Understanding the variations in grazing and rumination behaviours and their associations with production parameters in individual grazing dairy cows

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Abstract

This thesis aimed to understand: 1) the accuracy of an accelerometer-based sensor to monitor grazing and rumination behaviours in dairy cows; 2) grazing and rumination behaviour patterns and time budgets over 24 hours; 3) potential factors to influence grazing and rumination behaviours; and 4) effects of grazing and rumination behaviours on production parameters. To do this, data including, but not limited to, grazing time, rumination time, measures of cow performance (e.g., milk production and composition, body weight and body condition score), days in milk, and breeding worth index of 162 grazing dairy cows were collected for three consecutive lactation seasons (2018-2021). The analysis was performed on individual study years and results were reported separately for each year.

First, the accuracy of AfiCollar, an accelerometer sensor-based automated device to monitor and record grazing and rumination behaviours in dairy cows was evaluated for a grazing-based system. Spring-calved lactating cows (*n = 48*) wearing AfiCollar were continuously visually observed for 8 hours (9 am to 5 pm) to quantify minutes per hour spent grazing and rumination. The behaviours being observed were also recorded with the AfiCollar and compared with visual observations using Pearson's correlation coefficient (r), concordance correlation coefficient (CCC), and linear regression. A strong association was found between the data collected by AfiCollar and the data obtained through visual observation for grazing time (r = 0.91, CCC = 0.71) and rumination time (r = 0.89, CCC = 0.80) with a significant linear relationship between both datasets ($p<0.05$). Furthermore, variations in the temporal patterns (min/h) and time budgets (% min/day) of grazing and ruminating behaviours recorded using AfiCollar were evaluated in spring calving lactating (*n = 162*) Holstein-Friesian (HFR), Jersey (JE), and Holstein-Friesian Jersey crossbreed (KiwiCross, KC) cows in their different lactations (1st, 2nd, 3rd, 4th), and with different breeding worth index values (103<BW>151). A repeated measure design was performed in SAS using PROC MIXED considering the fixed effects of breed and lactation, the random effect of individual cows, and hours of the day as repeated measure to evaluate their effects on hourly patterns and time budgets of grazing, rumination, and idling behaviours. Regardless of the seasonal variations and feed consumed, cows spent most of their daytime grazing (with peaks around dawn and dusk) and most of their nighttime ruminating. Grazing and ruminating patterns were similar between cows from different breeds and lactations, however, JE cows grazed slightly longer than HFR and KC cows; and first-lactation cows grazed slightly longer than mature cows in their later lactations. The onset and cessation of grazing activity by the cows were adjusted according to varying day lengths by season. In addition, a general linear (PROC GLM) mixed model was fitted to test the effects of days in milk, breeding worth, breed, lactation year, individual cow, season, feed, and their interactions on variations in grazing time, rumination time and their relationship. Results indicated that grazing time varied among breeds in Year-2 and Year-3 and among lactation years in Year-1. Rumination time differed between breeds in only Year-3, and it remained the same within lactation years. Grazing time and rumination time varied among different seasons that were related to varying supplementary feeds. Days in milk, breeding worth (except Year-3), and the individual cow had effects ($P<0.05$) on grazing and rumination times. Grazing time and rumination time had a negative relationship with each other that varied between different seasons but remained the same among different breeds and lactation years. The variance in grazing and rumination times was mostly explained by individual cows (up to 24%), season (up to 12%), and feed (up to 8%). Moreover, results also showed that grazing and rumination times had positive associations with milk yield, fat, protein, and solids. Grazing time had negative and rumination time had positive associations with liveweight, while both grazing time and rumination time had negative associations with body condition score. Grazing time explained up to 1%, and rumination time explained up to 7% of the variance in milk yield, milk fat, protein, and solids.

AfiCollar can reliably monitor grazing and rumination behaviours in dairy cows, however, its accuracy can be improved for a grazing-based system. The animal itself, the season, and the feed are the potential sources of variation in grazing and rumination behaviours and should be considered for management decisions to address the animal's behavioural requirements. Grazing and rumination behaviours are moderately correlated with performance parameters and explain a small proportion of variance in animal productivity.

Key words: Automated behaviour monitoring; Individual animal-based data; Pasture-based dairy system; Behaviour patterns and time budgets; Behaviour variation; Animal productivity

Dedicated to

My Family especially my parents

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"O Allah, terrible was the calamity, and its evil consequences are visible, the covering has been removed, (all) hopes have been cut off, the (plentiful) earth has shrunk (with very little to spare), the heavenly blessings have been withheld. You alone can help, we refer our grief and sorrow to You, we have full faith in You, in the time of distress, as well as in good fortune. O Allah, send blessings on Muhammad and on the children of Muhammad, whom we must obey as per Your command, through which we become aware of their rank and status, and let there be joy after sorrow for us, for their sake, right away, in the twinkle of an eye, more rapidly than that. O Muhammad, O Ali, O Ali, O Muhammad, give me enough because both of you provide sufficiently. Help me because both of you help and protect. "O our master, O the living Imam, HELP! HELP! HELP! Reach me! Reach me! Reach me! At once, in this hour. Be quick, be quick, be quick, O the most merciful, for the sake of Muhammad and his pure children".

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Abbreviations

AC = AfiCollar

Am = actual mean (mean of the observed counts for each behaviour)

