–3] which are principally stored as fat. Positive and negative energy balances are expected at different times in the production cycle and there are recommended scores for key stages of production.[2,3] Body condition scoring can provide valuable information about the health, welfare, and production status of the goat, such as whether prior nutrition has been appropriate[2] and how the animal is likely to cope in the future. Therefore, body condition scores (BCS) can be a useful tool to for the routine management of goats on farms and a relevant variable to include in research studies.

Scoring farmed dairy goats appears to be a less well-established practice than scoring farmed dairy cattle. Scores appropriate for goats differ from those designed for cattle and sheep because goats store body fat differently, with a larger proportion of body fat stored internally as omental fat and a differing distribution of subcutaneous fat. In goats, validation studies that directly measure body fat post-slaughter have found sternal fat depots to be a more accurate measure of total body fat than lumbar fat depots.[2,3] Dairy goat breeds are more extreme in this respect than meat breeds. Scores that assess the lumbar area only can be appropriate for goats in certain contexts, such as meat breeds, young animals, or males[4–6] but palpation of the sternum is important when assessing the fat reserves in adult female dairy goats.[2,7]

Body condition scoring is subjective. Scores assigned to an animal can vary both within and between scorers, even where scoring systems provide clear descriptions and scorers are trained and experienced in the scoring method. Therefore, assessing the repeatability (precision) of scoring is helpful for informing inferences made from scoring data.

Studies of body condition scores in goats are limited. Some studies have evaluated the accuracy of in vivo body condition scoring, by comparing scores assigned with direct measures of body fat obtained using carcass analysis techniques post-mortem.[4,8–12] Other studies have included body condition score as a variable when assessing a range of areas relevant to health, welfare, and production such as gastrointestinal parasites,[13] feed management,[12,14,15] lactation,[16] milk composition,[17] hormones,

metabolism and metabolic profiles,[18,19] reproduction,[6,20–31] and on-farm welfare assessments.[32–34] Where studies have collected multiple scores for each goat at each time-point the values have been used in differing ways, with some studies using the mean of values as their data point,[12] and in other studies, scorers agreeing to a consensus if they have a discrepancy in the scores assigned.[34] There has been little evaluation of intra or inter-observer repeatability of body condition scoring by manual palpation in goats, with Aumont et al. (1994)[10] appearing to be the only published study to date.

This study evaluates the repeatability of a single scorer when body condition scoring farmed dairy goats, with the primary aim of improving inferences made from results of a subsequent goat colostrum quality study where body condition score would be included as a variable. The usefulness of the collecting area as a location for scoring goats was also evaluated. Comment is also made about the implications of findings for routine scoring of goats as a general farm management practice.

Materials and methods

Scoring was done on a commercial dairy goat farm holding approximately 2,400 adult dairy goats, predominantly Saanen and Saanen crossbreeds. Some 1,800 goats were being milked twice daily at the time of the study, with each milking comprising nine groups of approximately 200 goats entering the milking parlour over a period of between three and four hours. The milking rate was approximately 500 goats per hour.

Scoring system used

The scorer was experienced in scoring Saanen and Saanen cross-breed dairy goats and in using the score selected. The scoring system used was that described by Smith and Sherman (2009),[3] developed from the combined research of Morand-Fehr et al (1989), Santucci et al (1991), and Hervieu and Morand-Fehr (1999)[3]. This score is appropriate for dairy goats and is commonly cited in the published literature and in the main goat veterinary texts. A laminated scorecard (Figure C-1) combining key landmarks and descriptors from the full written description in Smith and Sherman (2009)[3] with diagrams of lumbar and sternal areas by Hervieu (1991), printed in Mendizabal (2011)[2] was used as a prompt to optimise scoring.

The score zero (emaciated) was removed from the score sheet as this was not expected to be observed. Lumbar and sternal scores were each from score one to five. Half-score increments were assigned where a goat's body condition was judged to fall between two of the full scores. This gave nine possible score values for the lumbar score and nine possible values for the sternal score. The

overall body condition score was the mean of these two scores providing 17 possible scores at 0.25 increments.

Location and handling of goats during scoring

Goats needed to be physically restrained and handled to score them by manual palpation. During the planned colostrum quality study, it would be possible to score goats when restrained in pens for colostrum collection. However, for the intra-observer repeatability study an alternative had to be found that fulfilled certain criteria within the resources available. Firstly, the scorer needed to remain adequately blinded to the previous scores assigned to goats. Secondly, the scorer needed to experience time and environmental constraints no less than would be faced in the colostrum quality study where BCS was used as a variable. Thirdly, it was preferable to score goats without disrupting the normal farm routine. Based on the scorer's previous experiences of scoring dairy goats in different parts of different farms in the area and when undertaking a welfare assessment study,[2] the area where goats collect prior to milking was used as the scoring location.

Goats were scored in the collecting area when waiting their turn to walk up the ramp onto the rotary parlour. The collecting area held approximately 100 goats at any one time with a constant steady flow of goats through the area as individuals gradually exited onto the rotary parlour. Goats were closely stocked with just enough space for the scorer to comfortably walk amongst them.

It was expected that a reasonable proportion of goats would allow themselves to be handled with minimal or no restraint, provided they were given sufficient time to become familiar with the scorer before data collection began. Prior to the first scoring session, the researcher spent the duration of the three previous milking sessions in the collecting area, walking amongst and handling goats, allowing the goats to become familiar with their presence.

Goats were scored at the next two milking sessions. The first scoring session was done early morning and the second scoring mid-afternoon the same day. The researcher spent approximately 2.5 hours in the collecting area amongst the goats at both milking sessions. Any goats allowing the researcher to approach and palpate them were scored. The goats' unique ear tag number, sternal score, and lumbar score were recorded on a digital Dictaphone (Olympus® digital voice recorder VN-711PC).

After scoring a goat the researcher moved to the next available goat. The total time spent palpating each goat was between 15 to 20 seconds with the remaining time spent moving between goats. The researcher scored as many individual goats as they could within the 2.5-hour time period. Scoring was repeated during the afternoon milking. It was presumed that a proportion of goats would inevitably be scored twice, once at each milking session, due to their inquisitive nature and interest

in the scorer. Using this approach, the researcher did not know which of the goats being scored at the second milking had already been scored at the first milking.

Data handling and statistics

Data were downloaded and recorded in a Microsoft Excel spreadsheet after both scoring sessions. Analyses were performed using R Studio (www.rstudio.com) using libraries tidyverse, boot and blandr.

The body condition score data were treated as continuous, as in Evans et al. (1978),[35] due to being an ordered scale with 17 possible values for the overall body condition score. Some consistency to the size of the interval between scores is presumed, as Mendizabal (2007),[9] found that a one-unit change in overall body condition score is the equivalent of 1415 g of subcutaneous fat in Blanca Celtibérica goats.

Data were analysed using Bland Altman plots[36] so that repeatability was quantified in score units. First scatterplots were used to check for linear, strong relationships between pairs of measures, and the distribution of differences between repeat measures for the different subjects was checked for normality. To create the Bland Altman plots, the mean of repeated measures for subjects was plotted on the x-axis, and the differences between these repeated measures on the y-axis. The solid blue lines superimposed on the plots represent the mean of the difference in measures or bias, and the blue dotted lines are the 95% confidence intervals for the bias. The solid red lines superimposed represent the upper and lower limits for the level of agreement, and the red dotted lines are the 95% confidence intervals.

The value for the bias indicates the extent to which the first measure for a subject is systematically higher or lower than the second value. The values for upper and lower agreement limits indicate the interval between which repeat measures for subjects can confidently be expected to lie in 95% of cases. All confidence intervals are at the 95% threshold and denoted by square brackets after the relevant statistic. Bootstrapping techniques (10,000 replicates with replacement) were used for calculating confidence intervals.

Results

A total of 73 individual goats were scored once or more over the course of the two milking sessions, giving a total of 158 individual scorings. Thirty-two goats were scored once only, either during the morning or afternoon milking. Of the remaining 41 goats, lumbar scores only could be obtained for two goats, so these were excluded from the analysis. The remaining 39 goats were scored at least

once during each of the morning and afternoon milking sessions. Of these goats, 18 were scored twice, nine were scored three times, five were scored four times, four were scored five times, two were scored six times and one goat was scored seven times.

For each goat, the first score performed during the morning milking session and the first score performed during the afternoon milking session were used in the analysis.

The overall body condition score for the 39 goats evaluated ranged from 1.75 to 3.75 (median 2.75, mean 2.8, IQR 2.5 – 3.1). The lumbar scores for the 39 goats ranged from 1.5 to 3 (median 2.5, mean 2.6, IQR 2.25 – 3) and the sternal scores ranged from 2 to 4.5 (median 3, mean 3.1, IQR 2.75 – 3.5).

Figures C-1, C-2, and C-3 are Bland Altman plots the level of agreement for overall body condition scores, for lumbar scores and for sternal scores respectively.

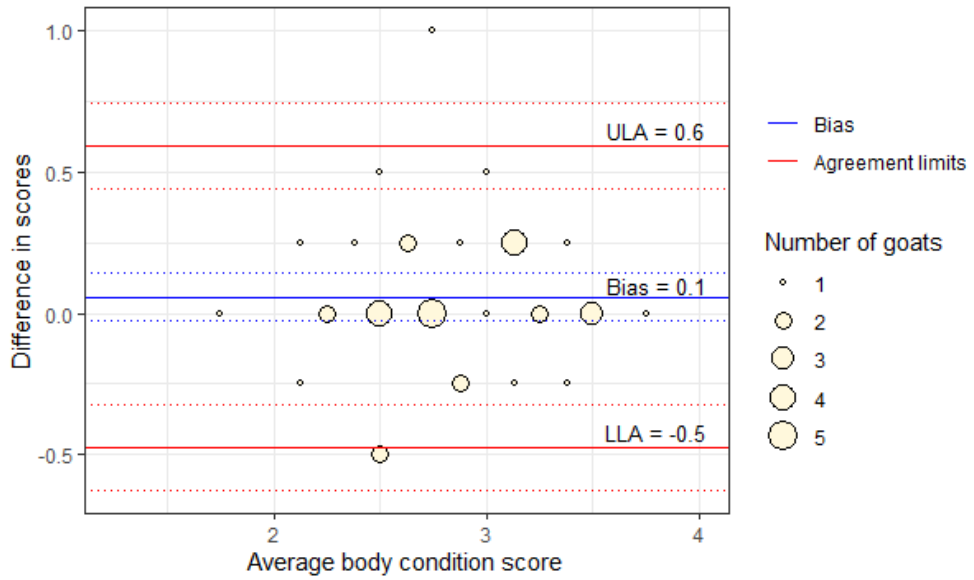

Figure C-1 **Bland Altman plot showing the agreement between repeated measures of overall body condition score (n=39)**

The mean values for repeat body condition scores were plotted on the x-axis. The differences in repeat scores were plotted on the y-axis, calculated by subtracting the afternoon milking score from the morning milking score. The bias value, or mean difference, shows the extent to which the measures differ systematically and is 0.1 [95% CI 0.0, 0.1] scores. The agreement limits show the interval where pairs of measures can confidently be expected to lie in 95% of cases. The upper limit of agreement (ULA) was 0.6 [95% CI 0.4, 0.7] scores and the lower limit of agreement (LLA) was -0.5 [95% CI -0.6 to -0.3] scores. The dotted lines on the plot represent 95% confidence intervals for values.

The first and second values for overall body condition scores were identical for 19 (48.7%) goats. The two scores differed by 0.25 scores for 15 (38.5%) goats, by 0.5 scores for four (10.3%) goats, and by one whole score for one (2.6%) goat.

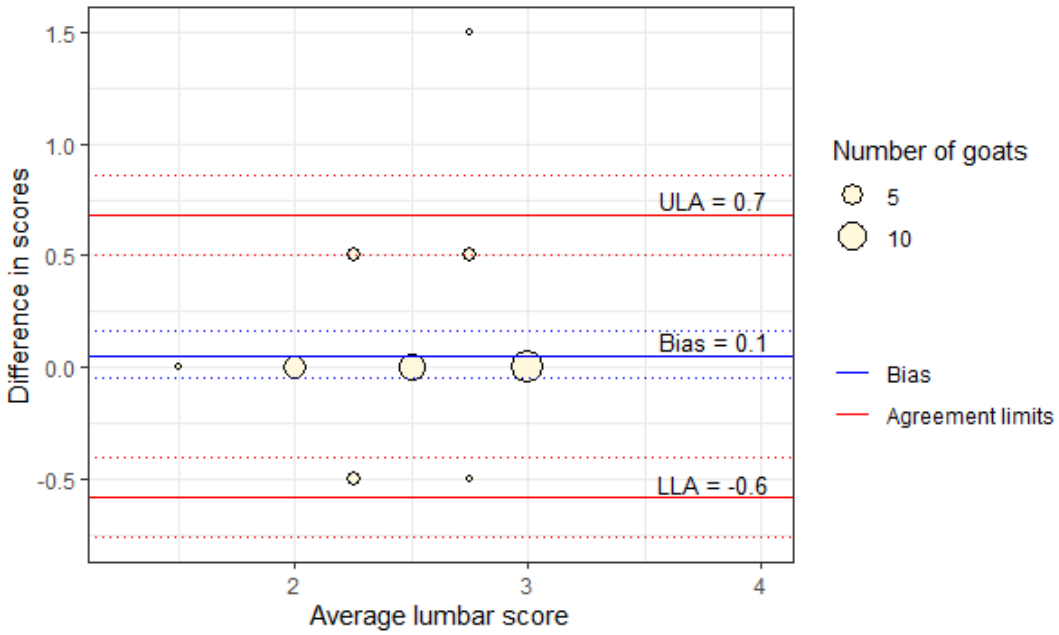

Figure C-2 **Bland Altman plot showing agreement between repeated lumbar scores (n=39)**
The mean values for repeat lumbar scores were plotted on the x-axis. The differences in repeat lumbar scores were plotted on the y-axis, calculated by subtracting the afternoon milking score from the morning milking score. The bias value, or mean difference, shows the extent to which the measures differ systematically and is 0.1 [95% CI -0.1, 0.2] scores. The agreement limits show the interval where pairs of measures can confidently be expected to lie in 95% of cases. The upper limit of agreement (ULA) was 0.7 [95% CI 0.5, 0.9] scores and the lower limit of agreement (LLA) was -0.6 [95% CI -0.8 to -0.4] scores). The dotted lines on the plot represent 95% confidence intervals for values.

The first and second lumbar scores were identical for 31 (79.5%) goats and differed by 0.5 scores for seven (17.9%) goats. One goat was an outlier with a score difference of 1.5.

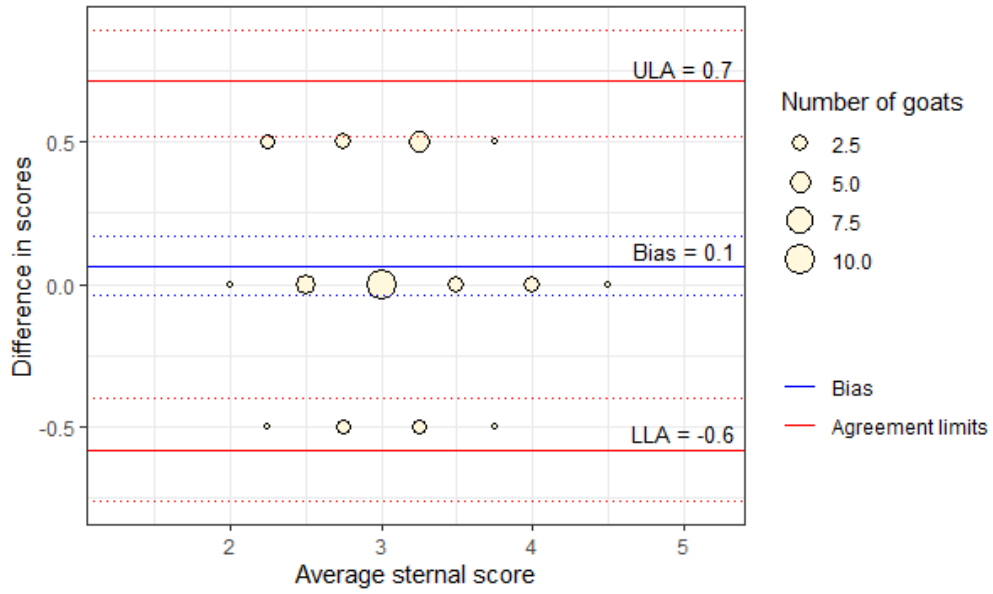

Figure C-3 **Bland Altman plot showing agreement between repeated sternal scores (n=39)**
The mean values for repeat sternal scores were plotted on the x-axis. The differences in repeat sternal scores were plotted on the y-axis, calculated by subtracting the afternoon milking score from the morning milking score. The bias value, or mean difference, shows the extent to which the measures differ systematically and was 0.1 [95% CI 0.0, 0.2] scores. The agreement limits show the interval where pairs of measures can confidently be expected to lie in 95% of cases. The upper limit of agreement (ULA) was 0.7 [95% CI 0.5, 0.9] scores and the lower limit of agreement (LLA) was -0.6 [95% CI -0.8 to -0.4] scores. The dotted lines on the plot represent 95% confidence intervals for values.

Comparison of lumbar and sternal scores within goats

The first and second sternal scores were identical for 22 (56.4%) of goats and differed by 0.5 scores for 17 (43.6%) goats. For five (12.8%) goats the lumbar score was the same as the sternal score. For 32 (82.1%) goats the lumbar score was less than the sternal score. The sternal score was greater than the lumbar score for only two (5.1%) goats and this was by an increment of only 0.5 scores.

Discussion

The scorer needed to rely on measures of repeatability for information about their accuracy[37] because performing direct measures of body fat to compare with scores assigned was not a practical option. Poor repeatability would presume poor accuracy, though good repeatability would not guarantee accuracy, as the possibility of body condition being consistently mismeasured could not be ruled out.

BA plots show negligible bias for all three types of scoring, indicating that the first score was not consistently higher or lower than the second score, suggesting the scorer anchored their scoring similarly during both milking sessions. The agreement limits indicate that the scorer is unlikely (probability 0.05) to assign the same goat with overall body condition scores that differ by more than approximately 0.5 scores.

Different factors relating to the scorer, the goats, and the environment in which the scoring was done will have contributed to this level of repeatability. Factors likely to have supported better repeatability were that the scorer was experienced in scoring Saanen and Saanen crossbreed dairy goats and experienced in using the body condition score selected. In addition, the laminated scorecard of diagrams and key descriptors enabled practical and hopefully more consistent use to be made of what is a very long verbal description of body condition score.

Factors likely to have reduced repeatability are the range of body conditions for goats on this farm. Unlike many commercial dairy goat farms in the UK,[38] this farm experienced few problems with overly fat goats. Therefore, it provided an opportunity to score goats that were mainly of mid-range body condition scores. This was useful as the scorer's prior impression was that sternal landmarks are less well-defined and harder to assign correctly or consistently for mid-range scores than for those at the outer bounds of the scoring system. It is interesting that, despite this prior impression, the agreement limits were not wider for sternal than lumbar measures. However, the distribution of data points within the agreement limits does suggest that lumbar scoring was more consistent than sternal scoring, with 31 (79.5%) pairs of lumbar scores having identical measures compared to 22 (56.4%) pairs of sternal scores.

The scoring was done under greater time pressure and in a more difficult environment than was expected during the subsequent quality study, where goats would be restrained individually in pens or in very small groups of four to five animals. Therefore, it is logical that repeatability would be the same or better during the later study.

The scorer could be confident they gained a realistic understanding of their repeatability by remaining blinded to scores they had previously assigned to goats, despite the short time intervals of several hours between the two milking sessions. Circumstances made it extremely difficult for the scorer to remember individual goats or to even know the overall scores assigned during the first milking session until the completion of the study. Goats were constantly scored during the time spent in the collecting area meaning many more scores were done than were used in the analysis and all scores were stored within the Dictaphone until the study was complete. In addition, ear tag numbers were several digits long and difficult to remember. When scoring goats at afternoon milking the researcher did not know which animals had already been scored at the morning milking. The goats previously scored were from three different pen groups and whilst the stockperson informed the researcher of the approximate time these pens would be passing through the parlour at the afternoon milking session, they did not disclose the order of the pens which differed to that at the early morning milking session. Evidence for the scorer remaining blinded is provided by the number of goats that were scored more than once during a milking session, despite the researcher believing they had moved onto different goats. This likely occurred because some goats seem to particularly enjoy the interaction, avoiding going to the parlour until the last possible moment. Goats were mainly white, being difficult to distinguish by colour. They were heterogenous, testing the scorer's ability to consistently score goats of differing shapes and sizes but not distinct enough to be remembered on repeat occasions.