BCS = body condition score

BW = breeding worth

CCC = concordance correlation coefficient

CG = corn gluten

CP = crude protein

DDG distilled dried grains

DIM = days in milk

DMI = dry matter intake

GT = grazing time

HFR = Holstein-Friesian

JE = Jersey

KC = KiwiCross

kg = kilogram

L = litre

LIC = livestock improvement corporation

LW = liveweight

MB = mean bias

ME = metabolisable energy

MF = milk fat

min/day = Minutes per day

min/h = minutes per hour

MJ = mega joules

MP = milk protein

MPSE = mean square prediction error

MS = maize silage

MS = milk solids

MY = milk yield

NDF = neutral detergent fibre

OAD = once a day

PLF = precision livestock farming

r = Pearson’s correlation coefficient

RT = rumination time

TAD = twice a day

tDM/ha = ton dry matter per hectare

TMR = total mixed ration

VO = visual observation

Chapter 1

Introduction

The New Zealand dairy industry accounts for 3% of the global milk production and shares 28% of the world's dairy trade (IDF, 2015) with an export of 95% of its total milk produced. Favourable environmental conditions enabled the New Zealand dairy industry to develop an efficient dairy production system (Moot et al., 2010). Nevertheless, a consistent focus is required to lift dairy production to ensure the competitiveness of the industry in the international marketplace. Dairy farming in New Zealand is characterized by a pasture grazing system with a supply of additional forage and/or conserved feed if demand exceeds the available resource. The main pasture used is a mixture of ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*). Grass (fresh or silage) is the cheapest source of feed and is used as the main component of feeding systems. The most prevalent dairy cattle breeds in New Zealand are Holstein-Friesian, Jersey, and Holstein-Friesian/Jersey crossbreed (also called KiwiCross). Most of the dairy herds calve in July and August, just before spring, when grass growth is optimum, and are dried off in autumn (April to May) when grass supply is low. The production cost per unit of milk in a grazing-based system is lower than that in an indoor system (Kolver and Muller 1998; Macdonald et al. 2011). However, grazing dairy cows are likely to produce a lower quantity of milk protein, milk fat and milk solids compared with housed cows consuming a total mixed ration. Thus, dairy systems based on grazing pasture require improvements in overall productivity, sustainability, and labour efficiency (Dillon et al. 2005; Dillon 2007; Macdonald et al. 2008; Peyraud et al. 2010; O'Brien et al. 2012).

The overall productivity of a pasture-based dairy system relies on meeting the challenging objectives: optimisation of grass intake by animals to optimise milk production and increase in grazing intensity to maximise pasture utilisation and milk production per hectare. Due to increased land usage for urbanization and ever-increasing population, producing the same or more amount of food from the even less available agricultural land in the future is a key challenge. Therefore, focusing on productivity per animal rather than per hectare is a more sustainable strategy for future dairy production. The productivity of agricultural animals is based on the quantity and quality of production from a single animal during a specific period (day, month, lactation period, year, lifetime). Animal productivity has several dimensions including genetics, feeding, reproduction, health, and overall management of animal operations. Studies have shown that genotype or breed, reproduction efficiency, parity, liveweight, age of the animal, pasture quality, diet, seasonal climate, and herd management practices influence the production of milk and milk solids under pasture-based conditions (Ash et al. 1982; Etherington et al. 1996; Garcia and Holmes 1999; Tekerli et al. 2000; Kolver et al.

2007; Adediran et al. 2010). Apart from that, grazing and rumination behaviours, due to their association with the quality and quantity of nutrients ingested, are also believed to potentially influence animal productivity (Dado and Allen 1994; Shabi et al. 2005; Soriani et al. 2013). Grazing and rumination are key behaviours affecting the amount, type, and rhythm of nutrients ingested by grazing animals (Power and Schulkin 2008).

Grazing dairy cows spend a substantial amount of daily time on grazing and rumination activities, they allocate 90–95% of their daily time to grazing, ruminating, and resting (Kilgour 2012). The quantity of herbage mass ingested by a grazing animal is regulated by the time spent grazing, bite rate and intake per bite (Holmes et al. 1987; Gibb 1998; Taweel et al. 2004; Dillon 2007). After a period of high grazing intensity, cows usually perform rumination for mechanical breakdown of the ingested feed, and the time spent ruminating is believed to be positively linked to herbage intake because greater intake may require more rumination time to process it. Grazing behaviour regulates intake from grazed herbage and rumination behaviour determines digestive efficiency, which is further indicative of the health, and wellbeing of the animal (Phillips and Hecheimi 1989; Kaske et al. 2005; Dillon et al. 2008). Grazing and ruminating behaviours, activity patterns, physical conditions, and health of animals are usually indicative of issues linked to management (e.g., feeding system failure), health (e.g., disease), or specific physiological status (e.g., oestrus). Thus, variations in the times spent on these behaviour activities reflect the changes in feed, feeding management, the cow's physical and social environment (cow grouping or movement), and overall cow comfort (Grant and Dann 2015). These behaviours, therefore, have significant importance in production efficiency, which, in turn, is linked to monetary and environmental consequences. Therefore, measuring grazing and rumination behaviours can help to understand and improve different components of farm management. The information can be used by farmers to improve their on-farm decision-making regarding dairy production. For example, consistent monitoring of grazing behaviour may help to better understand feeding strategies in dairy cows and improve the management practices for greater efficiency (Carvalho 2013). Recording grazing and rumination behaviours can also help to predict and detect reproductive and health events such as calving (Jensen 2012) or metabolic disorders, thus contributing to the better reproduction and health of animals on the farm.

Grazing herds in New Zealand are large with ~450 animals per herd (LIC/DairyNZ 2022) and the behaviour of animals is usually interpreted with average values based on the overall herd. This does not include the animals that are deviant from the herd average. Instead of the overall herd behaviour, considering individual animal behaviour is more helpful in producing concise inferences. Behaviour data (grazing time, rumination time) on an individual animal basis provides a deeper understanding of the interaction of each animal with the environment (e.g., stocking density, lighting, temperature, etc.), and production parameters. However, monitoring individual animal behaviour, particularly in outdoor grazing conditions has been a challenge. In small dairy herds, the condition of the individual animals (e.g., overall health, well-being, and performance) is easy to monitor but this is a difficult task when working with a large group of animals. The grazing and ruminating behaviours of grazing dairy cows have been studied through visual observation in the past, but the method is time-consuming and affected by human error. The support of data-intensive precision livestock farming (PLF) technologies has enabled the monitoring of individual behaviour in a herd. Precision devices are worn as ear tags, nose halters, neck collars or leg pedometers. Precision tools use biosensors, robotics, digital technologies, and integrated databases based on machine learning to produce and process promising data for the farmer, the environment, and the animal (Neethirajan et al. 2017). Recording the behaviour of farm animals using machine vision has shown great progress in research (Guzhva et al. 2018; Wurtz et al. 2019). The collected information supports decision-making to improve performance efficiency, welfare status, health, reproduction, and overall management focusing on the individual animals in the herd (Berckmans 2017; Benjamin and Yik 2019). This can lead to livestock enterprises carrying out evidence-based immediate decisions using a real-time monitoring system (Greenwood et al. 2014; Berckmans and Guarino 2017). In addition, these tools have made it possible to investigate the intra and inter-animal variation in behaviour which was not possible in the past. Thus, PLF technologies can potentially add value to the farm management process by improving data processing, decision-making, and implementation of everyday herd management (Rojo-Gimeno et al. 2019 Apart from these benefits, the accuracy of PLF devices to record animal behaviour in outdoor grazing conditions is still a challenge.