Several aspects were not tested. It would be useful to assess repeatability at the full range of scores rather than relying on the scorer's perception of better precision when scoring very fat and very thin goats. Also, repeatability was only tested over the course of one day. The same scorer might anchor the scores differently, assigning overall higher or lower scores to goats, on different days or on different farms. The sample size was also relatively small (n=39) giving relatively wide confidence intervals. Despite these shortcomings, the study provided sufficient information that was fit for the purpose of informing the main colostrum quality study (Chapter 4). It also provided useful insights for scoring goats routinely as part of farm management.

Whether the size of the agreement between measures is regarded as acceptable depends on the purposes for which measures are to be used. According to our results, a goat assigned an overall body condition score of 3 could have equally been scored as low as 2.5 or as high as 3.5. Whilst a difference of 0.5 units is small numerically it can be regarded as quite a large difference when considering the body condition scores desirable at different stages of production. In dairy goats, these are reported as between 2.25 and 3.5 at dry off, between 2.75 and 3.5 at parturition, and avoiding losing more than 0.5 scores during the dry period.[3] There is probably insufficient precision

in scoring for each of the scores from 1 through to 5 to be used as a factor in analysis in the planned colostrum quality study. However, there is sufficient precision for it to be appropriate to provide descriptive statistics for the overall body condition of the herd of goats.

In the subsequent study, the accuracy of scores assigned could theoretically be improved by scoring each goat more than once and using means of scores as the data point for that goat. However, it would not be practical for a single scorer to assign a second score whilst remaining blinded to the first score and there were insufficient resources to use more than one trained scorer.

The scoring system selected for our study was appropriate for adult dairy goats and has commonly been used in research, along with the very similar scores described by Villaquiran et al. (2005)[39] and Santucci et al. (1991).[1,7,8,10,12,14–16,18,21–23,26,29,34,40,41] Other studies, primarily those of meat breeds, use scores that assess the lumbar area only, mainly scores based on Walkden-Brown et al. (1993)[6,20,24,31] or McGregor et al. (1990).[4,5,11,13,22,25,27,30,33,42] Some studies have not specified the score used.[165 167 175 187] For these studies, details of who performed the scoring, and how, are variable. For some studies, there is no information on who did the scoring.[7,9,11,13,15–17,19,23,25–29,33,40,42] Some studies used a single trained scorer throughout[1,14,18,20–22,30–32,43] or two different scorers at separate times in the study.[24] Other studies used more than one trained scorer throughout.[8,44] Vieira et al. (2015)[34] used two trained scorers to assess the body condition by palpation of the 32 goats used in the initial development of their visual lumbar score. Ngwa et al. (2007)[12] used four scorers and Aumont et al. (1994)[10] used six scorers.

Where goats have been scored more than once at each time point, there has been little attention to repeatability.

Vieria et al. (2018)[41] provided detailed information on the repeatability of scorers when using the visual lumbar scale they created, but not for the two scorers in the preliminary study who scored the initial 32 goats by lumbar and sternal palpation using the full Hervieu score. For these 32 goats, the score was decided by consensus if the scorers had any discrepancies. In the two studies by Ngwa et al. (2007)[12] the mean of the four scores for each goat was regarded as the true score. Only Aumont et al. (1994)[10] focused on repeatability. Aumont et al. (1994)[10] used the score described by Santucci et al. (1991), on a scale of 1 to 5 whole scores with half-score increments. Six assessors scored each of the 18 Creole goats and this was repeated on subsequent dates. Evans et al. (1978)[35] advocated repeatability measures based on analysis of variance (ANOVA) and was cited in their analysis. The intra-observer repeatability for overall BCS was 0.22 scores and the authors stated that scoring to a half unit seemed unreliable unless the BCS could be determined by two assessors, instead advocating scoring to whole units. This intra-observer repeatability of 0.22 scores is lower than the 0.5 scores

found in our study. However, this is unsurprising as scoring was done for a different breed, in a different environment, and for a smaller number of goats. In relation to our study, scoring whole rather than half units might be more precise but not necessarily improve accuracy in measuring body condition.

Evaluation of the collecting area for scoring goats

Body condition scoring can be done most efficiently with the goats restrained, such as when moving through a raceway designed for handling goats. However, it is sometimes useful to be able to score goats without restraining them and without disrupting the normal farm routine. This might allow for more frequent routine scoring by farmers. It may also make scoring by an external assessor more practical, for example, if done as part of a farm assurance scheme.

The scorer found the collecting area a practical place to assess their repeatability without disrupting the normal farm routine. Whether other persons find this a useful area to test their scoring will depend in part on their prior experience in handling goats. Also, the layout of the collecting area and the temperament of goats may differ between farms affecting ease of scoring.

The collecting area was trialled based on the scorer's prior experience of scoring goats in different parts of different farms. They had found that when goats were housed in their pens, often in group sizes of 200 animals or more, the interaction they could have with different goats in the group varied greatly. Certain goats would spend all their time next to the scorer and not allow other goats near, whereas other goats were more cautious, often approaching but not allowing themselves to be handled. It was difficult to score a sufficient sample size for checking repeatability or a sufficiently representative sample to be useful for routine management purposes. There were too many distractions to properly focus on the scoring.

Goats can be scored properly by palpation when individually restrained in the milking parlour milking but not without adding significant time or disruption to the normal milking routine. There is much time pressure to routine milking, with milking rates commonly 300 to 500 goats per hour on large commercial farms, and ease of access to goats varies with parlour design. It can be difficult to reach and palpate both the lumbar and sternal area when working from the pit of the parlour and goats seem to dislike being disturbed in this way whilst they are being milked.

Several features of the collecting area made the researcher consider it might be suitable for use. Goats in the collecting area were more densely stocked and accessible than when loosely housed in their pens. They were gradually moving forward and exiting the parlour, meaning that goats that

would otherwise dominate contact with the researcher were moved forward and out. There was sufficient space to walk between and handle goats with minimal restraint and to fully palpate the goat.

Whilst useful for checking the repeatability of scoring, the collecting area is unlikely to be a useful site for scoring a representative sample of the herd for routine management purposes. Here, setting aside times and resources, such as using a handling-facilities used for moving goats for routine husbandry procedures, would be appropriate. Alternatively, goats could enter the parlour specifically with this purpose in mind, or extra time is added to the milking session.

However, the complexity of current scoring systems done by palpation and the large numbers of animals that need to be physically restrained for scoring create challenges. The authors' experience is that BCS is something that is often discussed for commercial dairy goats amongst farmers and vets but little is done in practice.

A simpler score and one based on visual appraisal only would be more practical. The difficulty is to create a visual score that gives sufficiently accurate information. Lerch et al. (2021)[1] used 3D body imaging to measure goat body fat but found that agreement between surface measures and body fat content was not as good as hoped for, attributed in part to using 3D technology designed for cattle rather than for small ruminants. Even if successful there would be the expense and farm investment to consider for use of such technology.

Vieira et al (2018)[34,41] recognised the practical difficulties posed by catching and palpating large numbers of goats to assess their body condition, when visiting commercial farms for welfare assessment purposes, leading to the investigation of whether body condition could be assessed accurately by observation only.

Vieira et al. (2015)[34] modified the Hervieu score. Firstly, they simplified the score, replacing the six-point full score with a visual three-category score for better simplicity and hopefully better repeatability and making the score more user-friendly. In the three-category visual scoring system, Vieira et al. (2015)[34] set the threshold for 'very fat' goats at a lumbar score of 3.5 on the six-point scoring scale and the threshold for 'very thin' goats at a score of two. Secondly, they investigated replacing palpation with a visual appraisal.

Vieira et al. (2015)[34] found that the lumbar (rump) score only could be replaced by visual landmarks. It must be emphasised that the sternal score, which is a more accurate predictor of body fat, could not be replaced by visual scoring. Validation studies to date show the contrary – that sternal scoring

is a more accurate predictor of goat body fat reserves. Visual lumbar scores should not be conflated with the overall body condition score of the animal.

However, the Vieira score[34] is fit for its intended purposes as an initial screening score for welfare assessment purposes. In addition, this score also has scope to be used routinely by farmers to inform their production provided interpretation is carefully considered, as follows.

From the researcher's previous experience, Saanen and Saanen cross-adult dairy goats tend to have a similar or greater sternal score than the lumbar score. This is evidenced by comparing lumbar and sternal scores within goats from in our repeatability study, which found 32 (82.1%) goats had a greater sternal score than the lumbar score and five (12.8%) goats had the same lumbar and sternal scores. Only two (5%) goats were fatter on lumbar scoring and by a margin of only 0.5 scores. These measures are for a small sample of 39 goats. On subsequent scoring of 308 Saanen and Saanen cross goats during the colostrum quality study, 27 of these goats had identical lumbar and sternal score values. For the remaining 281 goats, sternal scores were higher values than lumbar scores. The size of the differences between the sternal and the lumbar scores ranged from 0.5 scores to two scores (median 1 score, IQR 1 score – 1 score) (K.Anzuino, unpublished data).

Therefore, a goat identified as 'very fat' on the Vieira visual lumbar score will most likely have an overall BCS of 3.5 or greater when fully scored by palpation. For most UK farmers taking part in a postal survey,[38] overly fat goats were more of a concern than overly thin goats,[38] and being able to easily, visually identify goats in this category should be helpful. A goat in the 'normal category' is unlikely to be overly thin, though might be fatter than desirable. A goat identified as 'very thin' on the Vieira visual scale may or may not have an overall BCS greater than two on full scoring by palpation, and so would require restraining and palpating to confirm their score. Vieira (2015)[34] found good intra and inter-observer repeatability for the visual lumbar score they created. Further research into a simplified sternal score by palpation that provides farmers with enough information to supplement the three-point visual lumbar score would be useful.

Conclusion

Assessing the repeatability of BCS is a useful exercise, whether intending to use scoring as part of a research study or for routine management purposes, as this knowledge alters the inferences that will be made from data.

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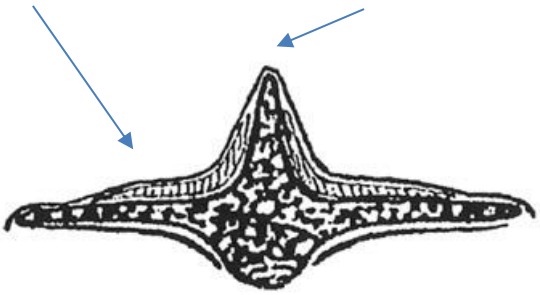
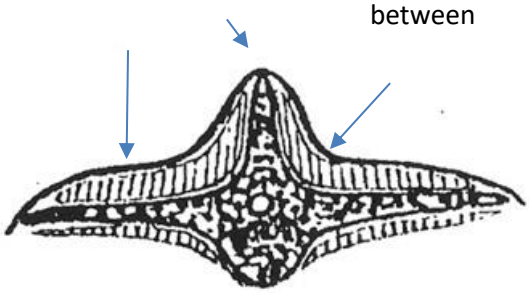
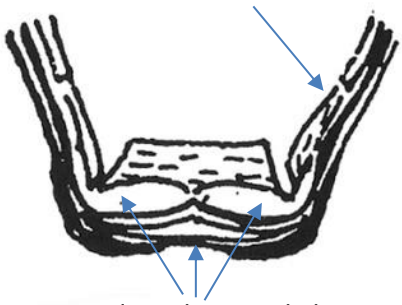
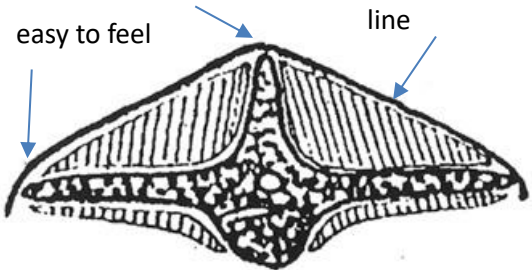
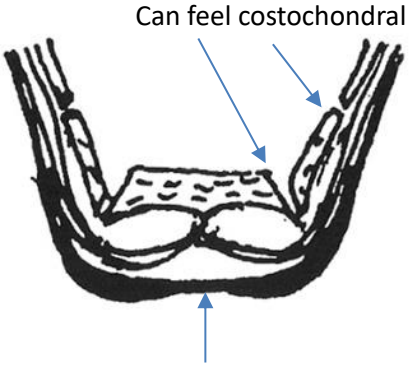
Figure C- 4 **Body condition score reminder card**

<table>
<tr>
<td>SCORE 1
Muscle 2/3rds of distance
Intervert art – can feel but not see
  </td>
<td>SCORE 1
Costo-sternal jts more rounded but easy to feel
 
Depression not filled
Callous movable</td>
</tr>
<tr>
<td>SCORE 2
Dorsal and transverse processes prominent
Skin concave between
  </td>
<td>SCORE 2
Costo sternal artics diff to feel
 
Fat pads under muscle layers each side of sternum
Subcut fat partially fills central depression</td>
</tr>
</table>

SCORE 3

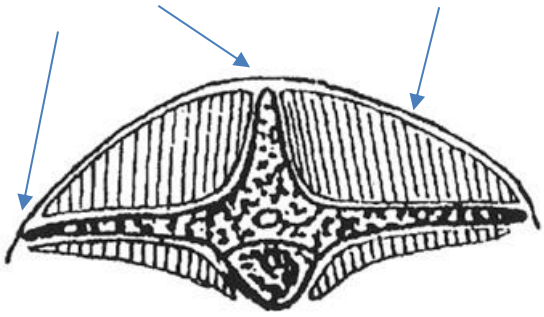


SCORE 3

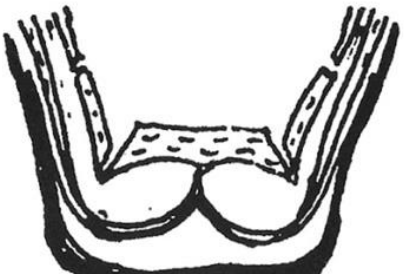


Distinct depressions either side between fat + muscle and the bones

SCORE 4



SCORE 4



Can't feel sterum or ribs

Can feel depression either side of fat, cannot feel ribs

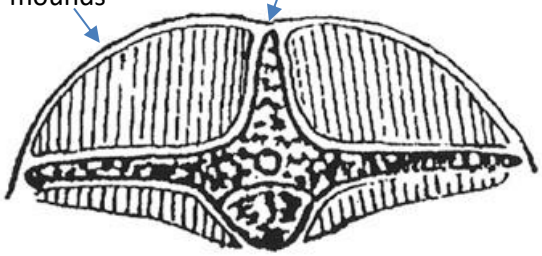
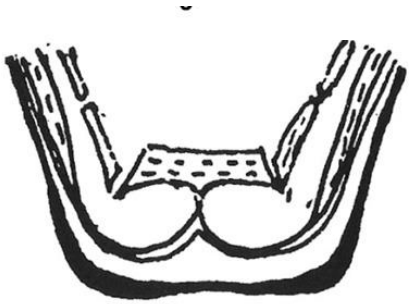
SCORE 5 Prominent groove mounds 	**SCORE 5**  No depressions laterally or caudally Subcut fat no longer mobile Skin 'tight'

Table C-2; **Verbal descriptions of the body condition scoring system for dairy goats** Pg 757, Chapter 19, Nutrition and metabolic diseases, in Goat Medicine by Smith and Sherman	
Lumbar score	
0	The animal is extremely emaciated. The intervertebral articulations are easily felt and the skin seems to be in direct contact with the bones.
1	Muscle extends almost two-thirds of the distance along the transverse processes, Intervertebral articulations are still palpable and barely visible.
2	Dorsal and transverse spinal processes are prominent, and the skin forms a concave line between them.
3	Spinous processes are still easily felt. The space in the vertebral angle is filled with muscle and the skin determines a straight line between dorsal and transverse processes.
4	Dorsal and transverse spinous processes are difficult to detect and the skin forms a convex line between them.
5	There is a prominent groove down the back line and the fat and muscles mound up each side of the groove.
Sternal score	
0	Costo-sternal articulations are very prominent. The bony surface of the sternum is easily felt. The skin callus over the sternum lacks mobility.
1	Costo-sternal articulations are more rounded but still easily felt. The depression over the sternum is not filled in but the callous is movable.
2	Costo-sternal articulations are difficult to feel. Internals fat pads develop under the muscle layers on each side of the sternum, and subcutaneous fat partially fills the central depression.
3	The central depression is completely filled with a thin and mobile mass of subcutaneous fat. Distinct depressions are palpable on each side between the mass of fat and muscle and bones. The costo-chondral articulations are palpable.
4	Sternum and ribs are no longer palpable but a depression is still palpable on each side of a thick mass of subcutaneous fat.
5	Subcutaneous fat is no longer mobile. No depression are palpable laterally or caudally.

Appendix D Observations when using ELISA tests to measure goat colostrum

Observations when using the ELISA method to measure the immunoglobulin content of goat colostrum are presented and discussed. The findings led to the use of RID testing in the colostrum quality study (Chapter 4).

Introduction

RID and ELISA tests are direct measures of immunoglobulin; they specifically target and bind unique features of the immunoglobulin molecules. As such they are considered accurate measures of immunoglobulin. RID is one of the oldest techniques available[1] and has traditionally been considered the 'gold standard' method for measuring the immunoglobulin content of colostrum in a wide range of species in research, including goats.[2–15] However, the ELISA method has become an increasingly common measure of the immunoglobulin content of goat colostrum.[16–23] A sandwich ELISA test in the form of an ELISA kit has commonly been used in goat colostrum research, principally the goat IgG quantitation set by Bethyl Laboratories, Montgomery, TX, USA) E50-1404.[6,16,18,20,23] Two studies[17,19] have used the Calokit-Cabra (Zeu-Inmunotec S.L., Zaragoza, Spain). Reported reasons for choosing ELISAs over RID have included lower costs, faster testing times and higher testing capacity[24] made possible due to the wide availability of commercial ELISA kits. ELISA kits provide the researcher with relevant reagents and materials, and detailed instructions for their usage, and assure a level of quality control in testing.

Therefore, ELISA tests were the logical first choice for measuring the IgG content of goat colostrum in the thesis colostrum research. However, the use of ELISA tests was less straightforward than expected and there was not enough confidence in the accuracy of the measures to use them in the main colostrum quality study (Chapter 4). Further research evaluating the level of agreement between RID and ELISA measures of colostrum is important.

Summary of the ELISA test method and colostrum samples

ELISA tests were performed in the laboratory at the University of Bristol Veterinary School in the autumn of 2018, using the Goat IgG quantitation set by Bethyl Laboratories, Montgomery, TX, USA, E50-1404, similar to other studies of goat colostrum.[6, 16, 18, 21, 22, 2,3 25, 29, 30]

The main steps when running the ELISA tests are as follows. A 96-well, modified polystyrene plate is prepared for capturing the IgG molecules by coating it with affinity-purified rabbit anti-goat IgG. The goat reference serum is used to create the standard curve and the prepared colostrum samples are then added to the plate. Subsequently, the horse radish peroxidase conjugated rabbit anti-goat IgG

detection antibody is added to the plate and captures the goat IgG analyte. This enzyme detection system is then activated and produces a colour change that can be measured using a plate reader. Samples are tested in duplicate and an intra-assay coefficient of variation (CV) value of less than 10% was considered acceptable. Colostrum samples were selected from those obtained during kidding 1A, as described in the main colostrum quality study. They were stored frozen at minus 20°C until tested. Full details of how to prepare the plate and use all the reagents are provided with the kit.

Observations and areas of concern

The main observations and areas of concern are as follows;

Firstly, the manufacturers state that they have validated the ELISA tests for use with serum. Their usage with colostrum is at the researcher's discretion. With this test kit (Goat IgG quantitation set by Bethyl Laboratories, Montgomery, TX, USA, E50-1404) no instructions for handling and preparing colostrum are provided.

Secondly, there were insufficient details of colostrum preparation in relevant published research.

When selecting the ELISA kit there was an expectation that the manufacturer's instructions could be relied upon for instruction as to how colostrum should be handled, as published research papers generally provided few details beyond stating the manufacturer's instructions had been followed.[17–19,22,28–30] At the time of testing in 2018, only Rudovsky et al. (2008)[16] specified that they centrifuged the colostrum and only Castro et al. (2011)[25] reported the dilution factor used.

Thirdly, colostrum preparation was more labour intensive than initially expected, requiring centrifuging of samples followed by extensive dilutions of the supernatant.