In the pasture-based production system, grazing and rumination behaviours are believed to be considerably varying from herd to herd and from animal to animal due to several factors, including temperature, rainfall, soil fertility, stocking rate, the genetic merit of the herd, and farm management practices (Leso et al. 2018; Al-Marashdeh et al. 2020; Neave et al. 2022). Animal breed type, lactation stage, year of lactation coupled with the feed type and quality, and level of supplementary feed consumed are also expected to have effects on grazing and ruminating behaviours (Hessle et al. 2008; Pauler et al. 2020). Those variations in behaviours are further expected to potentially impact the performance parameters in dairy cows (Bao et al. 1992; Pauler et al. 2020). To my knowledge, no studies to date have focused on the individual or combined effects of those factors (e.g., breed and lactation year of individual animal, season, feed) on the behaviour of grazing dairy cows. Also, no studies have measured the effect size or magnitude of grazing and rumination behaviours on animal performance (e.g., milk yield, milk protein yield, milk fat yield, and total milk solids yield) in grazing dairy cows.

Therefore, the overall aim of this thesis was to investigate the variations in grazing and ruminating behaviours of dairy cows measured using an automated device, considering the effects of the animal itself, breed, lactation year, days in milk, breeding worth, season, and supplementary feed. The thesis also aimed to evaluate the associations of behaviours with production parameters and explore how grazing and rumination behaviours affect productivity in dairy cows. To achieve this aim, four specific objectives were decided:

1) Test the accuracy of an automated AfiCollar device to monitor and record behaviour in grazing dairy cows.
2) Investigate the variations in 24-hour behaviour patterns and time budgets in grazing dairy cows recorded using the AfiCollar device.
3) Determine the effects of breed, lactation year, and genetic merit of animal, season, feed, and days in milk on variations in grazing and ruminating behaviours in dairy cows.
4) Evaluate the effects of grazing and ruminating behaviours on production parameters in dairy cows.

Chapter 2

Review of literature

2.1. Dairy production in New Zealand

Dairy is the principal livestock industry in New Zealand and the 8th largest dairy industry in the world producing 3% of the global milk with 95% of its milk exported to 140 different international markets. Dairy production in New Zealand is a pasture-based grazing system, distinctive from dairy production in other parts of the world. Due to the favourable climate and suitable land for pasture production, New Zealand dairy farms are self-reliant to address the requirements with most of the resources produced on farms with little off-farm inputs (Coquil et al. 2014). The most prominent feature of the pasture-based system is the conversion of low-cost feed (pasture) into milk, as feed is the single most expensive component, covering 50 to 70% of total input costs (Alqaisi et al. 2014). However, the grazing system also influences other aspects such as grassland productivity, the environment, labour, economy, and animal welfare. Some prominent features of the pasture-based grazing dairy system in New Zealand are reviewed below.

2.1.1. Genotype

The major dairy breeds in New Zealand are Holstein-Friesian (32.5%), Jersey (8.2%) and Holstein-Friesian Jersey crossbreed (49.6%), also called KiwiCross (LIC-DairyNZ 2021). The selection of a suitable cow genotype is crucial for a particular farming system (Dillon et al. 2008). The breed composition of the national dairy herd in New Zealand has changed over several decades based on the market requirements. In 1890, the major dairy breed was Shorthorn which was later replaced by Jersey because the emphasis was on high milk fat. After 1965, the number of Friesian cows increased as the focus on milk yield increased. Holstein-Friesian and Jersey crossbreed is the most popular breed now due to certain traits such as higher productivity, better fertility, and greater longevity compared to either Jersey or Holstein-Friesian individual breeds. This is due to hybrid vigour or heterosis effect; heterosis is the phenomenon in which progeny of crosses between inbred lines or purebred populations are better than the expected average of the two populations or lines for a particular trait (Wakchaure et al. 2015). Due to heterosis, crossbreds of Jersey-and Holsteins have superior performance compared with purebred Holsteins or Jerseys (Bryant et al. 2007). Jersey-Holstein crossbred cows are also capable of maintaining body condition scores and hence have lower levels of liveweight loss after calving (Heins 2007).

In quantitative genetics, the genotype is usually expressed by the approximate breeding worth index value (Falconer and Mackay 1989). In 1995, a multi-breed evaluation for different breeds was introduced, enabling the comparison of all breeds on a common scale (Harris et al. 1996), that common scale was named breeding worth (BW). Breeding worth includes ten traits: liveweight, body condition score, functional survival, Udder overall, somatic cell count, fertility, gestation length, and yields of milk, fat, and protein. and ranks the animals based on their approximate ability to produce efficient profitable progeny. Breeding worth is expressed as dollar ($) net farm income per 5 tonnes of dry matter.

2.1.2. Feeding management

In the New Zealand dairy system, grass/legume pasture is grazed in situ or conserved form (hay or silage) and is the major source of energy, protein, and minerals for cows (Bramley et al. 2012; Jacobs 2014; Jones and Tracy 2015). The feed consists of 82% of pasture (MPI 2016) that is mostly grown and consumed on the same grassland. Pasture mainly consists of perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) in a ratio of 0.8 to 0.2 (Holmes et al. 2002). Pasture normally contains 10-12 mega joules (MJ) of Metabolisable Energy (ME) and 15-30% crude protein (CP) per kilogram (Kg) of dry matter (DM) in the leafy state, whereas the energy content of more mature pasture is comparatively lower. Pasture production in New Zealand continues throughout the year, and on average, around 8-16 tonne dry matter basis per hectare (tDM/ha) of pasture is produced annually; it can reach 20-22 tDM/ha if irrigation technology is used. Spring (September to November) is the optimum season for pasture growth while Summer (Dec to Mar) has relatively lower pasture, and winter (Jun to Aug) is the lowest pasture production season (Shadbolt and Apparao 2016). Management factors such as stocking rate, calving and dry-off dates, fertilizer use, the intensity of grazing, drainage and fencing all can influence pasture production (Homes and Roche 2007); however, climatic conditions, especially rainfall and temperature, are the main factors in this regard (Shadbolt & Apparao, 2016). Other crops such as chicory, kale, lucerne, and turnips are also used in some instances to bridge the periods of feed deficit.