The following protocol for preparing colostrum was used. It was thought essential to centrifuge the colostrum to remove any particulate matter that could interfere with antibody binding in the immunoassay, in particular lipid, as recommended by Wilde (2013).[26] IgG is not lipid soluble, so lipid removal would not inadvertently remove IgG from the sample.[26] Gradually increasing centrifugal forces were trialled to establish a single centrifugation protocol that adequately separated all samples. The final protocol was to centrifuge the colostrum at 23,000 times the relative centrifugal force (23,000 x g) for 30 minutes, at a temperature of at 4°C, to effectively pellet the cells and any residues at bottom of the tube and raise the lipid to the surface. A glass pipette was used to make a hole in the lipid layer and the clear supernatant was aspirated via this hole, and then placed in a fresh Eppendorf tube. Centrifuging and aspiration were then repeated using the same parameters, resulting in a clear supernatant which was used in the ELISA tests.

The viscosity of the different colostrum samples was observed to vary significantly. Some colostrum samples readily separated on the first centrifugation cycle providing a watery clear supernatant, whereas others required two complete centrifugation cycles to separate adequately.

It is interesting that Rudovsky et al. (2008)[16] found they required much lower centrifugal force (13,000 x g at 4°C for 10 minutes) to obtain clear supernatant from all 30 colostrum samples. Zarrilli et al. (2003)[31] centrifuged goat colostrum for use in gel electrophoresis using higher centrifugal forces of 4,000 x g for 15 minutes to remove fat and sediments, followed by 20,000 x g for 30 minutes for the supernatant, which is more in line with our findings.

Dilution factors that placed samples correctly on the standard curve of the ELISA test also had to be determined. The IgG values of the ELISA test standard curve range from 0 ng/ml to 500 ng/ml. Between these values the standard curve is sigmoidal in shape, plateauing after the upper inflection. It is the lower linear region of the standard curve that makes ELISA results accurate and repeatable so test samples should ideally locate here.

Colostrum was measured using a Brix refractometer to provide some guidance as to the likely immunoglobulin content of the colostrum, which in turn could help guide the extent of dilution. At this stage (2018) there was no evidence validating the Brix refractometer as a measure of goat colostrum quality, so a cattle guideline where a 22% Brix reading indicates an average of 50 g/L of immunoglobulin was used.

Initially, two colostrum samples of Brix values 35% and 28% were tested in duplicate on a single plate, at doubling dilutions of 1:100,000, 1:200,000, 1:400,000, 1:800,000 and 1:1,600,000. At dilutions of 1:100,000 and 1:200,000 samples were still too concentrated to register on the standard curve. Dilutions of 1:400,000 placed both samples on the standard curve but the 28% Brix sample was positioned too high at the upper inflection. Dilutions of 1:800,000 placed both samples ideally on the linear portion, whereas dilutions of 1:1,600,000 dilution placed samples overly low. Some 15 individual colostrum samples were then tested on a second plate, at a dilution factor of 1:800,000. This dilution factor placed six of 15 samples ideally on the straight portion of the standard curve. These samples had Brix values of 20.4%, 23.2%, 26.6%, 28.4%, 30.5% and 36.1%. The remaining nine samples were located too high on the standard curve to give accurate results. These samples had Brix values 29.2%, 30%, 31%, 32.9%, 34.2%, 35.7%, 36%, 37.5% and 39.2%. Therefore, it was decided to routinely use dilution factors of 1:800,000 or 1:1,000,000 for the initial testing of any colostrum, with the higher dilution factor used for samples over 30% Brix.

Predicting the appropriate dilution factor was not straightforward, even with estimates made from Brix values. Sixty-four centrifuged colostrum samples, chosen to span a wide Brix range (10% – 36.1%), were then tested in duplicate across three separate plates after centrifuging and at dilutions of 1:800,000 or 1:1,000,000. Thirty-nine of the 64 samples tested were ideally placed on the linear portion of the standard curve. The immunoglobulin content ranged from 2.5 g/L to 56.7 g/L (median 29.6 g/L, mean 29.4 g/L, IQR 20.8 g/L – 39.1 g/L). Intra-assay CV values for all 39 samples were acceptable at less than 10% (range 0.6% – 9.9%). Some 25 samples were located at or above the upper inflection of the standard curve and so were excluded from the analysis.

Only Castro et al. (2011)[25] and subsequently Kessler et al. (2019)[21] reported the dilution factors used for colostrum samples, of 1:100,000 (n=16) and 1:400,000 (n=116) respectively, which are much lower than required for our samples, despite the same type of ELISA kit being used. Castro et al (2011)[25] also reported diluting the conjugated antibody to 1:4,000, though the authors did not specify why.

The need for differing dilutions introduced variability into the testing process. Accurate pipetting of the very small quantities of colostrum could be problematic where the supernatant was very viscous and risked introducing error.

Reasons for choosing RID tests

RID tests were chosen over ELISA tests in the main colostrum quality study (Chapter 4) due to the above factors combined with a lack of evidence for good agreement between ELISA and RID measures of colostrum. RID has traditionally been considered a reference measurement method. Evaluating the agreement between the newer methods and older, 'gold standard' methods is one of the most important requirements for method evaluation.[32] However, the agreement between RID and ELISA measures of colostrum has been little studied in any species.

Subsequently, this choice was supported by the evidence of Zobel et al (2020)[6] who tested 298 unique goat colostrum samples using both ELISA and RID tests, finding no agreement between measures, using Lins concordance coefficient in the analysis. In addition, it was subsequently possible to check the level of agreement between ELISA and RID measures for 20 colostrum samples during this Ph.D. research. RID measures were done by Saskatoon Colostrum Company Limited as described in the main colostrum quality study (Chapter 4). The findings of a poor agreement are in line with those of Zobel et al. (2020). The results are presented below.

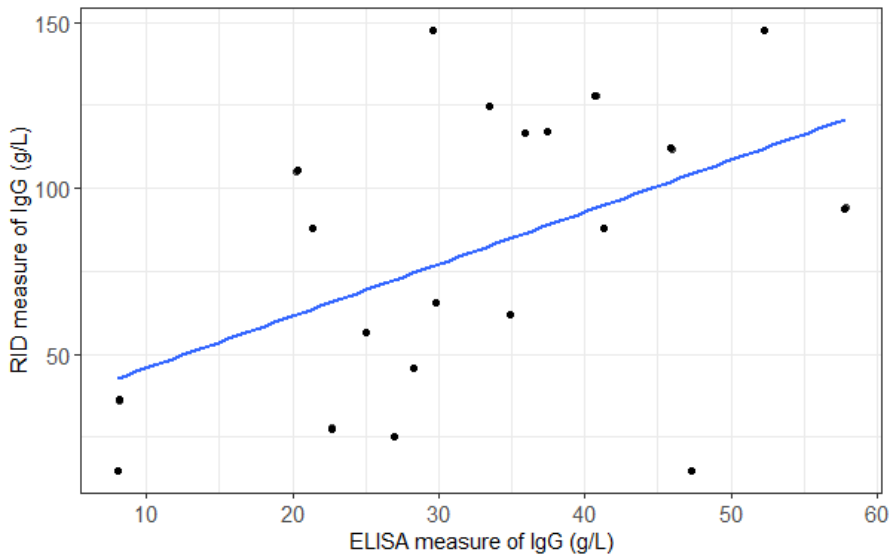


Figure D-1 **Scatterplot illustrating the relationship between ELISA and RID measures of IgG (n=20)**

The regression line is superimposed. There was a significant, weak to moderate positive correlation (*r*=0.471 [95% CI 0.039, 0.790], *P*<.001). Confidence intervals were too wide to make inferences about the strength of association, other than it is unlikely that a strong association (*r*>0.8) exists. While correlation is not a measure of agreement, a strong, positive relationship should be found where measures agree. The difference between RID and IgG measures ranged from -32.5 g/L to 118 g/L (median 41.5 g/L, IQR 24.8 g/L – 81.9 g/L).

Bland Altman plots were created to quantify the level of agreement between ELISA and RID measures of IgG,[27] as described in Chapter 4.

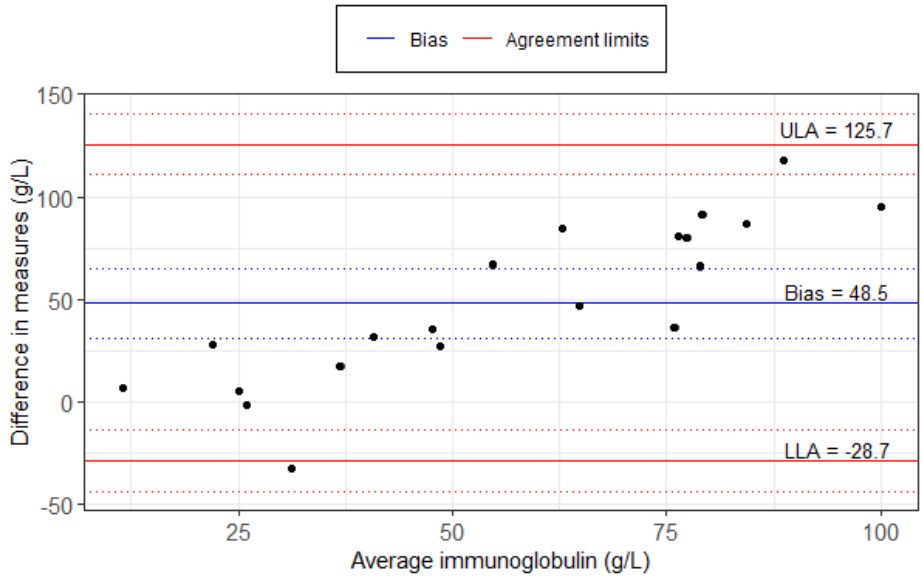


Figure D-2 **Bland Altman plot illustrating the level of agreement between ELISA and RID measures of IgG in absolute units (n=20).** The means of the RID and ELISA measures of IgG for the samples were plotted on the x-axis and the differences in measures were plotted on the y-axis, calculated by subtracting the ELISA values from the RID values. The bias value, or mean difference, shows the extent to which the RID and ELISA measures differ systematically and was 48.5 [95% CI 31.2, 65.2] g/L. The agreement limits show the interval where pairs of measures can confidently be expected to lie in 95% of cases. The upper limit of agreement (ULA) was 125.7 [95% CI 110.7, 140.8] g/L, and the lower limit of agreement (LLA) was -28.7 [95% CI -43.8 to -13.7] g/L. The dotted lines on the plot represent 95% confidence intervals for values.

These values represent a marked systematic bias with the RID measures much greater than the ELISA measures on average, and very poor agreement between ELISA and RID measures. Agreement limit confidence intervals are wide, probably due to the small sample size. However, even in the most optimistic scenario that considers the narrowest agreement interval defined by the confidence intervals to be the relevant interval (LLA -13.7 g/L, ULA 110.7 g/L), there was still very poor agreement, with it being likely (probability 0.95) that the RID test result would differ from the ELISA test result by up to 62.2 g/L.

There was a significant, positive linear relationship between values for the difference in measures and the average measures (r=0.864 [95% CI 0.762, 0.942], P<.001), probably produced by the wide

range of values on the x-axis and a quite consistent proportional difference in values at the differing x-axis increments.

Therefore, it is unsurprising that this pattern was removed when the Bland Altman plot was constructed (Figure D-3) with the difference in measures expressed as a percentage of the mean value, or coefficient of variation (%).

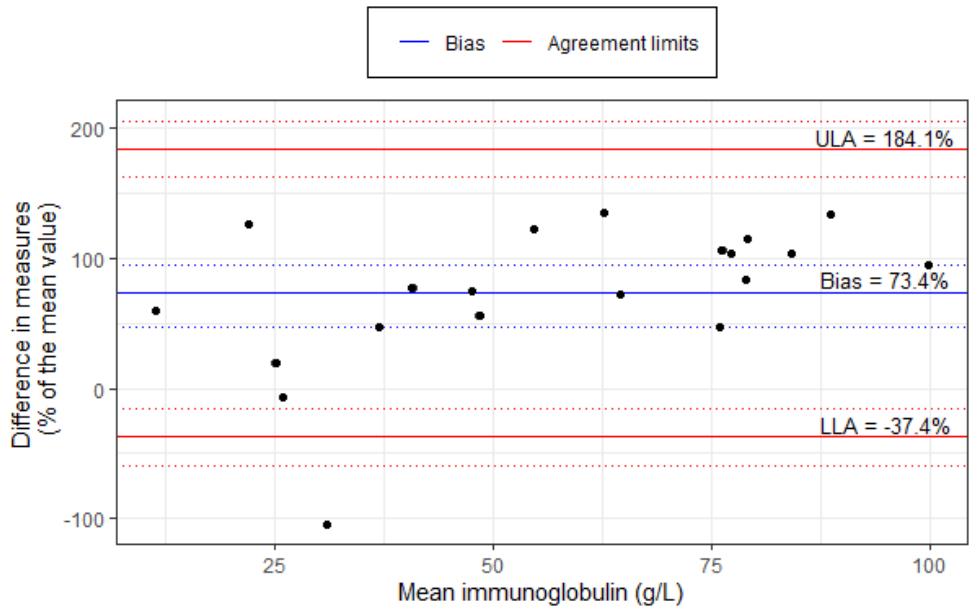


Figure D-3; **Bland Altman plot illustrating agreement between RID and ELISA measures of IgG with the difference in measures expressed as a coefficient of variation (n=20).** The mean IgG values for colostrum samples were plotted on the x-axis. The differences in measures, expressed as coefficients of variation (%) were plotted on the y-axis, with the ELISA values subtracted from the RID values. The bias value expressed as a coefficient of variation, was 73.4 [95% CI 46.6, 95.2] %, the ULA 184.1 [95% CI 162.5, 205.7] % and the LLA -37.4 [95% CI -58.9 to -15.7] %. In the most optimistic scenario, as defined above, it is likely (probability 0.95) that ELISA and RID measures would differ by a CV values of up to 89.1%.

Discussion

Due to the scarcity of goat-specific data, it is helpful to consider similar studies in bovine colostrum, although they are also sparse.[33–35] It must be borne in mind that the colostrum and details of the ELISA test will differ from those for goats but similar principles may well apply.

Data provided by Gelsinger et al. (2015)[33] (n=59) and Dunn et al. (2018)[34] (n=20) shows a very poor level of agreement between ELISA and RID measures of IgG in unpasteurised bovine colostrum. The scatterplot created by Gelsinger et al. (2015)[33] shows a significant, weak linear relationship between ELISA and RID measures (r=0.36, P=.01), much weaker than expected for two measures with a high level of agreement. The authors did not progress the analysis using a measure of agreement but the differences between ELISA and RID measures for many samples are so large that they can be readily detected by simply observing the x and y axes of the scatterplot.

Dunn et al. (2018)[34] evaluated the level of agreement using a Bland Altman plot, which showed systematic bias, with the RID values measuring on average 31.89 g/L greater than the ELISA values. This is not dissimilar to our findings in goats (bias or mean difference 48.5 [95% CI 31.2, 65.2] g/L). However, the authors appear to have conflated the purpose of the bias value with that of the agreement limits. They appear to have assumed that the bias represents the extent to which RID values are consistently greater than ELISA values, rather than it being the average difference for all samples. The plot shows a lower agreement limit of 12.61 g/L and an upper agreement limit of 51.17 g/L suggesting it is likely (probability 0.95) that the ELISA and RID measures will differ by up to 20 g/L, which can be regarded as a poor level of agreement. It must be noted that the sample size is small and confidence intervals would likely be wide. The distribution of data points mirrors that found on our goat plot, where the size of the difference in absolute units (g/L) increases as the average measures increased (x-axis) and may also be due to the wide range of values possible on the x-axis (40 g/L to 100 g/L) accompanied by a somewhat, constant proportional difference in measures.

Gelsinger et al. (2015),[33] Dunn et al. (2018),[34] and Zobel et al. (2020)[6] stated that the results from studies using the ELISA and RID methods of testing should not be compared. However, a stronger comment is probably warranted. RID is widely regarded as the 'gold standard' for measuring IgG in colostrum. As such, the RID method is considered to provide values with high accuracy and precision. Therefore, ELISA values should align with the RID values if they are accurate. As a minimum, ELISA test results should differ from the RID results by a consistent amount and in a consistent direction, enabling them to be calibrated against RID values. However, the small amount of evidence to date shows this is not the case.

The reasons why the ELISA tests produced such differing results to the RID tests when measuring colostrum should be considered, given that the ELISA tests are highly specific for IgG molecules and these molecules are biologically the same whether located in serum, plasma, or colostrum.

It is known that sample components other than the analyte, often referred to as sample matrix, can affect how an ELISA test works.[32] Matrix effects are where sample constituents interfere with analyte detection, for example, by binding analyte molecules so that quantities are underestimated or by reacting with assay reagents so that quantities are overestimated.[32] The colostrum matrix is very different from that of serum or plasma and could be interfering with the ELISA tests.

Different colostrum samples may have slightly different matrix compositions, test interference may occur with some samples but not others or the type of interference and effect on accuracy may differ between samples. Further research would be needed, covering not only large numbers of sample colostrum covering a wide Brix range but also numerous samples within each Brix value.

A combination of other assays can be used to evaluate the validity of the ELISA tests and assess whether there may be matrix effects. These include linearity of dilution and spike recovery assays. Linearity of dilution assays compares the test results of samples under a wide range of dilution factors, assessing the flexibility of the assay to provide accurate and precise results at differing dilution factors.[32] Spike recovery assays compare the amount of analyte recovered from standard diluent with that recovered from the sample matrix, with the difference indicating the amount of analyte bound by the sample matrix.[32] Both the conventional linearity of dilution and spike recovery tests are difficult to perform using colostrum because the conventional standard curve of the ELISA tests limits the range of dilutions factors that can be tested and because obtaining colostrum samples matrix that is devoid of IgG is usually not possible. However, Baumrucker et al. (2014)[35] overcame these difficulties by using a novel spike recovery method, called the standard addition method (SAM) when validating ELISA tests used with a small number of bovine colostrum samples ($n<8$). While useful for studies focussed on assessing validity, the process is labour intensive requiring multiple dilutions of each sample and complex calculations, and not compatible with measuring large numbers of colostrum samples quickly.

It must be noted that Baumrucker et al. (2014)[35] found that the extreme dilutions of 1:1,000,000 required to place bovine colostrum samples on the standard curve also overcame matrix effects in the small number of samples they tested. Extreme dilutions work by diluting the sample to such an extent that problematic matrix components are too low in concentration to interfere with the test. The analyte can still be detected and quantified due to the high sensitivity and specificity of the test. However, at this stage, there is not enough robust evidence to generalise this finding, as a very small

number of samples were tested and different colostrum samples may have differing matrices. Gelsinger et al. (2015)[33] used the same dilutions as Baumrucker et al. (2014),[35] assuming they would overcome matrix effects, which may in part explain their statement about not being able to vouch for the validity of either the RID or ELISA tests.

The Goat IgG ELISA Kit E50 104 is now unavailable, having been superseded by the Goat IgG ELISA kit E55 104. The new kit is described by manufacturers as being for the detection of goat IgG in serum, plasma, milk, and colostrum. The manufacturers do not state they validated the ELISA for use with colostrum. They do, however, cite the independent, published goat colostrum research studies where the previous kit, E50 104 has been used. Some additional advice is provided for users with colostrum, presumably based on these independent papers, that is, the range of IgG in goat colostrum is purported to be 40 g/L to 60 g/L, and a starting dilution of 1:500,000 for colostrum is advised. Much of the remainder of the test procedure appears the same, though the number of washes at each stage has been reduced from five to four.

Conclusion

The use of ELISA tests to measure the immunoglobulin content of goat colostrum has gained momentum amongst researchers of goat colostrum, becoming a commonly used method.

To date, there is no robust evidence for the ELISA tests being an accurate, reference method when testing colostrum. There is some evidence that ELISA and RID measures poorly agree. The extent to which extreme dilutions of colostrum will overcome any matrix effects has not been adequately investigated. Currently, the validity of ELISA tests when measuring the immunoglobulin content of colostrum appears to have been treated as a foregone conclusion and could be producing misleading results. Therefore, this is a priority area for further research.

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Appendix E Postal survey and summary of results distributed to farmers

MILKING GOAT ASSOCIATION

University of BRISTOL

DAIRY GOAT RESEARCH ALLIANCE SURVEY

Thank you for your time in completing this questionnaire, which will be used to help direct research to improve the industry.

Please circle the answers that apply to you.