Forage in general has two important attributes including, quality and seasonal distribution. These are further influenced by other environmental factors such as temperature, soil fertility, moisture supply, grazing management, pests, and diseases; and by the genetics of the forage plants (Lambert et al. 2004). Although pasture DM yield has been improved using nitrogen fertilisers, often the amount of pasture produced is still not enough to address the animal’s nutrient requirements (Kolver and Muller 1998). This is due to some negative features of pasture, such as the seasonal pattern of growth, variable nutritive profile, DM intake restrictions, and limited mineral concentrations that could negatively impact cow’s performance (Nobilly et al. 2013; Jacobs 2014; Rugoho et al. 2014; Jones and Tracy 2015).

The pasture growth rate is high in spring leading to a rotation length of 21 days, and the diet during that time is mostly pasture. Whereas, when pasture growth is slow such as in winter, the cows' diet is mostly comprised of pasture at longer rotational length, and could also include conserved feed such as grass silage, maize (*Zea mays*), winter oats (*Avena sativa*), swedes (*Brassica napobrassica*), kale, and fodder beet (*Beta vulgaris*), and some by-products such as palm kernel expeller (De Ruiter et al. 2007; Stafford 2017). Maize silage is a moderate source of ME (10.8 MJ/kgDM) but it is low in protein content. Digestible leaves of kale (11.2 MJME/kgDM), turnip (11.7 MJME/kgDM) and rape (12.9 MJME/kgDM) species of Brassica (Brassica rapasubsp. Rapa) are good options to cover the feed deficit during Summer and Autumn months (Westwood and Mulcock 2012; Kleinmans et al. 2016). Palm kernel expeller is also a considerable source of energy and protein, but its palatability is low (De Ruiter et al. 2007). The objectives of those supplements are to optimise milk production, increase the stocking rate, and sometimes compensate for the diet requirements during periods of low growth of pasture (Clark and Woodward 2007). However, the decision of what type and amount of supplement to be fed varies depending on individual farm circumstances and milk prices (Homes and Roche 2007; Bramley et al. 2012).

2.1.3. Production systems

Dairy production systems in New Zealand are classified into five categories. This classification is based on the key diet fed to animals (Stafford 2017).

System 1: All grass, a self-contained traditional dairy system with grazed pasture as the predominant feed source. No supplement is fed to the herd except supplements harvested from the effective milking area, and the herd is not grazed off from the effective milking area.

System 2: There is imported feed in this system, either supplement or grazing off for the dry cows. Imported feed accounts for 4 to 14% of the total feed on the farm either as a supplement or in the form of dry cows grazing off-farm. This rate of supplement feed is variable and driven by the required amount of feed for dry cows.

System 3: Approximately, 10-20 % of feed is imported in this system. The importation of feed is carried out for dry cows and lactating cows, especially autumn feed to extend the lactation. Farms normally feed 1-2 kg of meal or grain per cow per day for most of the season.

System 4: Imported feed accounts for approximately 20-30% of total feed. The imported feed is offered at both ends of the lactation and to the dry cows.

System 5: Approximately 25-40 % of the total feed on the farm is outsourced in this system and used all year around throughout lactation and for dry cows; in some instances, this may vary and go up to 55%.

2.1.4. Seasonality and calving system

Milk production in the New Zealand dairy system is seasonal. The feed requirement of a herd is aligned with the pasture growth curve to obtain the greatest possible efficiency with the minimum possible cost of production (Holmes et al. 1987). The typical grazing season is from early spring to late autumn with cows calving just before the pasture production is at its highest rate, to synchronise the availability of pasture and the herd’s feed intake requirements (Dillon et al. 1995; Macdonald et al. 2008).

In a pasture-based dairy system, calving is used as an important management tool. The calving date is highly dependent on the pasture growth rate in late winter, accessibility of conserved feeds, and stocking rate to guarantee enough pasture to address the demands in early lactation. Pasture production is the main factor driving calving date, and hence milk production. In the New Zealand dairy system, most cows calve at the end of winter or in early spring, and the spring calving strategy is considered the key area for the sustainable development of dairy farming (Dillon et al. 2008). The average lactation length of dairy cows is around 270 days (Stafford 2017). Animals expected to calve in late winter are dried off in May when they have 5 litres or less milk production per day. This practice provides sufficient periods for animals to attain body conditions before calving. If pasture availability is low in autumn, it causes early drying off (Holmes et al., 2002) the cows to restrict the excessive loss of body condition and pasture cover, hence protecting the performance for the next lactation season (Parker 1995). In this case, feeding sufficient supplements or silage along with pasture can bring extra days in milk and milk yield per cow. Feeding silage (295 kg DM/cow) along with pasture leads to 54 extra days in milk with 58 kg of extra milk solids produced per cow (Patiño1996).

To keep the supply of fresh dairy products to the domestic market and to maintain the export of short shelf-life products, split calving is practised with some cows calving in autumn (April to May); however, this is less common. Autumn-calved herds bring in a bonus payment for winter milk production from June to July (Holmes et al., 2002). The cows calving in autumn exhibit lower milk yields (12.3 kg/animal/day) than those calving in spring (17.4 kg/animal/day) during their peak lactations and need a greater quantity of supplements (Garcia and Holmes 1999; Shadbolt and Apparao 2016). This is due to pasture deficit because pasture growth is low in the winter and animals need additional supplement diets to fulfil their production demands.

2.1.5. Once a day and twice a day milking system

New Zealand dairy system traditionally used twice a day (TAD) milking system in which cows are milked twice in 24 hours (Tong et al. 2002). However, the once a day (OAD) milking system has attracted many farms and reached 9% of total dairy farms in 2015/16 (Lembeye et al. 2016; Edwards 2019). Initially, OAD milking was adopted as a temporary strategy to cope with feed shortages particularly in summer due to adverse conditions; however, some farmers adopted this practice for the whole season (Stafford 2017). Accepting OAD as a management strategy for the full milking season is a practical alternative and viable option as it ensures benefits to animals, the farm system and labour (Stelwagen et al. 2013). This system offers reduced shed expenditures, better utilization of the milking plant, and increased labour productivity (Tong et al. 2002). Cows that are adapted to OAD usually dry off earlier and show lower somatic cell count and incidence of mastitis and are better at maintaining their body condition score and reproductive cyclicity with better conception rates (Mikkelsen 2012). Once-a-day milking system also poses some negative impacts such as lower milk yields due to reduced milking frequency; a 34% decrease in milk yield in OAD relative to TAD systems has been reported (Stelwagen et al., 2013). Issues pertaining to udder conformation and milking management have also been observed in the cows following the OAD milking strategy (McCarthy 2012).