1. **How many milking goats do you currently have?** (include dry does) ☐

2. **For how long have you been farming dairy goats?** ☐ years

3. **Do you rear your own replacement goats?** Yes No

4. **Do you rear all your replacement goats, including males?** (i.e. completely closed herd) Yes No

5. **Do you breed out of season?** Yes No

6. **Do your goats ever graze outdoors?** Yes No

7. **Average milk yield?** ☐ litres per goat per year

8. **Which are the main breed(s) in your herd?** ☐

COLOSTRUM

Please circle all responses that apply

9. For how long do kids remain with their mothers?

Removed at birth	up to 12 hours	12 – 24 hours	25 – 48 hours	over 48 hours*

*If over 48 hours, please specify; .....

10. Are kids fed colostrum, other than by suckling their mothers?

Yes – routinely	Yes - sometimes	No

11. If yes, what type of colostrum is fed?

From doe	Other (please specify) .....

12. How is this colostrum fed?

By bottle	By stomach tube

13. For how long are kids generally fed this colostrum?

Less than 1 day	1 – 2 days	over 2 days

14. Do you pasteurise colostrum before feeding it? Yes No

15. Do you measure the quality of colostrum? Yes No

If yes, then how? e.g. refractometer

16. What volume of colostrum is fed?

FEEDING KIDS

Please circle responses and fill in boxes that apply

17. Are kids fed milk replacer? Yes No
(i.e. milk not from does)

If yes, what age are kids first fed milk replacer?

Name of milk replacer, if known?

18. How are kids fed milk replacer?

Ad lib (milk always available)	Restricted (milk available in meals)	Varies with kid age

19. Are kids fed creep feed/starter feed? Yes No

If yes, what age are kids first offered this feed?

Name of creep/starter feed, if known?

20. Are kids fed forage? Yes No

If yes, what age are kids first offered forage?

Type of forage fed?

21. Do you have a target weaning weight? Yes No

If yes, what weight is this?

22. Do you have a target weaning age? Yes No

If yes, what age is this?

FEEDING MILKING GOATS

Please circle responses and fill in boxes that apply.

23. Are milking goats fed forage? Yes No

If yes, which forages are fed?

24. Is the forage analysed? Yes No

25. Are milking goats fed concentrate? Yes No

If yes, which concentrate(s) are fed?
e.g. brand name or type

If yes, how are concentrates fed?

Ad lib	Set ration per goat	Total mixed ration (TMR)	Mixed with forage

26. Are milking goats fed according to yield? Yes No

If yes, please indicate the number of feed groups?

27. Do you aim to give goats a dry period? Yes No

If yes, then for how long?

Less than 2 weeks	3 – 4 weeks	5 – 6 weeks	over 7 weeks

FEEDING YOUNGSTOCK

28. What do you feed your youngstock from weaning to first service?

FEEDING BILLIES

29. What do you feed your billies?

MALE KIDS

30. Do you have a market for your male kids? Yes No

If yes, then what market?

Males reared for breeding	Males reared for meat	Other

31. Do you rear any kids for meat on your farm? Yes No

MILKING ROUTINE

Please circle all responses that apply and complete any boxes

32. How often are goats milked (at peak yield)**?**

Once daily	Twice daily	Three times daily	Other

33. Which of the following are done routinely at milking?

Gloves worn	Foremilk checked	Teats wiped
Teat dip pre-milking	Teat dip post-milking	

34. Do you record milk yields? Yes No

If yes, then how do you milk record?

Yields for individual goats	Total yield for groups of goats
Automatic/electronic recording	Manual recording

35. Are goats fed whilst in the parlour? Yes No

If yes, then how are they fed?

Individual ration	Small amount for encouragement

36. What is your target kidding interval? _____

37. Are goats routinely foot trimmed? Yes No

If yes, at what age are they first trimmed?

How often are they trimmed?

38. Are goats routinely foot bathed? Yes No

If yes, please specify;

39. Are kids disbudded? Yes No

If yes, what age are they disbudded?

40. Do your local vets have sufficient knowledge and experience of dairy goats?

Yes No Not sure

Further comments *(optional)*;

INFECTIOUS DISEASES

41. Has your herd ever been affected by the following diseases?

Please circle your responses.

Johnes	Yes	No	Don't know	Never heard of it
CLA	Yes	No	Don't know	Never heard of it
TB	Yes	No	Don't know	Never heard of it
Scrapie	Yes	No	Don't know	Never heard of it
CAE*	Yes	No	Don't know	Never heard of it

*CAE = caprine arthritis encephalitis

42. Do you currently vaccinate against Johnes disease? Yes No

43. Do you use other vaccines in your goats? Yes No

If yes, which vaccine(s) do you use?

Lambivac	Enzovax	Toxovax
Heptavac P Plus	CEVAC Chlamydia	Coxevax

Other; please specify; ☐

KIDS (from birth to weaning)

44. Approximately how many of your kids have shown these signs over the last 12 months?

Please circle your responses.

Poor growth	under 2%	under 5%	5 – 15%	over 15%
Deaths	under 2%	under 5%	5 – 15%	over 15%
Scour/diarrhoea	under 2%	under 5%	5 – 15%	over 15%
Pneumonia or excess coughing	under 2%	under 5%	5 – 15%	over 15%
Swollen joints or naval	under 2%	under 5%	5 – 15%	over 15%
Skin problems (include itchy kids)	under 2%	under 5%	5 – 15%	over 15%

45. Have you seen any other problems in your kids over the last 12 months?

Yes No

If yes, please specify;

YOUNGSTOCK (from weaning to first kidding)

46.Approximately how many of your youngstock have shown these signs over the last 12 months? *Please circle your responses.*

Poor growth	under 2%	under 5%	5 – 15%	over 15%
Deaths	under 2%	under 5%	5 – 15%	over 15%
Scour/diarrhoea	under 2%	under 5%	5 – 15%	over 15%
Pneumonia or excess coughing	under 2%	under 5%	5 – 15%	over 15%
Skin problems (include itchy kids)	under 2%	under 5%	5 – 15%	over 15%
Difficult to get into kid when first mated	under 2%	under 5%	5 – 15%	over 15%

47. Have you seen any other problems in your youngstock over the last 12 months?

Yes No

If yes, please specify;

48. What is your target age for first service? ☐ months

49. What is your target weight at first service? ☐ kg

MAIN MILKING HERD (including dry does)

50. Approximately how many of your milking goats have shown these signs over the last 12 months? *Please circle your responses.*

Overly fat	under 2%	under 5%	5 – 15%	over 15%
Overly thin	under 2%	under 5%	5 – 15%	over 15%
Difficult to get in kid	under 2%	under 5%	5 – 15%	over 15%
Difficult to dry off	under 2%	under 5%	5 – 15%	over 15%
Assisted kidding	under 2%	under 5%	5 – 15%	over 15%
Abortion or stillbirth	under 2%	under 5%	5 – 15%	over 15%
Cloudburst	under 2%	under 5%	5 – 15%	over 15%
Lameness (include footrot)	under 2%	under 5%	5 – 15%	over 15%
Mastitis	under 2%	under 5%	5 – 15%	over 15%
Scour/diarrhoea	under 2%	under 5%	5 – 15%	over 15%
Pneumonia or excess coughing	under 2%	under 5%	5 – 15%	over 15%
Skin problems (include itchy goats)	under 2%	under 5%	5 – 15%	over 15%

51.Have you seen any other problems in your milking goats over the last 12 months?

Yes No

If yes, please specify;

BILLIES (includes both vasectomised billies and entire billies)

52. Have any of your billies shown the following signs over the last 12 months?

Please circle your responses.

Overly fat	Yes	No
Overly thin	Yes	No
Lameness	Yes	No
Scour/diarrhoea	Yes	No
Skin problems (include itch)	Yes	No

53. Have you seen any other problems in your billies over the last 12 months?

Yes No

If yes, please specify;

RESEARCH PRIORITIES

54. Which issues are you most concerned about?

*Please circle the **5 issues** that concern you most. Please **rank** these 5 issues in order of importance, by writing a number next to them (number 1 being the most important).*

pneumonia → kids / youngstock / adults	lameness	scour → kids / youngstock / adults
CAE	Johnes	fertility
mastitis	abortion/stillbirths	TB
colostrum management	CLA	skin problems
growth rates → kids / youngstock / adults	nutrition/feed management → kids / youngstock / adults	

55. Are there other issues you would have liked opportunity to include in your top five?

Yes No

If yes, please specify;

Thank you for completing this questionnaire!

Would you like to receive a summary of the survey results?	Yes	No
Would you be happy for me to contact you to follow up on any of these findings?	Yes	No

Contact details

Name:

e mail:

Phone number:

MILKING GOAT ASSOCIATION

University of BRISTOL

DAIRY GOAT RESEARCH ALLIANCE SURVEY

Farmer Summary

20.02.18

Kathy Anzuino MRCVS

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46 dairy goat farms completed the survey. All farms were located in England or Wales.

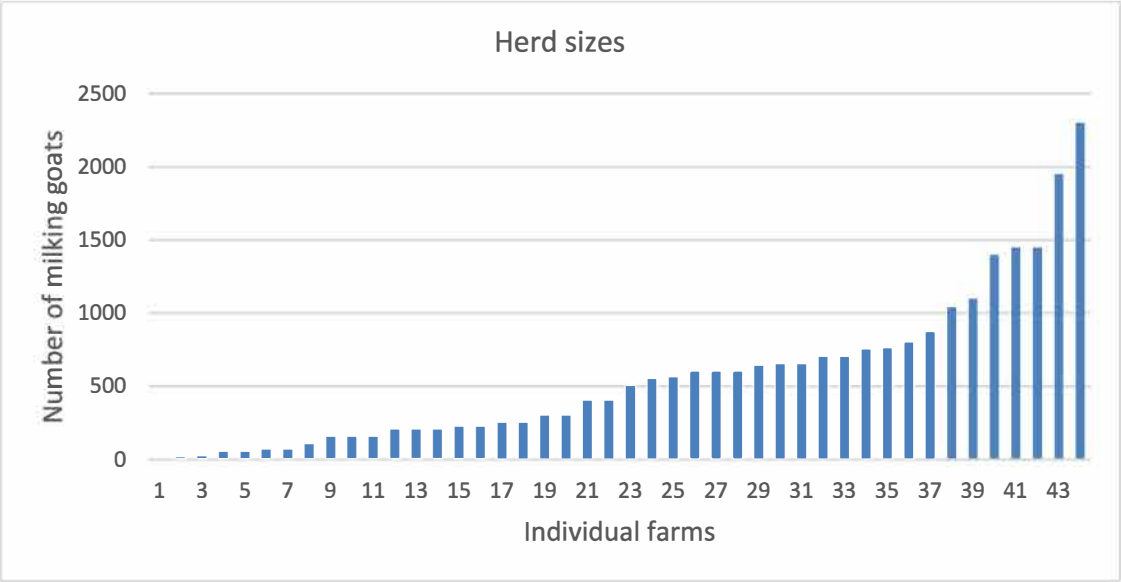
The survey had 55 main questions. In this summary each question is set out in the same order as in the survey and a summary of responses follows each question. **Most questions were answered by all 46 farms. Where fewer farms answered a question then the number of farmers answering is given.**

.....

Question 1. **How many milking goats do you currently have** (include dry does)**?** (45 farms answered)

Herd sizes ranges from 6 goats to 2300 goats.

- 8 farms had 50 or fewer milking goats
- 8 farms had 51 to 200 milking goats
- 9 farms had 201 to 500 milking goats
- 13 farms 501 to 1000 milking goats
- 7 farms had greater than 1000 milking goats

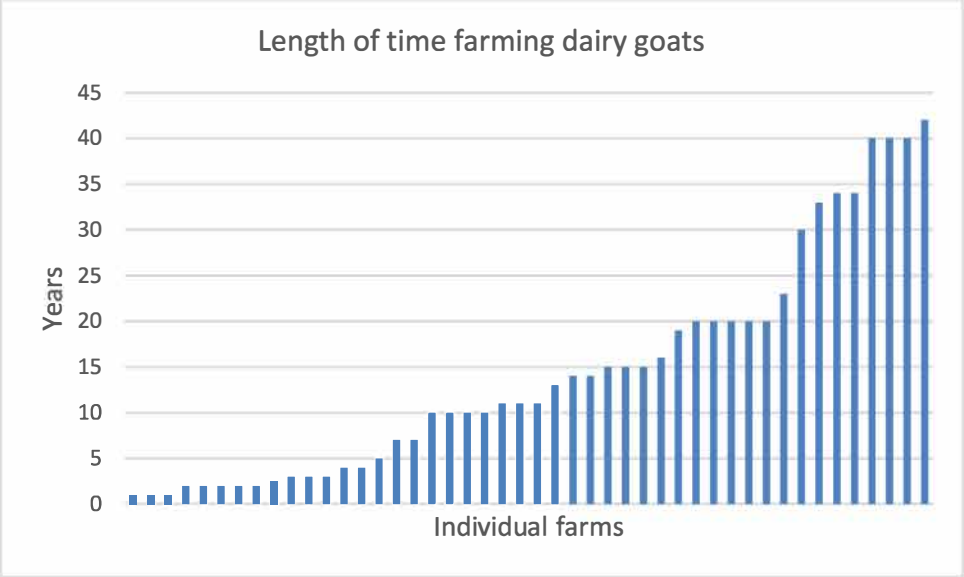


*Farms are placed in order of increasing herd size. Each blue column is an individual farm.

There were 24, 372 milking goats in total on these 45 farms, comprising approximately 54% of all commercial dairy goats in England and Wales.

Question 2. For how long have you been farming dairy goats?

Answers ranged from 1 to 42 years.



*Farms are placed in order of increasing age.

.....

Question 3. Do you rear your own replacement goats?

Yes, for 46 (100%) of the farms.

.....

Question 4. Do you rear all your replacement goats, including males?

(i.e. completely closed herd) (45 farm answered)

Yes, for 14 (31%) of the farms. .

.....

Question 5. Do you breed out of season?

Yes, for 31 (30%) of the farms.

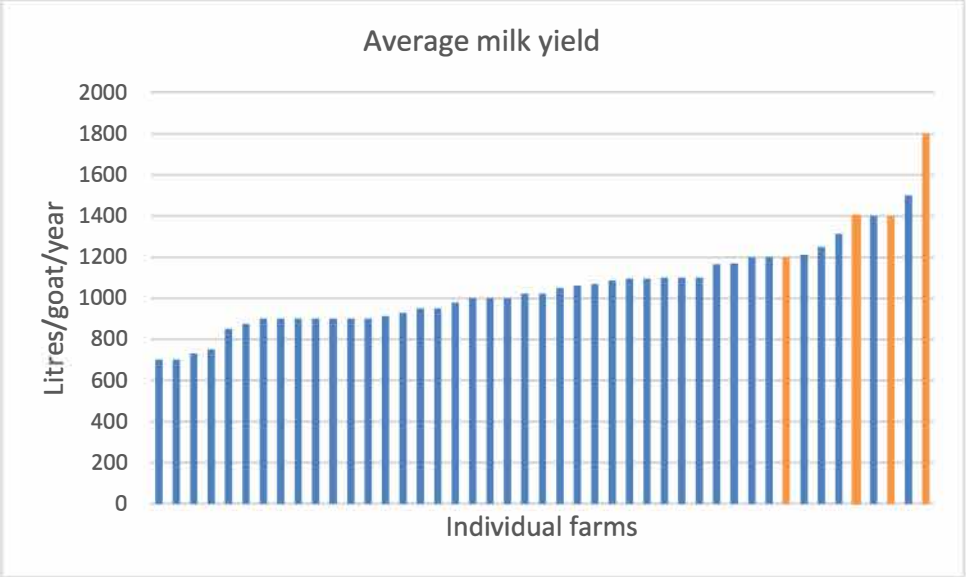
.....

Question 6. Do your goats ever graze outdoors?

Yes, for 8 (17%) of the farms. Farms grazing outdoors were smaller herd sizes - 2 farms had approximately 200 goats and the remaining 6 farms with herd sizes of under 60 goats.

Question 7. What is your average milk yield? (litres/goat/year) (45 farms answered)

Reported average yields ranged from 700 to 1800 litres/goat/year.



Farms are placed in order of increasing milk yield. Farms with herds of less than 50 goats are shown on the graph in orange colour.

.....

Question 8. Which are the main breeds in your herd?

- Saanen/Saanen crosses 40 farms
- Toggenburg/Toggenburg crosses 25 farms
- Alpine/Alpine crosses 12 farms
- Anglo Nubian/AN crosses 9 farms
- Golden Guernseys 1 farm

Of the 40 farms with Saanen /Saanen crosses, 11 farms gave more detail. 9 farms said British Saanen, 1 farm said French Saanen and 1 farm (<20 goats) said Pure Saanen.

Of the 12 farms with Alpine/Alpine crosses, 5 farms gave more detail. 4 farms said British Alpine and 1 farm said Swiss Alpine.

Question 9. For how long do kids remain with their mothers?

- Removed at birth 10 farms
- Under 12 hours 4 farms
- 12 – 24 hours 10 farms
- 25 – 48 hours 10 farms
- Over 48 hours** 12 farms

****If over 48 hours, then specify how long;**

- 3 days; 4 farms (herd sizes 200 goats, 196 goats, 870 goats, 100 goats)
- 4 days 1 farm (herd size 7 goats)
- 5 to 7 days 1 farm (herd size 6 goats)
- 7 days 3 farms (herd sizes 219 goats, 300 goats, over 1000 goats)
- 5 weeks or more 1 farm (herd size 500 goats)

2 farms did not say how long.

Question 10 Are kids fed colostrum other than by suckling their mothers? (45 farms answered)

- Yes, sometimes 19 farms
- Yes, routinely 18 farms
- No 8 farms

In total, 37 farms feed some colostrum to the kid, either in addition or instead of what it receives from suckling its mother. **Questions 11 to17 record more details about the 37 farms feeding colostrum.**

Question 11. If yes, what type of colostrum is fed? (37 farms answered)

- Colostrum from doe 33 farms
- Colostrum from another source 7 farms

3 farms feed their kids colostrum both from a doe and/or from another source depending on circumstances.

Question 12. **How is this colostrum fed?** (37 farms answered)

- Bottle fed 28 farms
- By stomach tube 16 farms

8 of these farms reported they use both bottle feeding and tube feeding depending on circumstances.

Question 13. **For how long are kids generally fed this colostrum?** (37 farms answered)

- Less than 1 day 8 farms
- Between 1 and 2 days 24 farms
- More than 2 days 5 farms

Question 14. **Do you pasteurise colostrum before feeding it?** (37 farms answered)

4 farms pasteurise colostrum.

Question 15. **Do you measure colostrum quality before feeding it?** (37 farms answered)

4 farms measure colostrum quality.

1 farm both pasteurises colostrum and measures colostrum quality

If yes, how is colostrum quality measured? (4 farms answered)

- Refractometer 2 farms
- Colostrometer (basic float) 1 farm
- Syringe and measuring jug 1 farm

.....

Further information on colostrum

There are 7 farms that feed colostrum replacer, either instead of doe colostrum or in addition to doe colostrum.

4 of these farms fed colostrum replacer routinely as their only source of colostrum. Here kids are removed from mothers at birth.

- 2 of these farms feed 'powder from Holland/Dutch powder' (most likely to be Capracol).
- 1 farm feeds replacer colostrum
- 1 farm feeds bagged colostrum

3 farms feed colostrum replacer sometimes e.g. if the doe not producing enough.

- 1 of these farm feeds Wynnstay own make
- 1 farm feeds Volostrum
- 1 farm did not specify the name/brand

One farm reported that they are planning to change feeding solely colostrum replacer (Capracol) next kidding. Currently they remove kids at birth and feed pasteurised doe colostrum.

Question 16. What volume of colostrum is fed?

The volume of colostrum fed varies greatly across farms. The details for the 32 farms that responded to this question are shown below.

1. 25 – 50ml
2. 150ml
3. 250ml
4. Minimum 300ml
5. 300ml per kid, 300ml per kid
6. 400ml per kid
7. 400mls
8. 200mls
9. 250 – 500ml
10. Aim for 180ml
11. 500ml
12. 150ml in first 6 hours
13. 200ml per feed
14. 10% bodyweight, typically 300ml
15. 10% of bodyweight
16. 100ml/kg
17. 800 – 1000ml over 1 – 2 days
18. 1.5 litres/day
19. 500ml x 4
20. 100ml x 2
21. 1 litres plus
22. 60mls plus depending on kid
23. As much as possible in 24 hours
24. As much as they will take 4 X daily
25. As much as they will take 3 X daily
26. To appetite
27. Whatever needed
28. Ad lib
29. Ad lib
30. As much as they need
31. As much as they drink in 24 hours
32. Not sure

Question 17. Are kids fed milk replacer?

Yes, on 40 (87%) of the farms.

6 farms do not feed milk replacer. 5 of these farms have herd sizes of 60 or less goats. 1 farm has 500 goats and runs the kids with their dams until they are 5 weeks age.

If yes, at what age are they first fed milk replacer?

38 of the 40 farms feeding milk replacer gave the age at which they first fed milk replacer. Reponses are summarized as follows;

- Between 1 and 2 days old 23 farms
- Between 3 and 4 days old 10 farms
- 5 days old 1 farm
- 6 days old 1 farm
- 7 days old 2 farms
- 14 – 21 days old 1 farm

1 farm did not give a definite age, but said they use replacer occasionally if they run out of cows' milk.

Name of milk replacer, if known.

34 farms gave the name of the milk replacer they use. A summary of responses is given below.

- Kiddomel 3 farms
- Lamlac 9 farms
- Volac Lamlac 4 farms
- Volac 4 farms
- Shine goat milk replacer 2 farms
- Mole Valley Farmers Lamlac 1 farm
- Wynnstay goat 2 farms
- Wynnstay Lamlac goat 1 farm
- Milkivit goat cream + Greeline + EMX 1 farm
- Milkivit 1 farm
- Omnistart 1 farm
- Multistart 1 farm
- Nukamel 3 farms
- Wonder kid 2 farms
- Stellargold 1 farm
- Volac Gold Supreme 1 farm
- First Feed calf milk replacer 1 farm
- Downland ewe replacer 1 farm

Question 18. How are kids fed milk replacer?

The 40 farms that feed milk replacer, feed it in the following ways.

- Ad lib (milk always available) only 34 farms
- Restricted (milk available in meals) only 4 farms
- Varies whether ad lib or restricted depending on kid age 2 farms

Question 19. Are kids fed creep feed/starter feed?

Yes, for 44 (96%) of the farms.

If yes, at what age are kids first fed starter feed?

42 of these farms gave the age starter was first introduced to kids. The responses are summarised below;

- Under 7 days 19 farms
- From 7 upto 14 days 15 farms
- From 14 upto 21 days 1 farm
- 21 days 5 farms
- 30 days 1 farm
- 42 days 1 farm

Name of creep/starter feed, if known

1. ForFarmers Prestige pellets
2. ForFarmers Prestige Pellets
3. ForFarmers Prestige Pellets
4. Lamb creep
5. Ewbol Prestige lamb pellets
6. 18% lamb pellets
7. Wynnstay lamb creep
8. Mole valley multi lamb pellet
9. 18% protein lamb pellets
10. Aston lamb starter finisher
11. NWF fast lamb
12. Lamb creep pellets
13. Calf starter feed
14. 16% coarse calf
15. Calf starter pellets (Harpers)
16. Calf course at first 18% nuts
17. 16% protein
18. Hay and Brecon feed
19. Duffields creep feed
20. Dairy nut
21. It has varied
22. Coarse ration Wynnstay
23. Coarse mix
24. Own mix
25. Own mix
26. Own mix
27. Own mix, (rolled barley, Lucerne, little sugar beet)
28. Badminton course mix high yield
29. Mole valley goat grower 16%
30. Dugdales creep feed
31. Harper mix
32. Help themselves to the main milking goat ration, along with does – not a starter feed
33. Carr's Billington – Nustart
34. GLW creep feed

Question 20. Are kids fed forage?

Yes, on 44 (96%) of the farms.

Of the 2 farms that do not feed forage, 1 farm of herd size 50 goats fed milking goats cut herbage and hedgerow. The herd size of the other farm is not known.

If yes, what age are kids first offered forage?

42 farms gave the age kids were first fed forage. These are summarised below.

- Under 7 days — 20 farms (*6 of these farms offer forage from birth)
- 7 – 14 days — 18 farms
- 21 days — 1 farm
- 28 days — 1 farm
- 42 days — 2 farms

If yes, what type of forage is fed?

42 farms gave the type of forage that was fed. Responses are summarised below.

- Hay fed to kids 21 farms
- Straw 25 farms
- Haylage 4 farms
- Silage 2 farms

9 farms feed kids more than one type of forage (generally hay and straw). The 4 farms feeding kids haylage were larger herd sizes (over 700 goats).

Of the 2 farms that feed silage to kids, 1 farm feeds kids just silage, the other farm feeds hay/straw as well as silage.

Question 21. Do you have a target weaning weight?

19 (41%) of the farms have a target weaning weight.

If yes, what weight is this?

15kg was by far the most commonly used weaning weight, used by 11 of the 19 farms. Weaning weights ranged from 12 up to 20kg.

Question 22. Do you have a target weaning age? (45 farms answered)

34 farms have a target weaning age.

If yes, what age is this?

30 of these farms gave their target weaning age. Responses have been summarised. By far the commonest age for weaning was between **6 and 8 weeks age** (20 farms).

- 5 weeks age 1 farm (herd size, 500 goats)
- From 6 to 8 weeks 20 farms
- 12 weeks 4 farms
- From 12 upto 16 weeks 1 farm (herd size, 150 goats)
- 18 weeks 1 farm (herd size, 50 goats)
- 6 months 1 farm (herd size, under 50 goats)
- 8 months 1 farm (herd size, under 50 goats)

11 farms had both a target weaning weight and a target weaning age, 5 farms had neither.

Question 23. Are milking goats fed forage?

46 (100%) of the farms feed their milking goats forage. A summary of responses is given below:

- Haylage 9 farms
- Hay 5 farms
- Straw, hay and silage 2 farms
- Straw, hay and haylage 2 farms
- Hay and straw 2 farms
- Hay, haylage 2 farms

Other individual farms gave more detail;

- Grass silage, oat wholecrop, haylage
- Ryegrass hay
- Cut herbage and cut hedgerow
- Hay, dried Lucerne
- Lucerne, hay, red clover, straw/ryegrass
- 2 acre field for 12 goats
- Whole crop/pea + barley, maize, grass silage, Lucerne
- Whole crop wheat B/grains
- Hay, barley straw, green browsings
- Whole crop barley, grass
- Maize, silage, hay, haylage
- Hay, silage maize
- Maize, oats, Lucerne
- Maize, grass, silage
- Good silage round bale
- Haylage, hay, straw
- Maize silage
- Grass, maize, straw
- Grass silage, maize, whole crop
- Grass, haylage
- Grass, red clover haylage
- Hay in feeders and straw bedding
- Maize or pea barley whole crop, haylage, red clover hay

Question 24. Is forage analysed?

Yes, for 23 (50%) of the farms.

Question 25. Are milking goats fed concentrate?

Yes, for 45 (98%) of the farms.

If yes, which concentrates are fed? e.g. brand name or type

1. For Farmers goat blend
2. For Farmers Capri Maxima forage nuts 18%
3. For Farmers Eco special milking goat
4. For Farmers goat mix
5. For Farmers parlour cake, SW buying group pellets and hipro/rape meal blend in TMR + soya hulls, sugar beet nuts
6. For Farmers goat mix
7. For Farmers 16% goat
8. Duffield's Gold 17 Pencil, Duffield Gold 17 pencils
9. (NWF Haskett dairy 16) 5mm goat nuts at 16% protein
10. Blend from NWF feeds
11. Blend from NWF feeds
12. Hay and Brecon milking goat nut
13. HBF goat nut
14. Charnwood Milling Co., Nuts and coarse mix 18%
15. Blend (GM free soya) rapemeal, wheat, Dist. Minerals
16. Dairy cake
17. South West special milking goat
18. Mix own TMR, as much of own feed stuff as possible, plus GM free protein mix from Lloyds feeds
19. Our own formulation
20. Own mix
21. Our own blend, soya hulls, rolled barley, yeast, C16, lime stone flavour?
22. Home mixed
23. Own rolled barley and sugar beet
24. Harpers goat milk pellet
25. Harpers goat 18% protein
26. Harpers dairy goat pellets 18% protein
27. Mole Valley 16% coarse calf
28. Mole Valley milkers blend
29. Mole Valley Farmers, Dairy cow performance 18
30. Mole Valley Monmouthshire goat nuts 18%
31. Wynnstay 18% dairy cake
32. Milkers goat nut SW goat group
33. Milkers goat nut SW goat group
34. Lea Oakes milk dairy goat nuts
35. Meal, Mol
36. Complete milking nut
37. Dairy cake
38. Soya
39. Dairy goat nuts
40. 18% goat pellets
41. Ad lib dairy cake
42. Soya, oats, rape seed meal
43. High fibre dairy cake 18%
44. Grainbeet fed in parlour as an incentive
45. Ad lib milking goat ration

If yes, how are the concentrates fed?

- Ad lib 17 farms
- Set ration per goat 17 farms
- TMR/mixed with forage 11 farms

Question 26. Are milking goats fed according to yield?

Yes, for 16 (35%) of the farms.

If yes, please indicate the number of feed groups?

13 out of 16 farms indicated the number of feed groups;

- 2 groups 5 farms
- More than 2 groups 8 farms

Question 27. Do you aim to give goats a dry period?

Yes, for 46 (100%) of the farms.

If yes, then for how long?

- Under 2 weeks 2 farms
- 3 – 4 weeks 8 farms
- 5 – 6 weeks 17 farms
- *6 – 7 weeks* *3 farms (these 3 farms circled between 2 categories)*
- 7 weeks or more 16 farms

Question 28. **What do you feed your youngstock from weaning to first service?**

1. Ad lib creep and haylage to around 6 months, then TMR (when big enough to reach through barrier without escaping)
2. ForFarmers lamb pellets
3. Oats, soya/rape, molasses, haylage, barley straw
4. Lamb creep, hay, straw, silage*
5. Ad lib rearing nut
6. 18% rearer going to 16% rearer pellet, straw/hay, grazing at 1 year old
7. 16% protein nuts
8. Stay on lamb creep until 4 months, then onto milking goat nut
9. As milkers but less
10. Creep/hay/straw, creep mixed with oats/hay/straw from 12 weeks, TMR
11. 18% lamb pellets until 3 months age, then swap onto milkers food
12. Haylage, ad lib goat nut
13. Grass, branches, hay, apples concentrate
14. Ad lib hay, grazing, coarse calf and oats
15. Mole Valley grower pellets ad lib
16. Wynnstay lamb creep until 20 weeks, Wynnstay all rounder until 1st service
17. Ad lib concentrate and straw both to 5 months, then TMR
18. Dry coarse mix which includes dairy performance 18%
19. Hay and barley straw, ad lib concentrate
20. Badminton coarse mix, Duffields Gold 17 pencil, weaning off coarse mix before service at 18 months
21. Complete goat nut, hay, barley straw
22. Beef rearer cake, hay, maize silage
23. Ad lib cake, straw until 6 months, maize silage after
24. TMR, haylage
25. Ad lib pellets (Prestige lamb pellets For Farmers), ad lib haylage
26. Lamb starter nuts, ad lib hay/straw/haylage
27. Ad lib cake, silage
28. Coarse mix 4 – 5 months, then goat concentrate ForFarmers
29. Haylage, straw – rationed mix of dairy and rolled grains
30. Cake, hay, straw
31. Calf rearer pellets, then dairy goat mix as per herd
32. Dairy cake ad lib hay
33. TMR same as milkers
34. Blend and straw
35. Hay and ad lib cake, same as adults
36. Haylage, half kg cake
37. 4 days to 8 months old ad lib cake and barley straw, 8 months onwards TMR mix
38. Hay/barley straw, ad lib creep or home mix
39. Lamb creep, lamb fat, grain beet
40. Heifer rearer 16% protein
41. Hay and ad lib feed (milking ration)
42. Hay and lamb pellets, moved onto milk ration at service
43. Nustart lamb pellets Carrs Billington 20 weeks, then HBF goat nut, hay and straw
44. Ad lib creep feed 18% protein and haylage
45. Concentrate and hay
46. Rolled barley, Lucerne and sugar beet, unlimited hay/haylage

Question 29. **What do you feed your billies?**

1. TMR
2. Oats, soya/rape, molasses, haylage, barley straw
3. Lamb creep, hay, straw, silage
4. Haylage
5. Same as youngstock
6. Otley goat nuts
7. Stay on lamb creep for 4 months, then onto milking goat nut
8. As females
9. Little, hay as much as they want, some creep/oats but not much unless they have been working hard and lost condition
10. Haylage and milkers food
11. Haylage, ad lib goat nut
12. Graze grass/hay, branches
13. Grazing, 4 billies to half acre, hay, 3:1 coarse calf: oats
14. Dairy TMR and straw
15. Wynnstay lamb creep until 16 weeks, Wynnstay all rounder until finished
16. Same diet as milking herd
17. Dry coarse mix which includes dairy performance 18%
18. Hay and barley straw ad lib concentrate
19. Coarse mix – low yield
20. Complete milking nut/hay/barley straw
21. Beet nuts and hay
22. Ad lib cake and straw until 6 months, silage after
23. TMR, haylage
24. Upto 6 months ad lib Prestige lamb pellets for farmers, ad lib haylage
25. TMR, haylage, when working same as female group i.e. TMR or ad lib/restricted pellets
26. Lamb starter finishing nuts, ad lib hay/straw/haylage
27. Haylage/cake
28. Mix of dairy ration and rolled grains and forage
29. Cake, hay, haylage, straw
30. Deluxe beef nuts
31. Dairy cake ad lib plus hay
32. TMR same as milkers
33. Cake and haylage
34. Haylage, half kg cake
35. 4 days old to 8 moths old, ad lib cake barley straw, 8 months old onwards TMR mix
36. Home mix, hay/straw
37. Grainbeet, hay
38. Heifer rearer 16%
39. Hay, ad lib feed
40. Lamb pellets and hay ad lib
41. HBF goat nut, hay
42. 0.5kg creep feed and haylage
43. Concentrate and hay
44. Rolled barley, Lucerne (small amount) and sugar beet, unlimited hay/haylage

Question 30. Do you have a market for your male kids?

Yes, for 35 (76%) of the farms.

If yes, then what market(s)? (34 farms answered)

- Meat 34 farms
- Breeding 13 farms

.....

Question 31. Do you rear any kids for meat on your farm?

Yes, for 25 (54%) of the farms.

.....

Question 32. How often are goats milked (at peak yield)? (45 farms answered)

Frequency of milking at peak yield;

- Twice daily 42 farms
- Three times daily 3 farms

.....

Question 33. Which of the following are done routinely at milking?

- Gloves worn 25 farms
- Foremilk checked 17 farms
- Teat wiped 26 farms
- Teat dip pre-milking 3 farms
- Teat dip post milking 16 farms

8 farms do not do use any routine hygiene practices at milking.

.....

Question 34. Do you record milk yields?

24 (52%) of the farms milk record. 22 farms said whether their milk recording was manual or automatic/electronic.

- Automatic/electronic recording 10 farms
- Manual recording 12 farms

22 farms said whether they recorded yield from individual goats or for groups of goats.

- Yield for individual goats 20 farms
- Total yield for a group of goats 2 farms

Question 35. Are goats fed whilst in the parlour?

Yes, for 23 (50%) of the farms.

If yes, then how are they fed? (22 answers)

- Individual ration 11 farms
- Small amount for encouragement 11 farms

.....

Question 36. What is your target kidding interval?

39 farms gave a target kidding interval. These are summarised below;

- 12 months/annually 15 farms
- Between 12 and 24 months 18 farms
- Between 24 and 36 months 3 farms
- Flexible according to yield 3 farms

.....

Question 37. Are goats routinely foot trimmed?

Yes, for 46 (100%) of the farms.

If yes, at what age are they first trimmed?

Responses have been put in categories;

- Between 6 weeks and 2 months 4 farms
- From 3 to 5 months 7 farms
- From 6 to 8 months 15 farms
- From 9 to 12 months 13 farms
- 18 months age 2 farms
- As necessary 4 farms

1 farm said at first kidding

How often are they trimmed? (45 answers)

- Every 4 to 8 weeks 7 farms
- Every 3 to 4 months 16 farms
- Every 5 to 6 months 15 farms
- Every 7 to 12 months 3 farms
- As often as possible 1 farm
- When needed 3 farms

Question 38. Are goats routinely footbathed?

Yes, for 9 (20%) of the farms.

If yes, please specify;

- Formalin 2 farms
- Formalin and golden hoof, 3 times weekly 1 farm
- Golden hoof, weekly or every 2 weeks 2 farms
- Foot mat on entry to shed and Diacur advanced 1 farm
- Copper sulphate monthly 1 farm
- Lime 1 – 2 times per month depending on the weather 1 farm
- Footbathed twice weekly, substance not given 1 farm

.....

Question 39. Are kids disbudded?

Female kids are routinely disbudded on all 46 (100%) farms

If yes, then at what age are they disbudded?

Summary of responses;

- Under 7 days old 20 farms
- 7 to 14 days old 18 farms
- *Age range of 3 – 10 days (overlap of above 2 categories) 4 farms*
- 28 days old 2 farms
- 7 weeks old 1 farm

.....

Question 40. Do your local vets have sufficient knowledge and experience of dairy goats?

- Yes 38 farms
- No 3 farms
- Not sure 5 farms

Question 41. Has you herd ever been affected by the following diseases?

1. **Johnes disease** (45 answers)
- Yes 22 farms
- No 19 farms
- Don't know 4 farms

2. **CLA** (45 answers)
- Yes 10 farms
- No 32 farms
- Don't know 3 farms

3. **TB** (45 answers)
- Yes 3 farms
- No 42 farms
- Don't know 0 farms

4. **Scrapie**
- Yes 4 farms
- No 42 farms
- Don't know 0 farms

5. **CAE** (45 answers)
- Yes 5 farms
- No 33 farms
- Don't know 7 farms

Question 42. Do you currently vaccinate against Johnes? (45 farms answered)

26 (57%) of the farms vaccinate against Johnes (Guidair®)

Question 43 Do you use other vaccines in your goats?

Yes, for 44 (96%) of the farms.

If yes, which vaccines do you use?

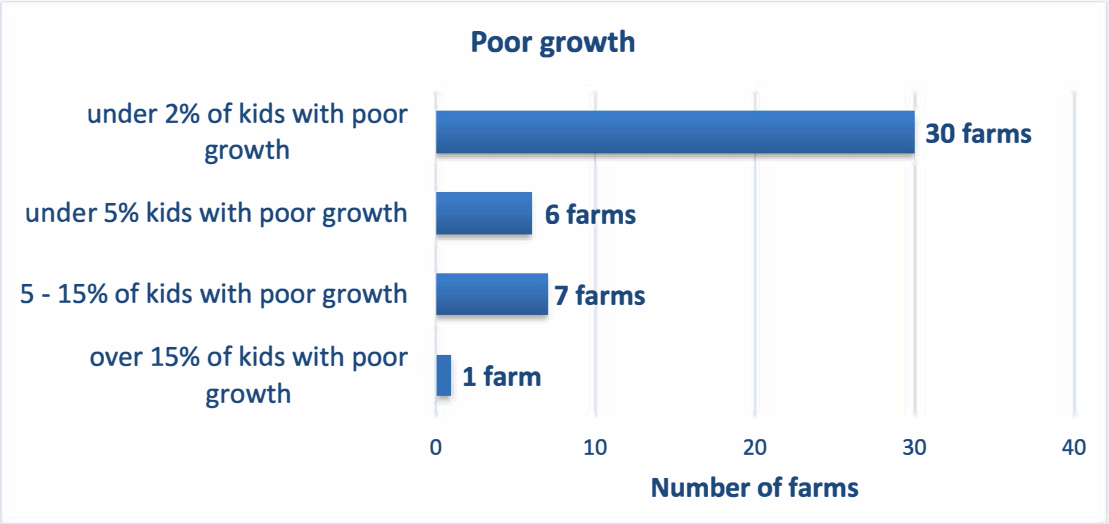
- Lambivac® 38 farms
- Toxovac® 11 farms
- Heptavac P Plus® 8 farms
- CEVAC® chlamydia 3 farms
- Coxevac® 3 farms
- Enzovac® 9 farms
- Other** 13 farms

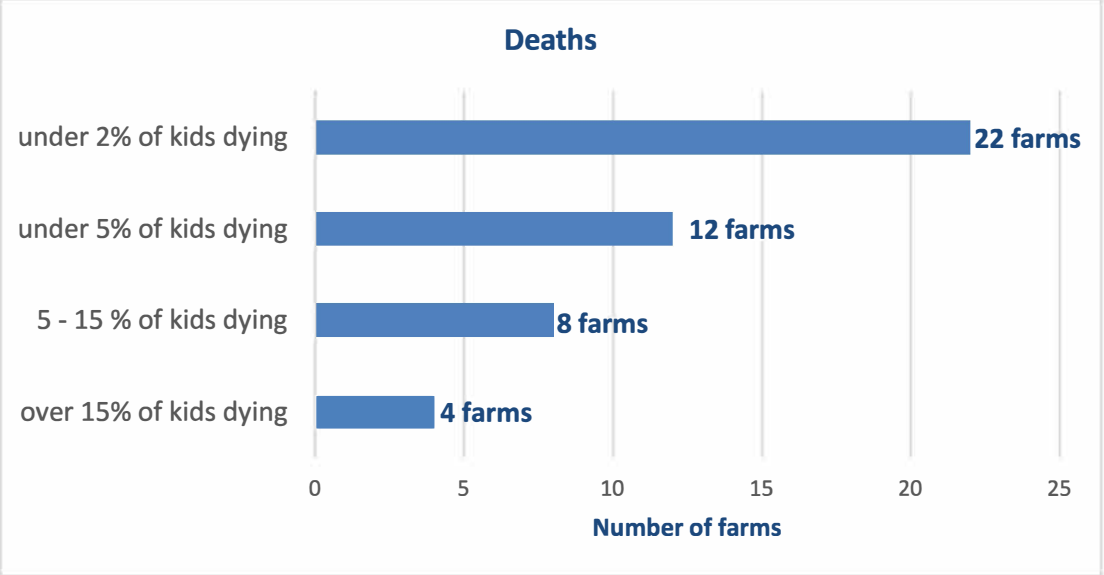
**Vaccine names given under 'other' were Ovipast Plus® (6 farms), Bravoxin® (1 farm), Covexin® (1 farm) and Glanvacc® 3 (3 farms).