2.1.6. Drivers of performance in the pasture-based dairy system

Production efficiency from a dairy farm perspective is the ratio of yield of milk and milk components to the nutritional cost of maintenance and production and retaining the body condition level of the cow that existed before the lactation (Bauman et al. 1985). The single most significant driver of production efficiency and profitability in a spring-calving dairy system is optimum grass utilisation (Hanrahan et al. 2018). Synchronising the pasture growth cycle with feed demand is the key benefit of a spring calving pattern in which the peak feed demand by the herd is matched with the peak pasture growth (Shalloo et al. 2007). Moreover, animal productivity is the major component of overall farm productivity. Animal productivity varies from herd to herd and between animals caused by many factors including animal genetics (Strucken et al. 2012; Aduli et al. 2021) and reproduction (Rearte et al. 2018; Abd-El Hamed and Kamel 2021), environmental factors including temperature, rainfall, soil fertility, stocking rate (Rearte et al. 2018), level of supplementary feed (Hills et al. 2015), and management practices (such as milking frequency, pasture allocation, and stocking density) (Macdonald et al. 2008). Farm management decisions need to ensure the creation of an environment of animal care that enables animals to express themselves naturally and remain healthy with a high quality of life (Cook and Nordlund 2009).

Improvements in production efficiency have been made through increased stocking densities (Philpott 1995) and strategic supplementation with external feed resources (Bargo et al. 2003); however, those strategies have some limitations like the type of supplement required by the farm, time of requirement, and costs involved. Furthermore, the selection of alternative high-yielding dairy cow breeds with appropriate breeding worth indices is another option that may help to fulfil future dairy demands. Using animals with higher genetic merit and feed conversion efficiency, reducing the number of non-productive animals, and increasing pasture quality offer potential improvements in the production efficiency of grazing-based dairy systems (Beukes et al. 2010).

In a grazing system, animal behaviour, particularly grazing and rumination are believed to be the factors potentially affecting animal productivity (King et al. 2017; Anzai and Hirata 2021). Grazing and rumination behaviours indicate pasture management and animal welfare and provide key knowledge about satiety needs, and an understanding of how animals fulfil their nutritional requirements (Gonçalves et al. 2009). Researchers have suggested that to optimise the grazing livestock system, a better understanding of grazing and rumination behaviours and their interaction with the environment is necessary (Manning et al. 2017). Thus, understanding cows' grazing behaviour in a pasture-based system can improve farm management decisions and consequently increase the efficiency of milk production (Alvarenga et al. 2016).

2.1.6.1. Grazing behaviour

Grazing dairy cows show a strong temporal pattern in their grazing behaviour with an average of 7 hours (or meals) of grazing per day (Hughes and Reid 1951). Grazing behaviour is measured in time, and the mean daylight grazing time has been reported as 4.4 to 7.5 hours with a range of 6 to 13 hours a day (Johnstone-Wallace and Kennedy 1944; Woolfolk 1955; Ruckebusch and Bueno 1978; Krysl and Hess 1993; Linnane et al. 2001; Kilgour 2012). Major peaks of grazing occur immediately after milking in the morning, before sunset, and a smaller peak around midnight (O'Connell et al. 1989; Orr et al. 2001; Gibb et al. 2002a). In the evening, the desire for more intensive grazing of herbage is higher than that in the morning; it is to maximize the intake when herbage is at its peak nutritive value (Gregorini 2012) and to provide optimum feed for digestion during the night (Gregorini et al. 2008). Grazing behaviour regulates herbage intake (Grant and Albright 2001; DeVries et al. 2003) which further drives animal productivity. Herbage intake is considered the product of grazing time, biting rate, and biting mass (Hodgson 1985; Forbes 1988). Bite mass is reported as one of the factors driving intake rate, cows can change their foraging behaviour to increase intake per bite (Newman et al. 1994).

The use of grazing behaviour is beneficial in many ways to improve animal production efficiency: The knowledge obtained through studying grazing behaviour can be applied to effectively address animals' demands for pasture or additional feeds and to improve its welfare and productivity (Carvalho 2013). Gaining an understanding of animal behaviour enables the farmer to recognize and treat sick animals, respond to immediate challenges, select animals for future breeding, and handle a herd without creating unnecessary stress (Lund and Weary 2004). For example, a decrease in the frequency of grazing bouts in cows indicates illness (Svensson and Jensen 2007) and also tells whether the feed allowance is sufficient or not (Borderas et al. 2009). The monitoring of grazing behaviour in dairy cattle can be effectively used to predict the early onset of disease (González et al. 2008). Thus, grazing behaviour helps in consistently providing quality pasture to milking animals and indicates if additional supplements are required, especially for high-producing cows; and directly helps to improve animal productivity and overall productivity of the production system.

2.1.6.2. Rumination Behaviour

In ruminants, the most important natural activity after grazing is rumination, also called chewing of cud (Realini et al. 1999). This is an innate behavioural requirement of cows that is performed quietly while lying or standing in a relaxed position, with heads down and eyelids lowered (Lindström and Redbo 2000; Cooper et al., 2007; Schirmann et al. 2012). Rumination follows a 24-hour rhythm with 80% of it occurring at night and afternoon. Under ideal conditions, mature cows normally spend 8 to 9 hours per day ruminating (Van Soest 1994).

Rumination is a cyclic process involving the regurgitation of fibrous digest from the rumen back into the mouth, remastication of the material, followed by swallowing of the material to the rumen (Welch 1982). Rumination stimulates saliva production which buffers the rumen and maintains a homeostatic environment for the gut microbes; it also increases the surface area of feed particles making them more accessible to the microbes (Erdman 1988; Beauchemin 1991; Allen 1997; Erina 2013). Rumination facilitates particle size reduction of the ingested feed, its digestion, and subsequent passage from the rumen thereby influencing dry matter intake; therefore, it has been suggested as a significant contributor to the herbage intake prediction model (Clement et al. 2014).