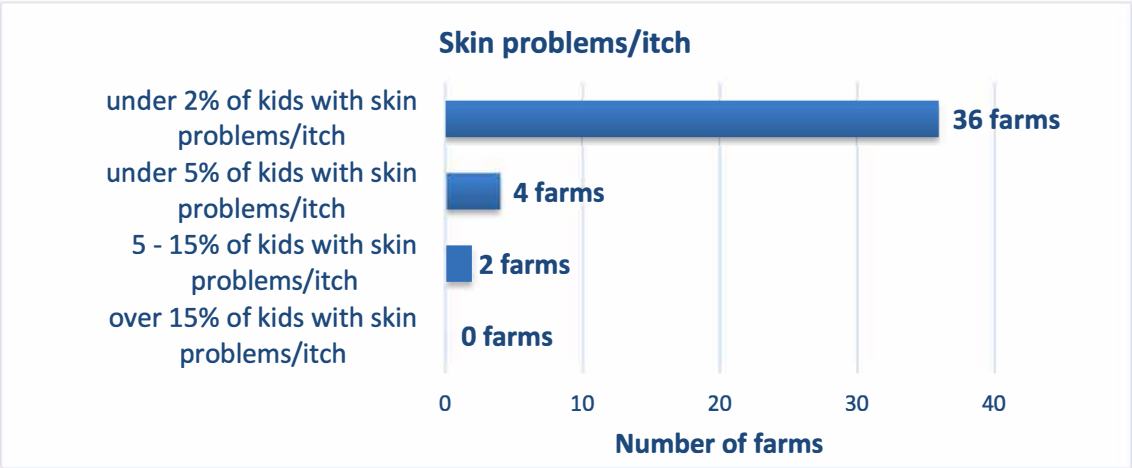
1 farm reported not using any vaccines.

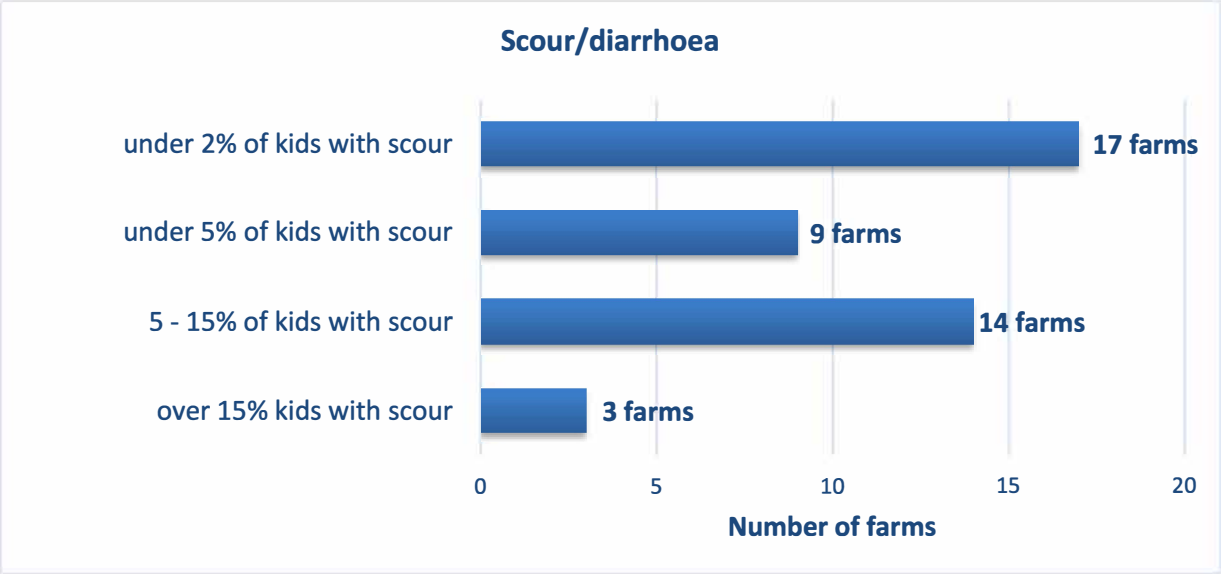
Question 44. **Approximately how many of your kids** (birth to weaning) **have shown these signs over the last 12 months?**

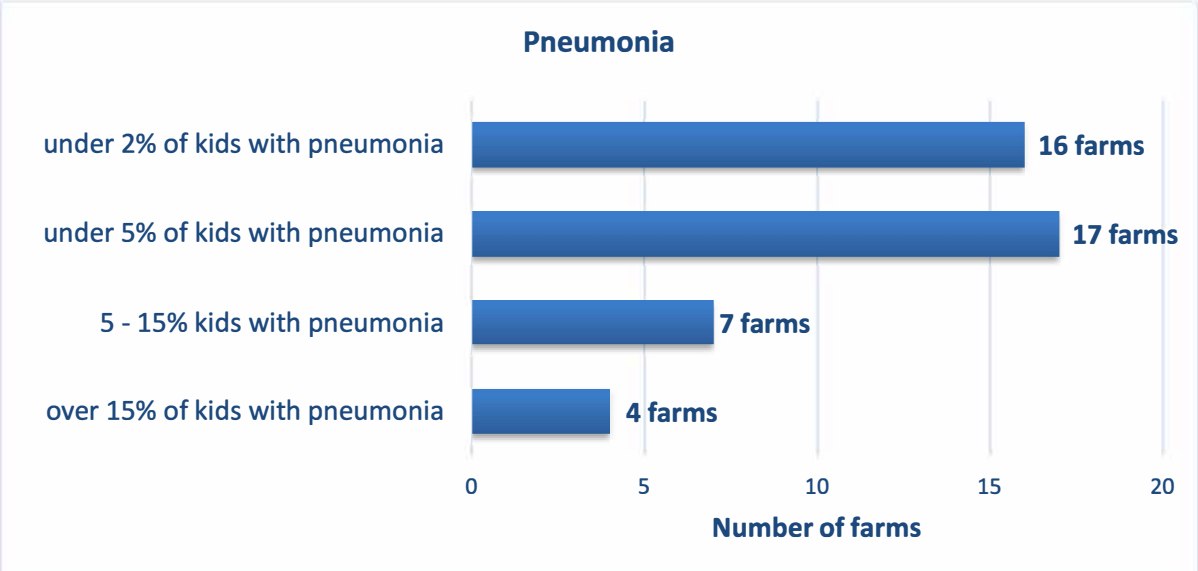
(poor growth, deaths, scour/diarrhoea, pneumonia, swollen joints &/or navel)

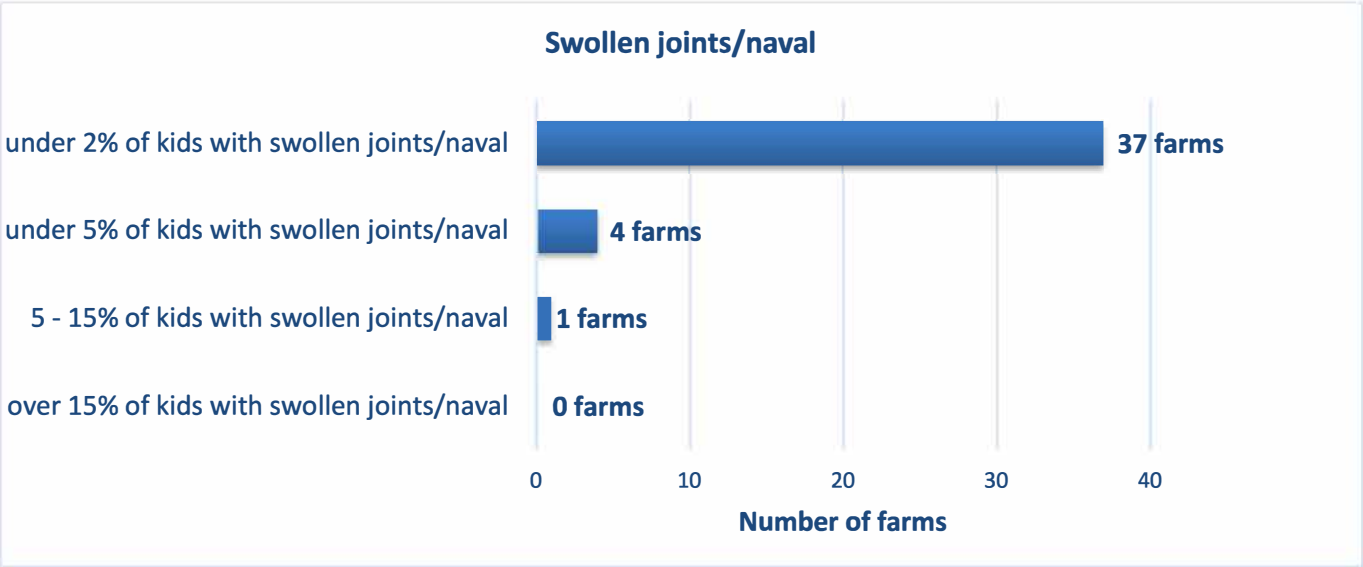





Skin problems/itch
under 2% of kids with skin problems/itch
under 5% of kids with skin problems/itch
5 - 15% of kids with skin problems/itch
over 15% of kids with skin problems/itch
36 farms
4 farms
2 farms
0 farms
0
10
20
30
40
Number of farms


Scour/diarrhoea
under 2% of kids with scour
under 5% of kids with scour
5 - 15% of kids with scour
over 15% kids with scour
17 farms
9 farms
14 farms
3 farms
0
5
10
15
20
Number of farms


Pneumonia
under 2% of kids with pneumonia
under 5% of kids with pneumonia
5 - 15% kids with pneumonia
over 15% of kids with pneumonia
16 farms
17 farms
7 farms
4 farms
0
5
10
15
20
Number of farms



Question 45 Have you seen any other problems in your kids over the last 12 months?

Yes, for 10 (22%) of the farms.

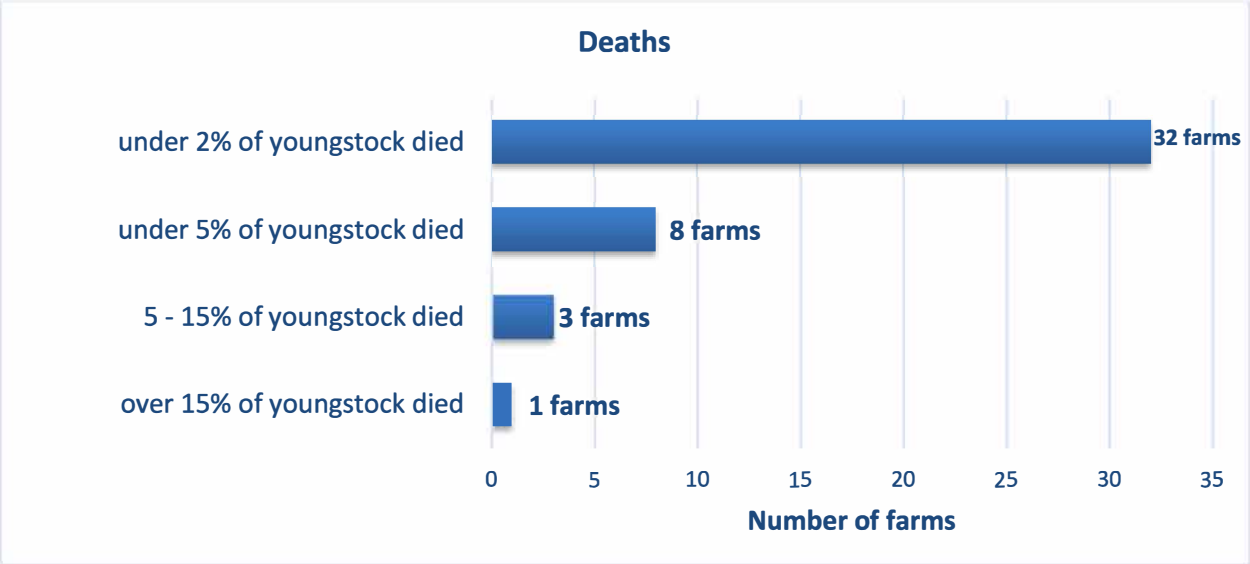
If yes, please specify;

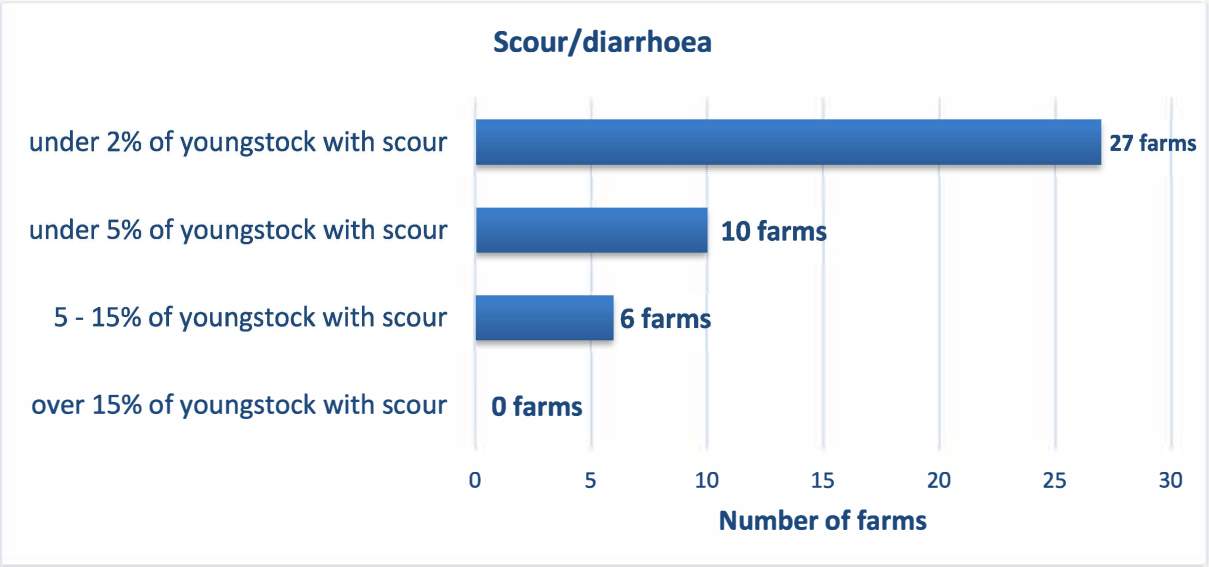
- Bloat
- Sore heads, secondary infections 2 to 3 weeks after disbudding
- 2 to 3 kids out of a group of around 160 kids were weak on their back legs, thriving in every other way, also, cryptosporidia, pasteurella
- Persistent diarrhoea/coccidiosis
- Navel hernias
- Sudden death at 9 days, (clostridium perfringens?)
- Cryptosporidia
- Scours
- Meningitis
- Coccidiosis

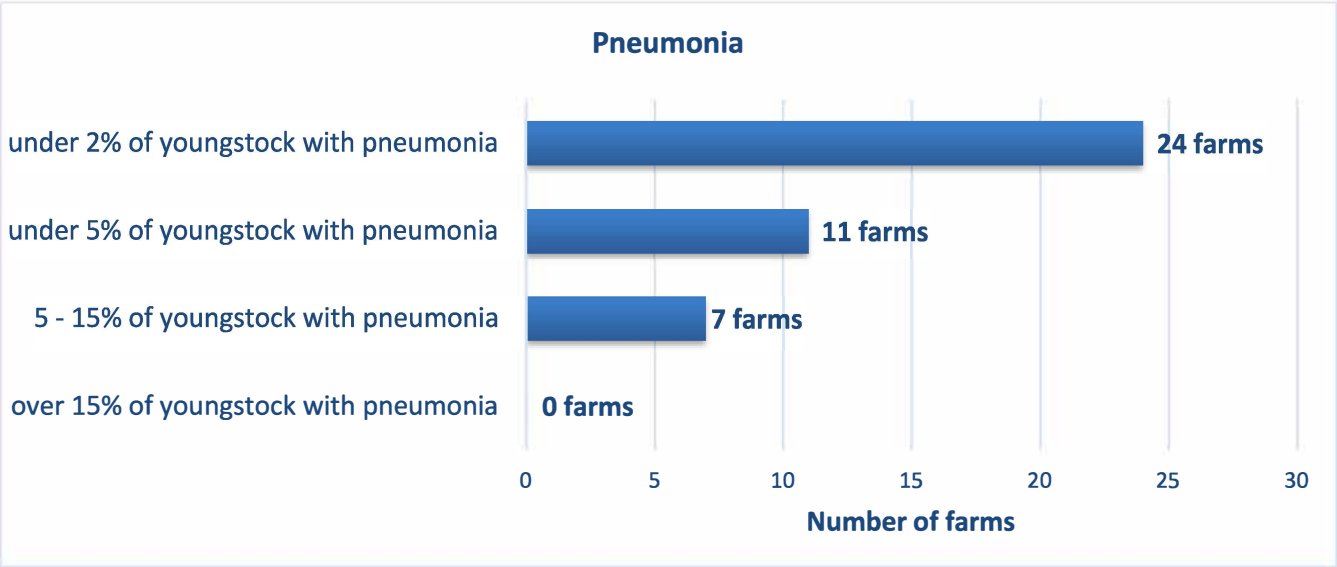
YOUNG STOCK (from weaning to first kidding)

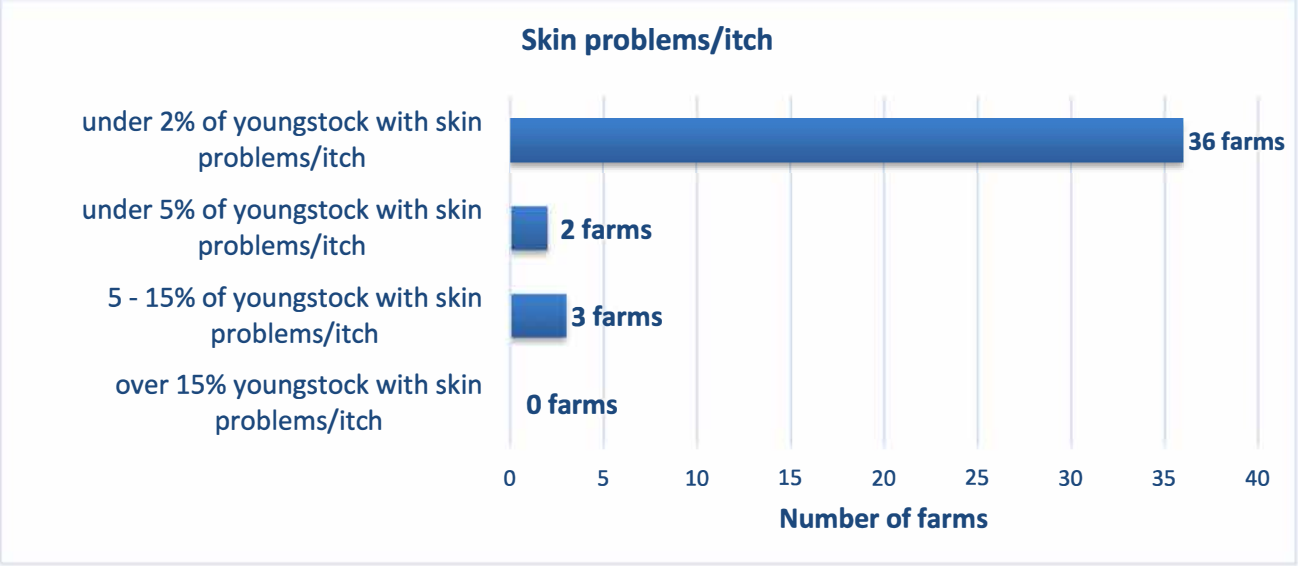
Question 46. Approximately how many of your young stock have shown these signs over the last 12 months?