Rumination behaviour reflects the physical and physiological states of ruminating animals. Routine challenges faced on dairy farms including identification of nutritional problems, detection of oestrus, prediction of health problems, and detection of mastitis and lameness can be benefited by monitoring rumination activity. Importantly, research to date indicates that it is not necessarily the time spent ruminating each day that must be monitored, but the change in rumination time from day to day that is more important (Grant and Dann 2015). Rumination time is considered a potential indicator of cow's health and early identification of disease development or other health disorders (Calamari et al. 2014; Stangaferro et al. 2016). Rumination activity responds to stressors (with decrees in rumination time) 12 to 24 hours earlier than traditional indicators including higher body temperature, lower feed intake, reduced milk yield, and other clinical signs (Bar and Solomon 2010). A recent study suggested that the rumination trait is potentially useful for animal selection in Holstein-Friesian cows (Moretti et al. 2018). With all these benefits, rumination behaviour is believed to be considerably contributing towards animal production efficiency.

2.1.6.3. Variation in grazing and rumination behaviours

Many factors including managemental, environmental and social tend to alter grazing and rumination behaviours in cows. When cows face a nutritional challenge (e.g., less availability of pasture), they adjust the time spent grazing accordingly (Chapman et al. 2007). It is believed that an increase in grazing time and biting rate occur together to improve intake when less pasture is available (Linnane et al. 2004; Manning et al. 2017). Length of sward also affects grazing time; for cattle, a grazing height of almost 9 cm is considered optimal to obtain the required intake (Gibb et al. 1997) because the quantity of herbage intake per bite is lower on short swards (Forbes 1988). Heifers in a previous study extended their grazing time when they were exposed to short-length sward (Ginane et al. 2003). Maturity of forage results in increased fibre (Hemicellulose, Cellulose and Lignin) content (Gill et al. 1989) which leads to reduced grazing time and intake due to quick rumen fill (Rutter 2006). In addition, along with height, maturity, and quality (Scarnecchia et al. 1985), sward composition and herbage mass vary seasonally and affect grazing behaviour. The social environment is another influencer of grazing behaviour in cows. It was observed by Phillips and Rind (2001) that multiparous and primiparous cows grazed for less time when grouped together than either multiparous or primiparous cows when grouped alone. The stocking rate is another limiting factor for grazing time; a higher stocking rate has been reported to lower grazing time because animals spent more time searching for quality forage (Hepworth et al. 1991; Hejcmanová et al. 2009;). The environmental temperature has been reported to influence grazing trends, especially during hot weather when cows prefer resting, they reduce their grazing time (Ginane and Petit 2005). Variation in grazing behaviour and ultimately intake rate also depends on the physiological status of the animal. For example, in lactating dairy cows, nutrient demand is different compared to that of non-lactating ones, and lactating cows have been found with higher (up to 29%) grazing time (Gibb et al. 1997). Also, nutrient demand varies for different stages of lactation according to levels of milk production. High-producing Holstein Friesian cows showed similar grazing time and higher biting rates than those of low-producing Holstein Friesian cows (O'Connell et al. 2000).

The rate and time of rumination are controlled mainly by diet type and digestibility (Phillips and Hecheimi 1989). Dietary factors such as fibre content and particle size, management factors including grouping strategies and degree of overcrowding, and potential stressors in the environment control rumination activity (Grant and Dann 2015). The fibre content of the feed, especially neutral detergent fibre (NDF) consists of cellulose and lignin and influences the rumination process (Dado and Allen 1995); higher NDF leads to longer rumination time. Mastication time in heifers increased when they consumed herbage of larger particle size (Albright 1993; Hejcmanová et al. 2009). Rumination is also influenced by the health status of cows, the farm management, and the environment (Calamari et al. 2014). Rumination is highly sensitive to cows' well-being and gets depressed under acute and chronic stress environments (Grant and Dann 2015). Hierarchy and social dominance also affect rumination activity, low-ranked cows ruminated less (35%) when kept together with socially higher-ranked cows (Ungerfeld et al. 2014).

2.1.6.4. Relationship between animal behaviour and production parameters

Few studies in the past have observed an association between behaviour and animal productivity in dairy cows. For example, a positive correlation between behaviour with productivity was observed in a recent study (Verdon et al. 2018). Another study noted that enhanced time spent eating and a higher biting rate resulted in improved milk yield (Shabi et al. 2005). Grazing frequency has also been found to have a potential effect on milk yield in dairy cows. Similarly, some other studies have identified a positive association between milk yield and rumination time (Soriani et al. 2013; Antanaitis et al. 2018). A positive correlation (r

= 0.38) between milk production and the rumination time of dairy cows has been recently reported by Antanaitis et al. (2018). Likewise, rumination time had a positive association with milk yield in early-lactation dairy cows (Kaufman et al. 2018). Holstein-Friesian cows with higher production potential spent a greater proportion of time ruminating compared with the Holstein-Friesian cows with lesser production potential (O'Connell et al. 2000).

Liveweight is considered a component of animal productivity, a positive correlation between liveweight (LW) and milk production (r = 0.20) was previously reported (Sieber et al. 1988). Feed requirement is a function of liveweight, dairy cows usually require a herbage intake of about 3.5% of their LW. Weight also has a linkage with maintenance requirements as animals with higher weights need more maintenance energy (more feed) compared to those of lighter weights (McGee 2015). Also, dietary choices by animals rely on their liveweight (Prache et al. 1998). Due to inadequate calf and heifer management, most of the heifers on New Zealand dairy farms are unable to gain their target liveweight (McNaughton and Lopdell 2012). Failure to reach the target liveweights results in less production (Macdonald et al. 2005) and poor reproductive performance (Hayes et al. 1999). Grazing time, due to association with intake is believed to have a relationship with liveweight. Nevertheless, to my knowledge, there is less literature available to explain this relationship. Understanding the relationship between grazing times and liveweight can help to efficiently address and manage feed demands for each animal according to their liveweight; sufficient feed supply according to liveweight can help the animal improve its productivity.

Body condition score (BCS) has significant effects on the performance level of dairy cows. The BCS is based on the amount of body fat possessed by the animal and is generally recognized as a gross measure of a cow's energy reserves. Dairy cows lose body condition approximately 40 to 100 d after calving (Roche et al. 2007). In New Zealand a 10-point scale is used to evaluate BCS in cows (Macdonald and Roche 2004) with a BCS target of 5-5.5 at calving (Roche et al. 2009). In New Zealand, cows often experience periods of reduced pasture availability in late lactation. Under these conditions, cows that maintain relatively high BCS in early lactation produce higher total yields of milk solids because they have body reserves available for mobilisation in late lactation (Pryce and Harris 2006).