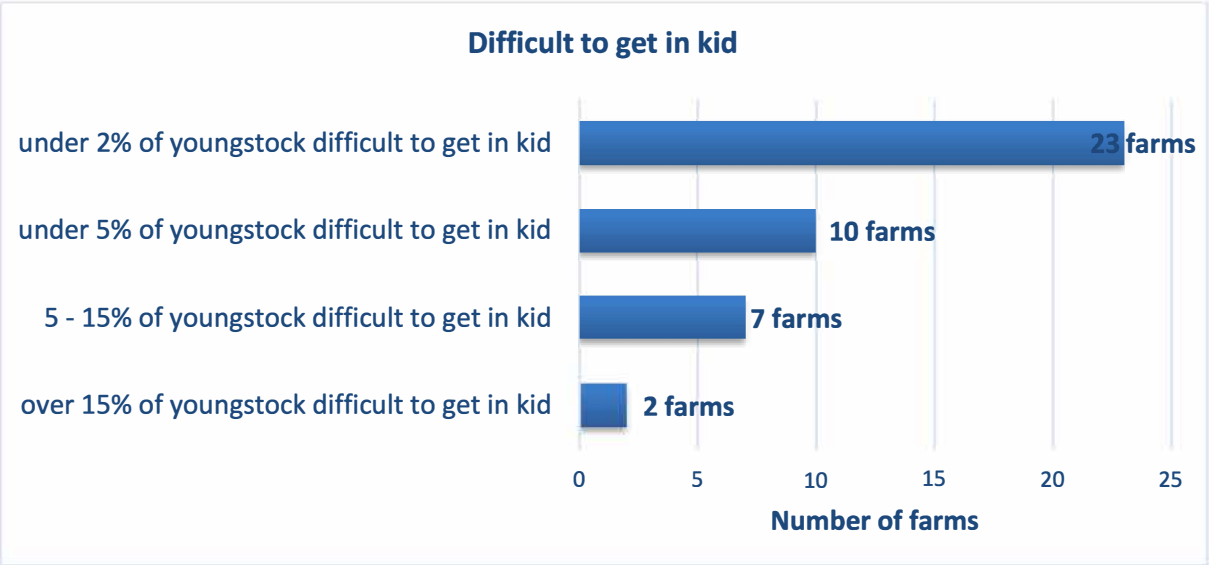
(Deaths, scour/diarrhoea, pneumonia, skin problem/itch, difficulty to get into kid, poor growth)

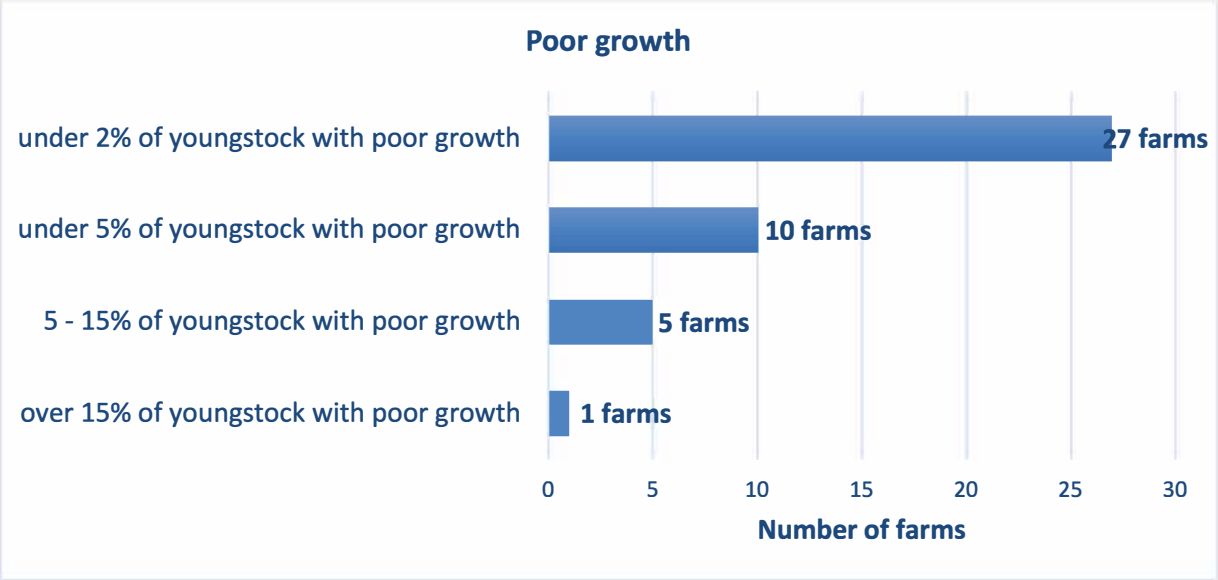





Pneumonia
under 2% of youngstock with pneumonia
24 farms
under 5% of youngstock with pneumonia
11 farms
5 - 15% of youngstock with pneumonia
7 farms
over 15% of youngstock with pneumonia
0 farms
0
5
10
15
20
25
30
Number of farms


Skin problems/itch
under 2% of youngstock with skin problems/itch
36 farms
under 5% of youngstock with skin problems/itch
2 farms
5 - 15% of youngstock with skin problems/itch
3 farms
over 15% youngstock with skin problems/itch
0 farms
0
5
10
15
20
25
30
35
40
Number of farms





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Question 47. **Have you seen any other problem in your young stock over the last 12 months?**

Yes, for 3 of the farms;

- listeria < 2%
- coccidiosis
- occasional orf or coccidiosis

Question 48. What is your target age for first service?

45 (98%) of the farms had a target age for first service.

Target age for first service ranged from 6 months to 19 months. Between 6 and 7 months was by far the commonest age.

- 6 – 7 months 18 farms
- 8 – 9 months 9 farms
- 10 – 12 months 9 farms
- 13 months 1 farm
- 14 months 1 farm
- 18 months 4 farms
- 19 months 2 farms

.....

Question 49. What is your target weight at first service?

31 (67%) of the farms have a target weight at first service.

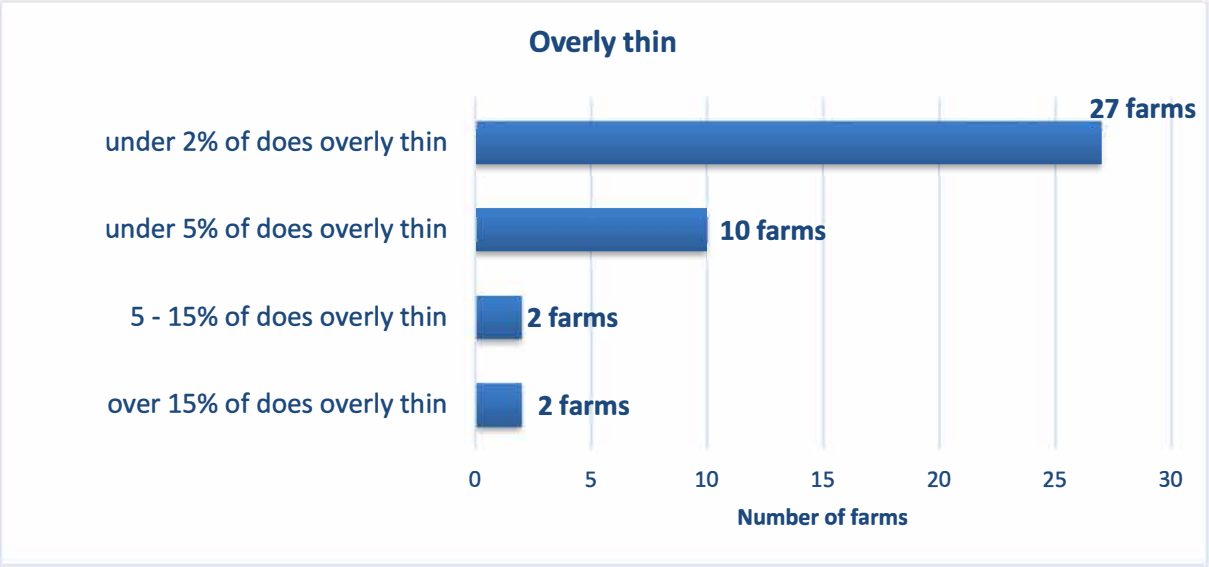
The commonest target weaning weight at first service was 35kg.

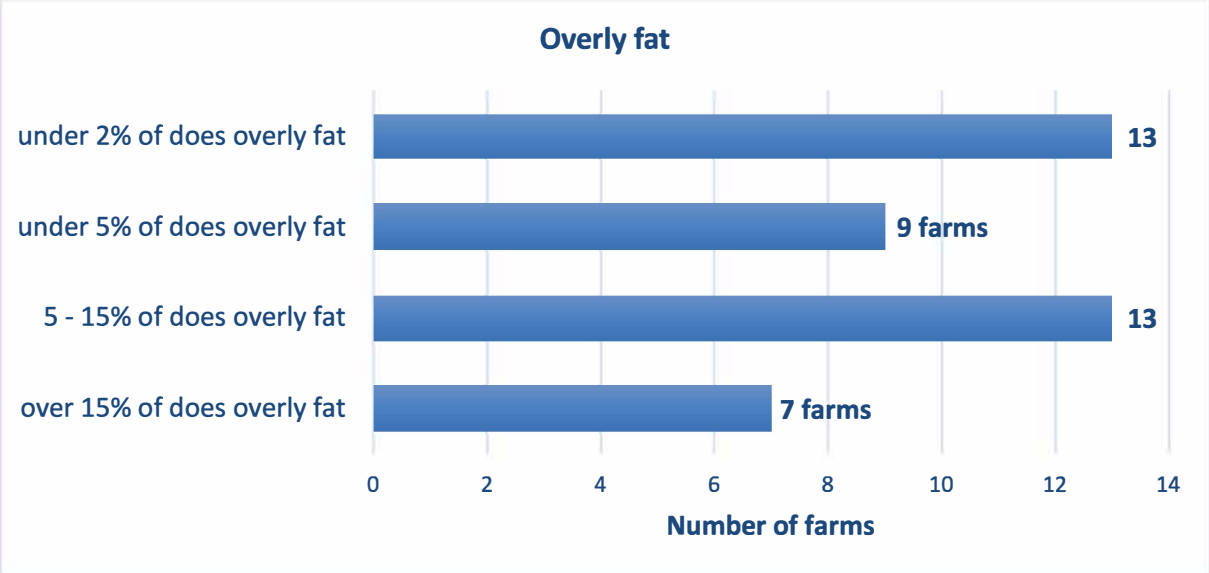
- 25 kg 1 farm
- 30kg 2 farms
- **35kg** **9 farms**
- **From 35 – 40kg** **6 farms**
- 40 kg 4 farms
- Between 40 and 50kg 1 farm
- 45kg 1 farm
- Over 45kg 1 farm
- 50kg 1 farm
- 55kg 1 farm

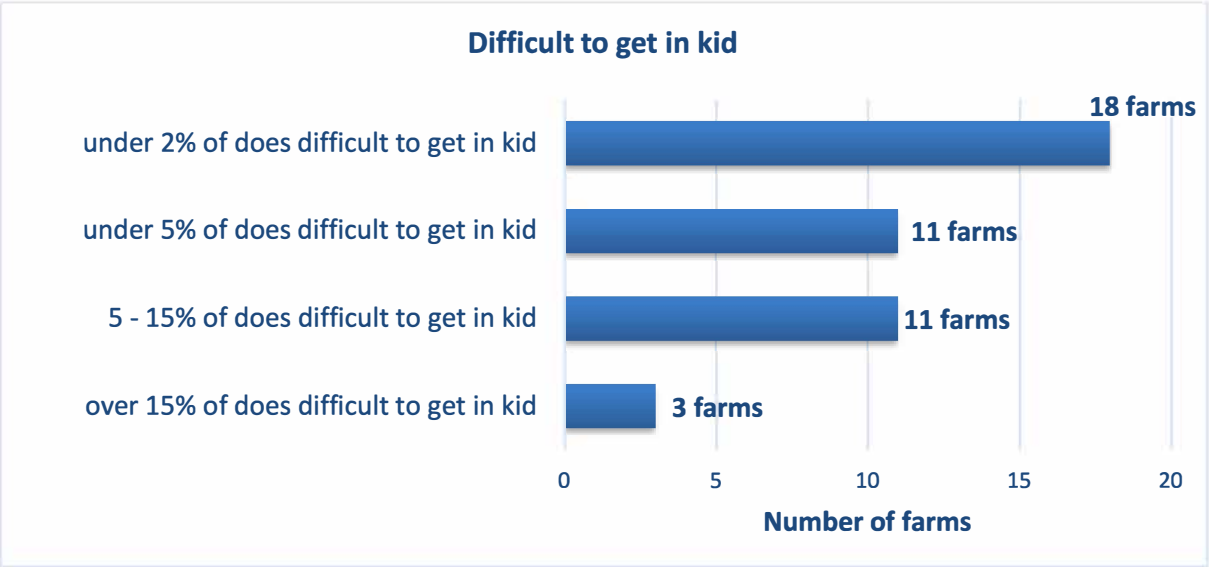
MAIN MILKING HERD

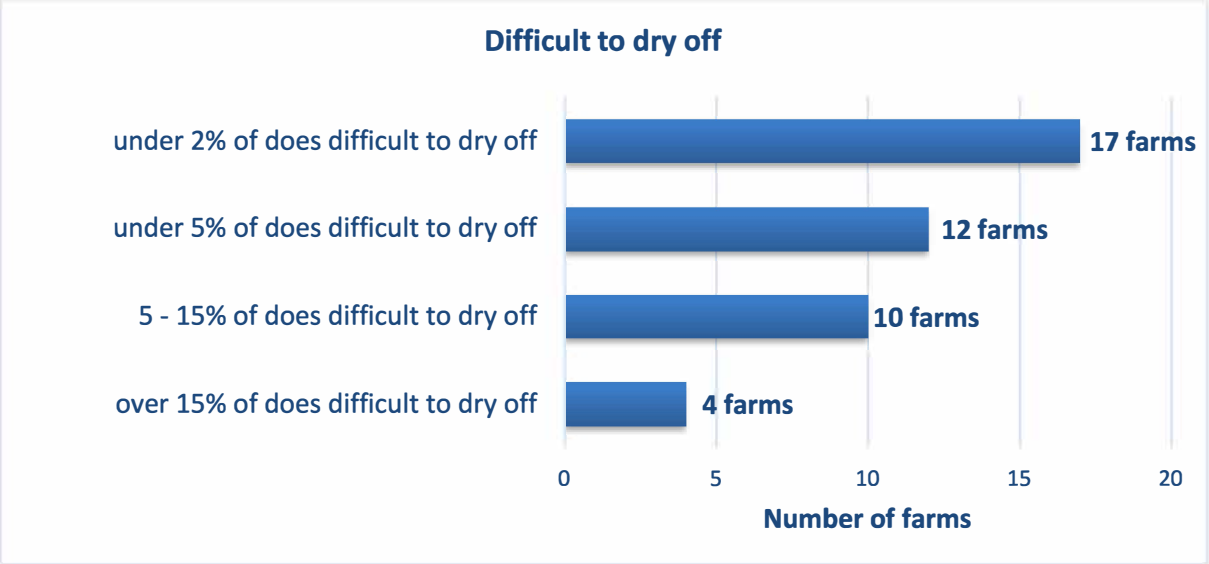
Question 50. Approximately how many of your milking goats have shown these signs over the last 12 months?

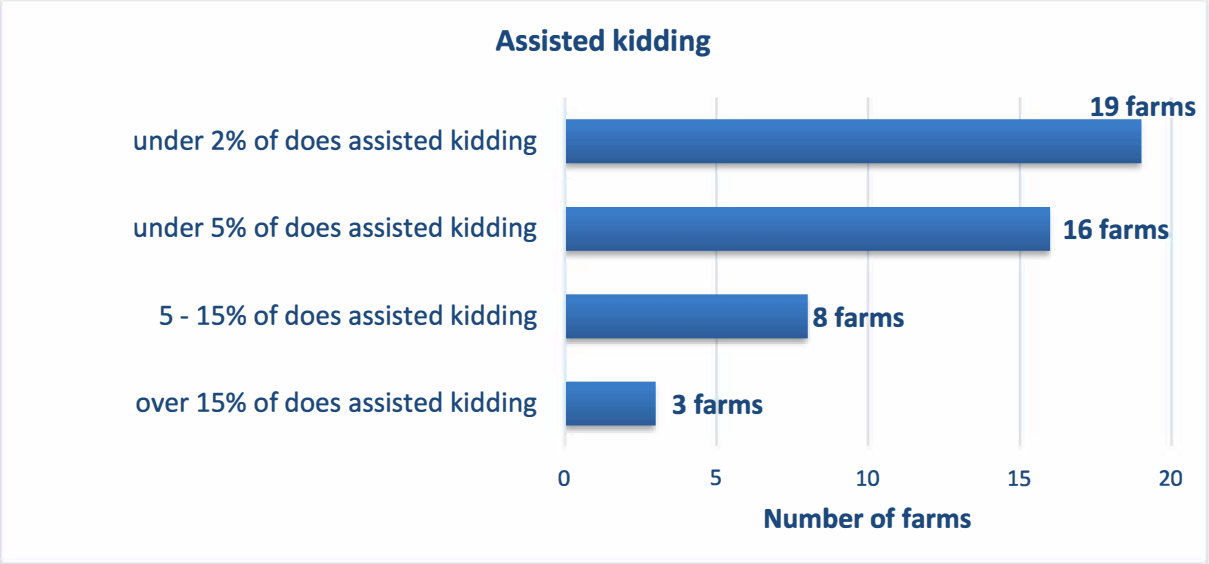
(Overly thin, overly fat, difficulty to get into kid, difficulty to dry off, assisted kidding, abortion or stillbirth, cloud burst, lame, mastitis, scour/diarrhoea, pneumonia, skin problem/ itch)