Animals with low BCS may have a low intake and therefore be more susceptible to higher BCS loss to satisfy the milk drive (Bauman and Currie 1980). Previous studies on dairy cows have reported a negative association between BCS and dry matter intake (Treacher et al. 1986;

Tolkamp et al. 2006). Most of the studies undertaken in the grazing-based system have concluded a positive association between BCS and milk production (Stockdale 2004, 2006; Roche et al. 2005); however, the relationship between BCS and grazing time is less studied in the literature to date. Understanding the relationship between behaviour and BCS of dairy cows could support the management decisions to maintain optimum productivity in grazing dairy cows.

2.1.6.5. Animal behaviour in a grazing-based system

Animal behaviour under grazing settings is more complex and highly variable than under indoor confined conditions. Therefore, on-farm monitoring of animal behaviour is more difficult in a grazing-based system compared to that in an indoor system. This is because animals must adapt their behaviour to their ever-changing environments such as sward and weather conditions (Anzai and Hirata 2021). In addition, dairy cows are usually maintained as a herd and their behaviour is often expressed as an average of the group. The average values are used as indicators of the external or internal environment to make managemental decisions. Whereas individual animal demonstrates different behavioural tendency due to differences in age, liveweight, physiological status, social dominance, and personality. The management decisions based on the average behaviour of the whole herd do not equally benefit all animals in the herd and may even negatively affect some animals (Richter and Hintze 2019). Thus, management decisions to improve the overall welfare and productivity of the whole herd should be based on individual behavioural tendencies which require individual monitoring of animal behaviour (Anzai and Hirata 2021). Due to frequent variations and more complexity of behaviour, on-farm monitoring of behaviour is less utilized in grazing-based systems. Therefore, the development of a reliable less time-consuming system has become an important requirement. More sensitive monitoring and detection of behavioural responses will provide the foundation for a more efficient and welfare-conscious management that better meets the needs of individual animals in the herd.

2.2. Precision Livestock Farming

The fourth industrial revolution within agriculture (around 2010) led to the concept of precision animal agriculture (Mazzetto et al. 2020) precision livestock farming (PLF) introduced several technologies from the industrial sector that can improve production and profit outcomes in livestock farming. Precision farming refers to management through continuous, automated, and real-time monitoring of the production/reproduction, health, and welfare, of animals (Berckmans 2017). Precision farming is a suite of various technologies with the shared goal of detecting subtle information about each animal on a farm and using that information in management decisions (Werkheiser 2020). Precision farming targets to develop a monitoring system for livestock management using sensor technologies to observe animal behavioural or physiological variables (Darr and Epperson 2009), modern control theory to refine the automation in the livestock production system (Frost et al. 2004), and the latest means to handle animal data (Terrasson et al. 2016). Precision farming applications are non-invasive, and most are in the form of tags attached to the animal's neck, leg, or ear. The first PLF application was an individual electronic milk meter for dairy cows in the 1970s (Peles 1990). Later, online real-time milk analysers (Schmilovitch et al. 2001), devices for oestrus detection (Firk et al. 2002) and rumination monitoring (Soriani et al. 2012) were adopted. Many technologies under the banner of PLF are emerging to monitor the health and welfare of animals (Rutten et al. 2016; Shalloo et al. 2021). With the use of electronic measurement, interpretation, and control systems, PLF has a vision where animal welfare, environmental sustainability, productivity, and profitability are all at optimum (Banhazi and Black 2009).

Precision farming technologies offer positive outcomes, but the tools have some limitations (Romanzini et al. 2022) which are technologic (e.g., internet access, weak signal, and absence of an ideal device), scientific (e.g., sensor position, transmission rate, forage management and animal nutrition) and economic (e.g., cost per device and labour efficiency). Despite the potential of PLF to increase production efficiency and sustainability of livestock farming systems, on-farm adoption of PLF is still incipient. This is due to the challenge that PLF tools should be designed according to the reality and climatic conditions of each global region, farm sizes and production system in the region (Rosa 2021). Another challenge for PLF devices is the continued development of more efficient and reliable sensors with improved sensitivity to measure specific variables. Many of the commercially available PLF tools have not been tested under rigorous scientific conditions. Different industries and research groups are involved in developing new PLF sensors, whereas not all newly developed sensors produced in lab-based controlled settings can be applied to commercial farming environmental conditions. Therefore, it is essential to validate the PLF tool at the commercial farm level (Stygar et al. 2021). However, these concerns are not a sufficient reason to abandon PLF, they are rather for consideration while working on developing, implementing, or legislating this technology (Werkheiser 2020).

2.2.1. Monitoring grazing and rumination behaviours

The consistent monitoring of grazing behaviour may help to better understand feeding strategies in dairy cows and improve management practices for greater efficiency (Carvalho 2013). Monitoring feeding behaviour can also help to predict and detect reproductive and health events such as calving and metabolic disorders and contributes to better reproduction and health on the farm (Jensen 2012). Doing so with conventional methods requires intensive contact hours with well-trained personnel that is time-consuming and subject to human error. In previous decades, measuring animal behaviour mostly relied on visual observations or video recordings, however, such methods are time-consuming, labour-intensive, and subject to human error (Elischer et al. 2013; Andriamandroso et al. 2016). Since the early 1990s, livestock production systems-initiated management based on information and communication technologies (Halachmi and Guarino 2016). Those technologies have the potential to measure different farm parameters including ventilation, feed supply, temperature, and humidity. However, most of those technologies do not consider the parameters related to animals which is the most crucial part of the production system. Due to challenges such as large grazing areas, long periods of data sampling, and constantly varying physical environments, it is hard to obtain reliable animal-related data using conventional technologies (Guo et al. 2006). Those limitations in traditional methods have been overcome to some extent by the latest technologies. Precision farming tools attempt to replicate and perhaps even improve behaviour monitoring through automated processes and technological innovation.