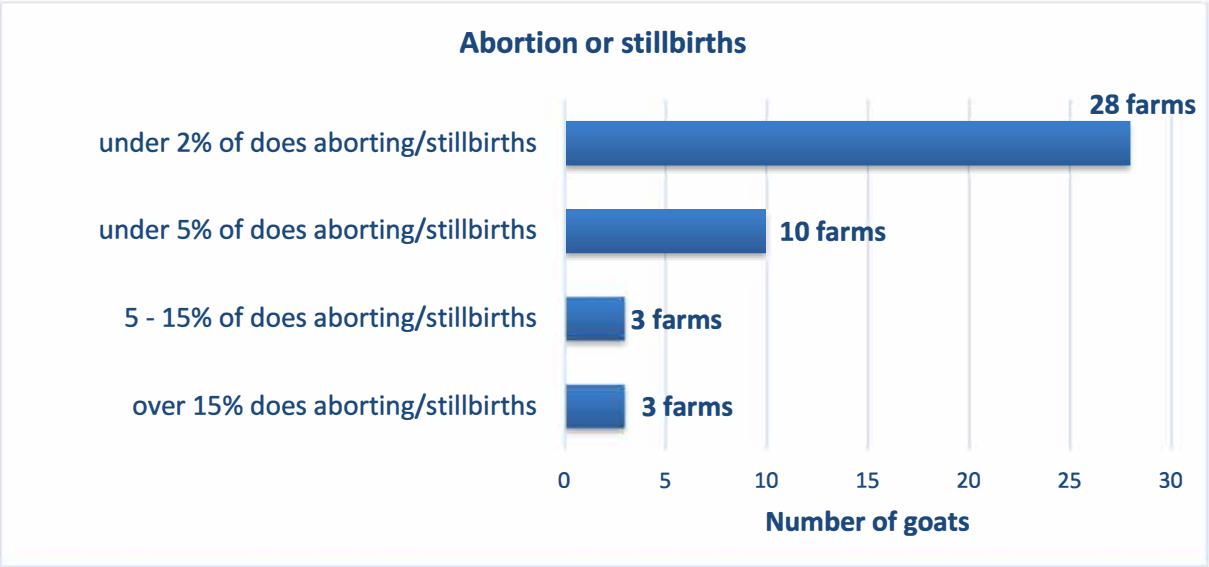


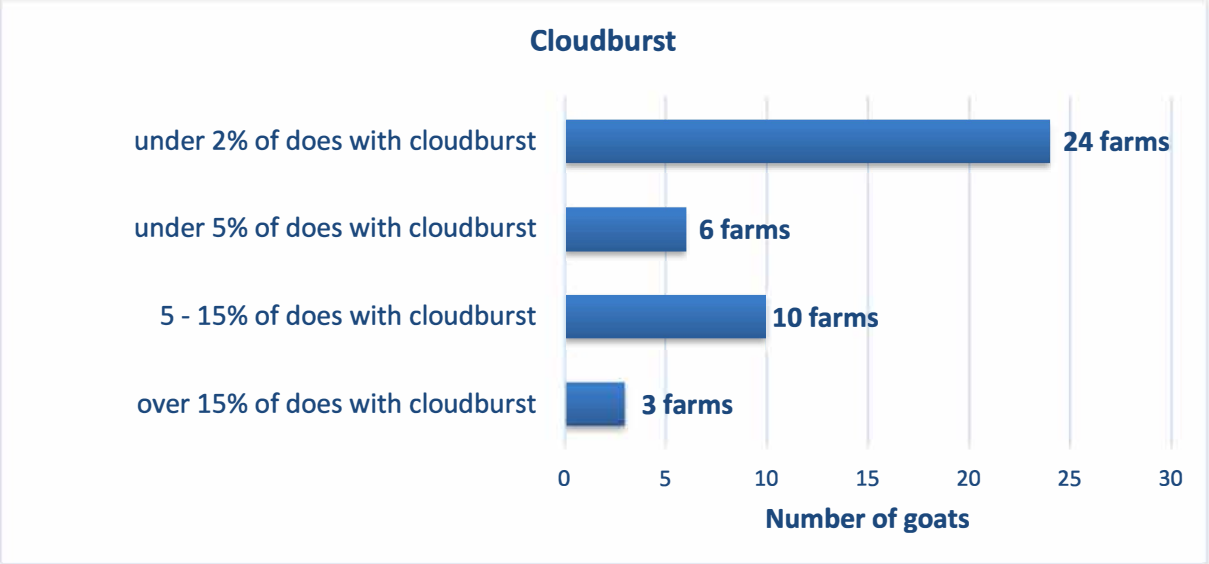


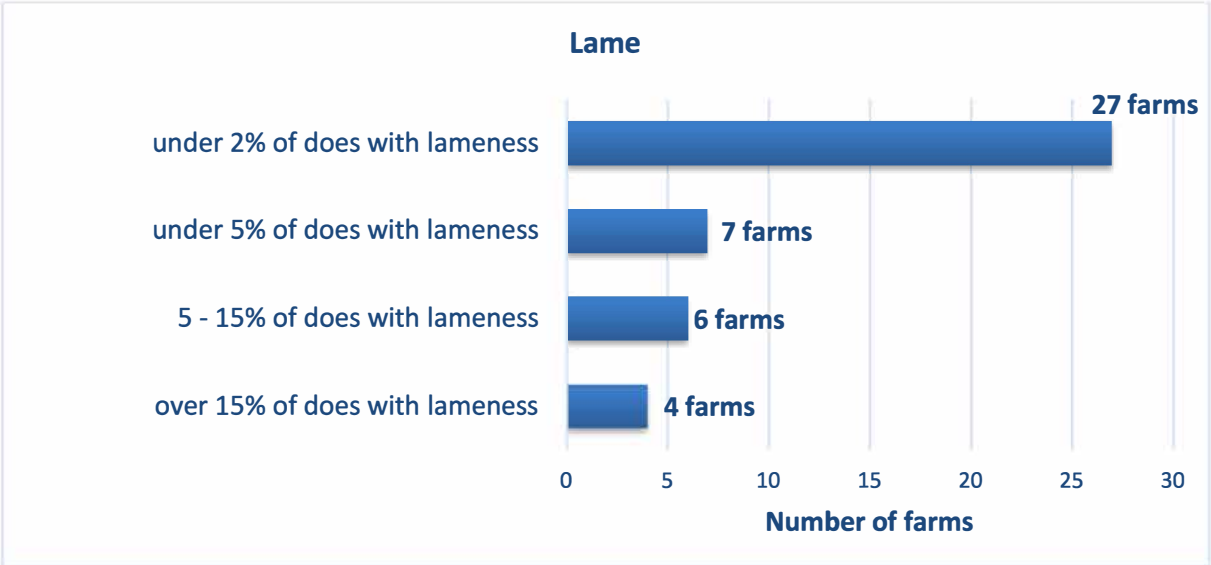

Difficult to get in kid
under 2% of does difficult to get in kid
under 5% of does difficult to get in kid
5 - 15% of does difficult to get in kid
over 15% of does difficult to get in kid
18 farms
11 farms
11 farms
3 farms
0
5
10
15
20
Number of farms

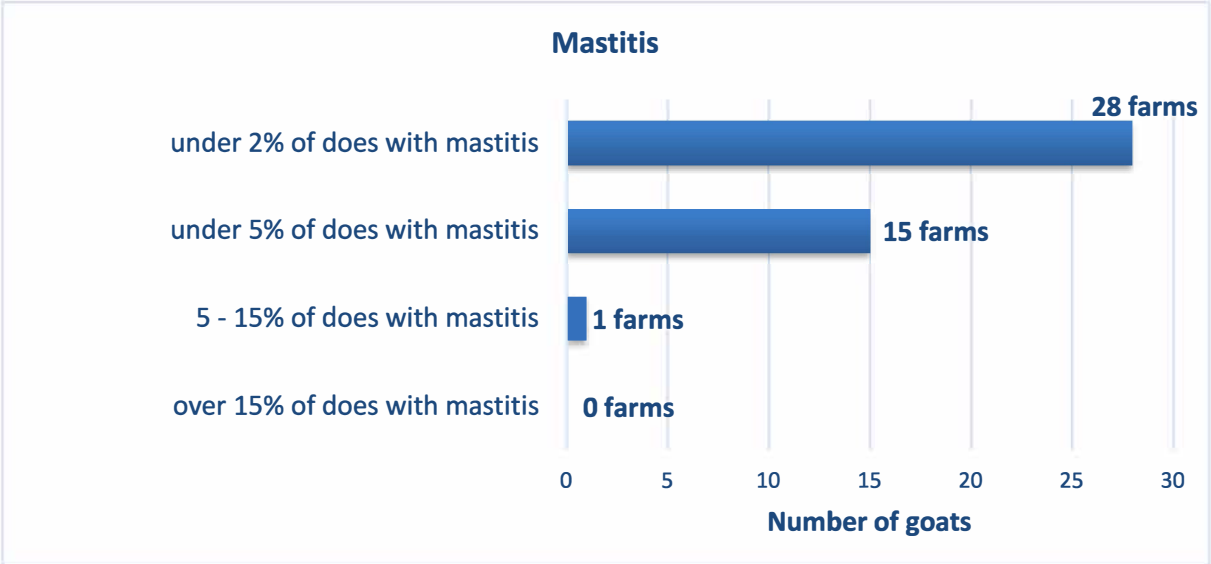

Difficult to dry off
under 2% of does difficult to dry off
under 5% of does difficult to dry off
5 - 15% of does difficult to dry off
over 15% of does difficult to dry off
17 farms
12 farms
10 farms
4 farms
0
5
10
15
20
Number of farms

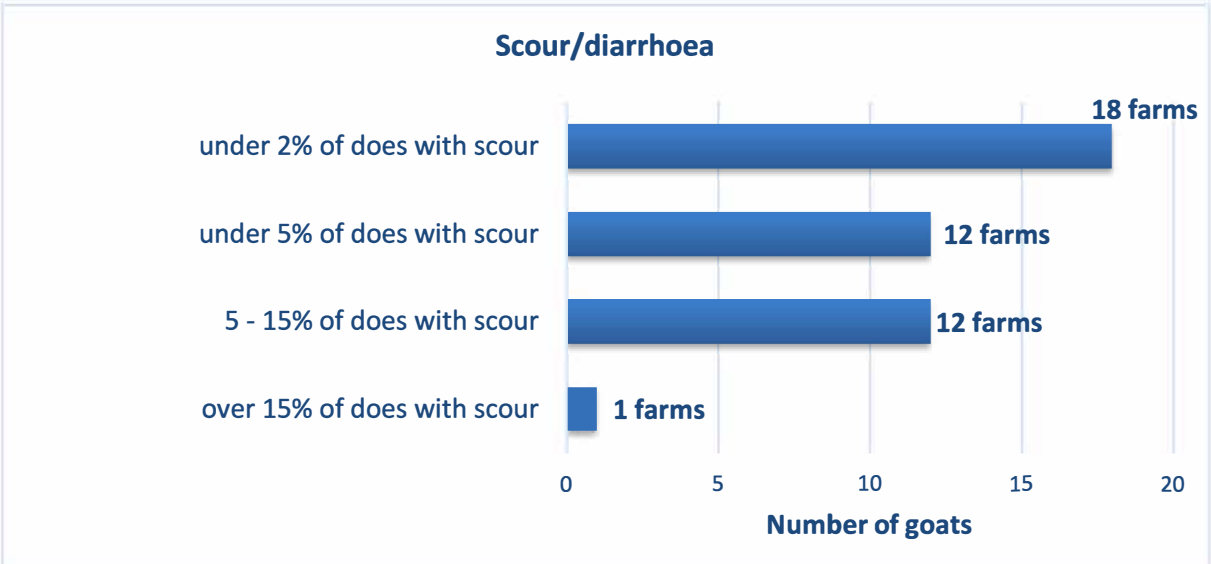

Assisted kidding
under 2% of does assisted kidding
under 5% of does assisted kidding
5 - 15% of does assisted kidding
over 15% of does assisted kidding
19 farms
16 farms
8 farms
3 farms
0
5
10
15
20
Number of farms

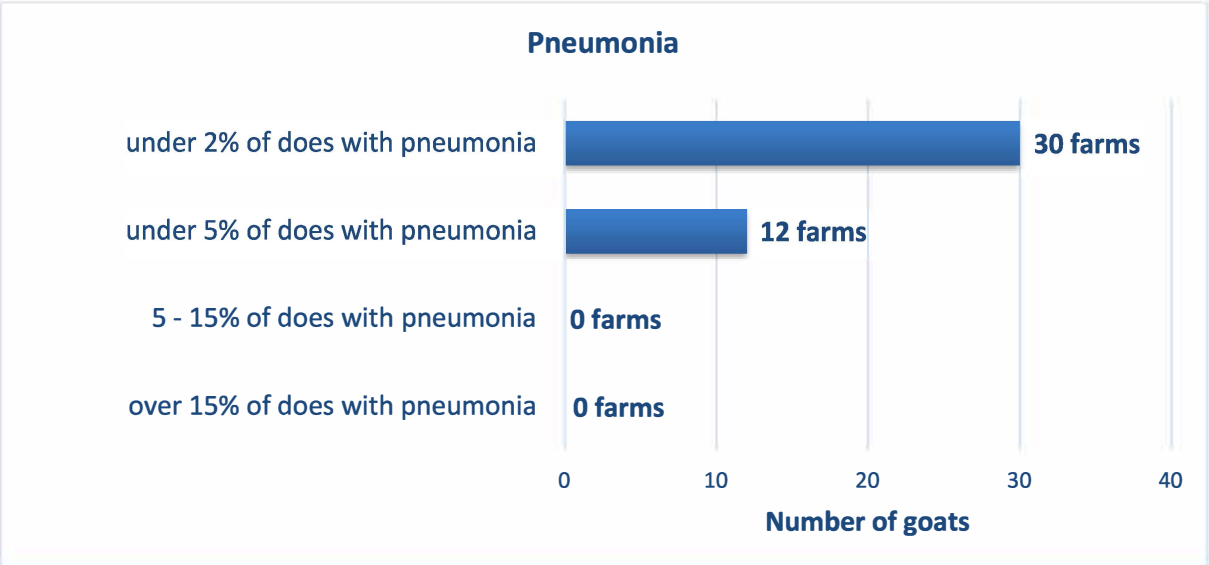

Abortion or stillbirths
under 2% of does aborting/stillbirths
under 5% of does aborting/stillbirths
5 - 15% of does aborting/stillbirths
over 15% does aborting/stillbirths
28 farms
10 farms
3 farms
3 farms
0
5
10
15
20
25
30
Number of goats

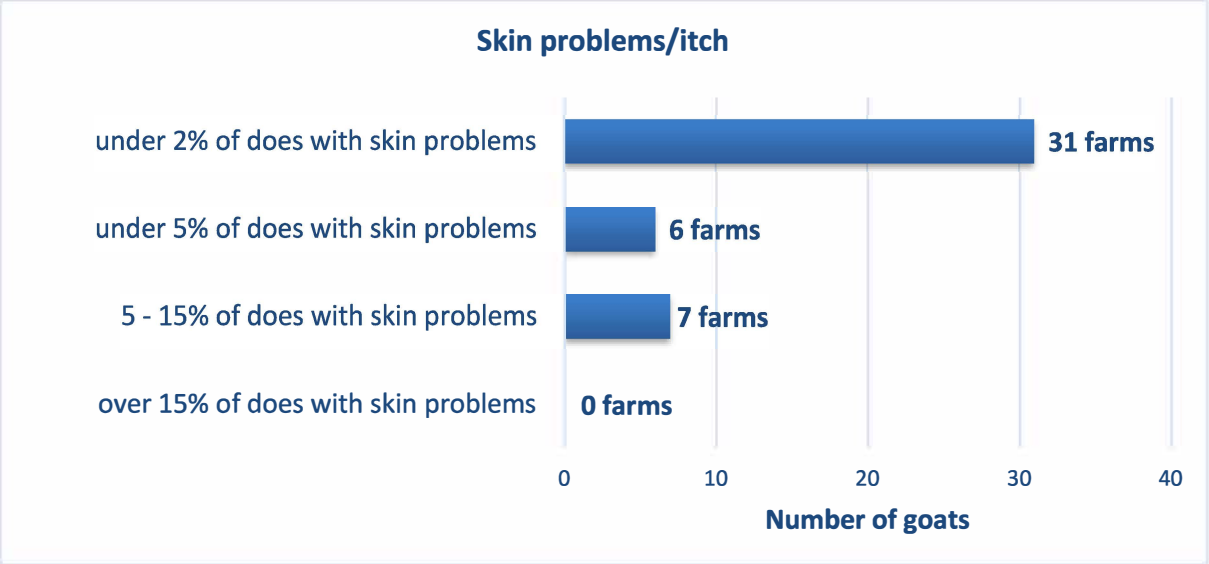

Cloudburst
under 2% of does with cloudburst
under 5% of does with cloudburst
5 - 15% of does with cloudburst
over 15% of does with cloudburst
24 farms
6 farms
10 farms
3 farms
0
5
10
15
20
25
30
Number of goats


Lame
under 2% of does with lameness
under 5% of does with lameness
5 - 15% of does with lameness
over 15% of does with lameness
27 farms
7 farms
6 farms
4 farms
0
5
10
15
20
25
30
Number of farms


Mastitis
under 2% of does with mastitis
under 5% of does with mastitis
5 - 15% of does with mastitis
over 15% of does with mastitis
28 farms
15 farms
1 farms
0 farms
0
5
10
15
20
25
30
Number of goats


Scour/diarrhoea
under 2% of does with scour
under 5% of does with scour
5 - 15% of does with scour
over 15% of does with scour
18 farms
12 farms
12 farms
1 farms
0
5
10
15
20
Number of goats


Pneumonia
under 2% of does with pneumonia
30 farms
under 5% of does with pneumonia
12 farms
5 - 15% of does with pneumonia
0 farms
over 15% of does with pneumonia
0 farms
0
10
20
30
40
Number of goats


Skin problems/itch
under 2% of does with skin problems
31 farms
under 5% of does with skin problems
6 farms
5 - 15% of does with skin problems
7 farms
over 15% of does with skin problems
0 farms
0
10
20
30
40
Number of goats

Question 51. Have you seen any other problems in your milking goats over the last 12 months?

Yes, for 7 (15%) of the farms. These were:

- Teat biting
- Odd listeria case with bad bale of silage
- Hernia occasionally
- Chlamydia/abortion rate to over 15%, now under control with antibiotics
- Yersinia in adults, always get some cases in the winter months, large problem 3 years ago, made a big economic impact
- Listeria <2%, twin lamb <2%, laminitis 5% (1st time kidding/pre kidding)
- CLA
- Ketosis 5 – 15%

BILLIES

Question 52. Have any of your billies shown the following signs over the last 12 months?

- Billies overly fat 3 farms
- Billies overly thin 6 farms
- Billies lame 12 farms
- Scour/diarrhoea 12 farms
- Skin problems/itch 8 farms

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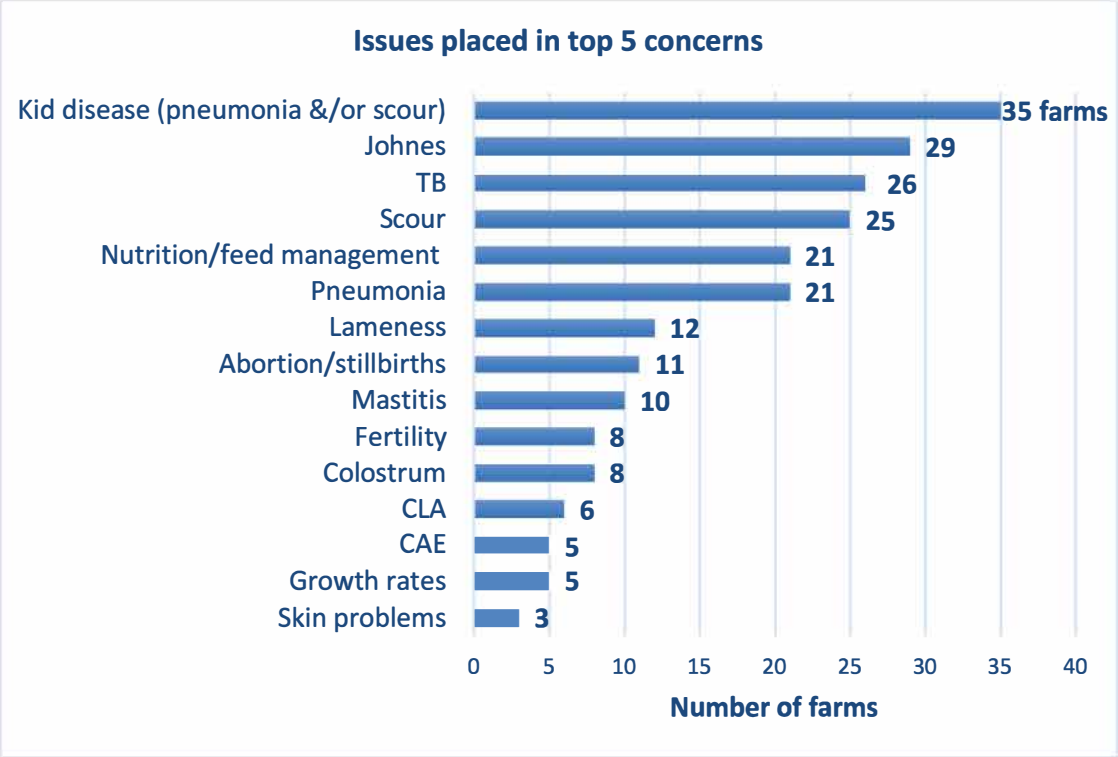
Question 53. Have you seen any other problems in your billies over the last 12 months?

Yes, for 5 (11%) of the farms. These were:

- CLA
- Excess horn growth on head 30 – 40%, listeria 2%
- Blocked urethra
- Mastitis
- 1 youngster had 2 bouts of pneumonia

Question 54. **Which issues are you most concerned about?** (40 farms answered)



Question 55. **Are there any other issues you would have like opportunity to include in your top five?**

Yes for 13 (28%) of the farms. These were:

- Kid housing design e.g. effect of temperature on growth rates
- Cloudburst (2 farms)
- AI success rate – to provide own replacement billies
- Bringing forward the breeding season
- Black bag
- Worming and internal parasites
- Yersinia has had a big economic impact
- Listeria research
- Disbudding
- Breeding selection, advice on inbreeding/conformation/genetics
- Good housing environment and bedding
- Getting high production without excessive fat build up/overall herd management.
- Fatty liver