Several systems for monitoring animal behaviour are currently available to livestock producers. A recent review of market research found a total of 129 different precision technologies with applications for animal-based welfare assessment; those systems include sensor-equipped wearable devices, terminals to remotely collect data from the devices and applications to see and manage behavioural data on smart devices (Stygar et al. 2021). There are several types of sensors reported in the literature to date to record cattle behaviour (Rutter et al. 1997; Delagarde et al. 1999; Ruuska et al. 2016) including mechanical sensors (pressure sensors), acoustic sensors (microphone) and electromyography sensors (Neethirajan et al. 2017). To specifically monitor feeding and ruminating behaviours in cows, previous studies have used a variety of sensors (Rutter 2000; Laca and DeVries 2000; Ungar and Rutter 2006; Nydegger et al. 2010; Braun et al. 2013). The triaxial accelerometer sensors are the most reliable sensing system (Bailey et al. 2018) and are currently the most popular in cattle production. Accelerometer sensors have been previously used to record jaw movements and feeding behaviour (Mattachini et al. 2016; Giovanetti et al. 2017). Accelerometer sensors record gravitational static and dynamic accelerations linked with animal movements and low-frequency parts of acceleration (Oudshoorn et al. 2013). Both single-axial (Andriamandroso et al. 2015) and three-axial (Oudshoorn et al. 2013) accelerometers are used to measure cow behaviour. Precision tools work with a combined communication of many processes. The first step is measuring the parameter of interest (e.g., grazing cow behaviour) through sensors. Tri-axial accelerometer sensor device mounted on the neck, ear or leg of the animal uses the information of angles and movements to classify the posture and behaviour of the animal (Andriamandroso et al. 2017). The second step is transferring the collected information to a base for integration. That information is then converted to useful data through built-in algorithms. This data is then processed to categorize animal behaviour such as grazing, travelling, and resting (Ungar et al. 2005; Augustine and Derner 2013). Finally, when this data is integrated with other data/interrogated/ modelled, useful decision-support information can be used to automate processes on the farm (e.g., cow drafting etc.) (Rutter 2007).

Recording the behaviour of farm animals using machine vision has shown great progress in research (Guzhva et al. 2018; Wurtz et al. 2019). However, most of these systems are validated for dairy cows kept in indoor confined systems not in outdoor grazing dairy systems. Production settings vary in the location of the validation experiment (commercial vs. experimental herd), criteria for animal selection (e.g., random or based on a stage of lactation), management characteristics (e.g., floor type and grazing), and feeding system produce different results (Hendriks et al. 2020). The feeding behaviour of dairy cows differs in grazing settings, thus the sensors that accurately measure feeding behaviour in the indoor system are not likely to be effective in grazing cows. The sensors may require recalibrations of algorithms after being tested for accuracy in grazing-based systems (Shalloo et al. 2021).

2.2.2. PLF as an individual animal approach

A feature of livestock production is the large variation from herd to herd and from animal to animal within a herd. This variation can be attributed to animal (genetics, behaviour, metabolic efficiency, and health), environment and management factors. Individual animals' production variability in a herd is considered a key mechanism for improving the overall productivity of the livestock system (Tichit et al. 2011; Dumont et al. 2014). Data on an average herd basis is a rough overall estimate and has the main disadvantage that it does not reflect the efficiency of each animal in the herd. Thus, to achieve a sound assessment of herd management and production efficiency, the consideration of individual animals' data is essential (Puillet et al.

2010). Studies have been conducted to explore the advantages of considering individual animal variability in response to herd management to improve overall herd production (Dumont et al. 2014; Tichit et al. 2011). However, those studies did not use PLF tools to record and analyse the data. One of the core issues is improving farm management while retaining individualized care and attention to animals. To address this problem, PLF promises to monitor and manage "each individual" in a herd. Precision technologies have made it possible to investigate individual animal behaviour, health status, nutrition, and reproduction which was not possible in the past. Previous studies have used the automatic systems for livestock to monitor their drinking behaviour (Domun et al. 2019), live weight estimation (Wu et al. 2004), activity patterns (Draganova et al. 2010), and grazing and rumination patterns (Becciolini and Ponzetta 2018) in the individual animals.

2.3. Conclusion

Grazing-based dairy system in New Zealand relies mainly on pasture as a dietary source with supplements provided when required, for example, during dry weather when quality pasture is less available. One of the key drivers of efficiency and profitability in pasture-based systems is pasture utilisation. Concerns about the sustainability of livestock farming systems are increasing which emphasizes the need to find new options to reduce the cost of production and improve production efficiency. The knowledge of grazing behaviour may ensure a betterment in feeding strategies to adapt management practices for greater efficiency (Carvalho 2013). Understanding rumination behaviour may improve cow care and well-being by helping to identify and predict health disorders in cows. Whereas, studying grazing and rumination behaviours in a grazing-based system has been a challenge in the past due to a lack of technology. Recent advancements in biosensor tools offer real-time and continuous monitoring of individual grazing and ruminating behaviours. However, the accuracy of those devices on a commercial farm in an outdoor grazing setting is still a challenge and a barrier to their adoption.

The New Zealand dairy system is populated with Holstein-Friesian, Jersey, and Crossbreed of Holstein-Friesian and Jersey breeds. Although Jersey cows are considered a relatively more suitable breed in the pasture-based system (Buckley et al. 2005; Prendiville et al. 2010), few studies compared the behaviour of Jersey cows with Holstein-Friesian cows in New Zealand's pasture-based conditions. Moreover, there is a lack of studies on the behaviours of Crossbreed, a breed that makes up about 50% of the New Zealand dairy herd. Due to the lack of behaviour monitoring tools, there is less scientific literature on normal trends of grazing and ruminating behaviours of lactating dairy cows kept in the grazing system, especially in New Zealand.

There is an absence of scientific reports on behavioural differences among dairy cows of different genotypes, genetic merits, and parities. Furthermore, there is no information on how grazing dairy cows pattern their grazing and rumination behaviours in different seasons and different stages over the lactation period with different milk production levels. Likewise, there is a lack of information on how different seasons affect time budgets for grazing and rumination behaviours in grazing dairy cows. To my knowledge, there are no studies in the literature that have explored the combined effects of all these factors including breed, parity, season, milk production level, and genetic merit on grazing and ruminating behaviours of grazing dairy cows in the New Zealand system. Furthermore, how the behaviour patterns and time budgets affect production parameters such as milk yield and quality, liveweight, and body condition score have been less studied in detail.

2.4. Objectives

Based on the review of the literature, the overall aim of this thesis was to understand the variations in individual grazing and rumination behaviours and evaluate if the behaviour can improve the prediction of animal productivity. The following objectives were set to achieve the thesis aim:

1. To evaluate the suitability and validate the grazing and rumination behaviour recording accuracy of a sensor-based collar.
2. To determine grazing and ruminating behaviour patterns and time budgets in grazing dairy cows and their variation due to breed, lactation year, season, and feed effects.
3. To investigate the effects of breed, lactation year, genetic merit, days in milk, season, and feed on grazing and rumination behaviours in grazing dairy cows.
4. To examine the effect of grazing time and rumination time on milk production and composition, body condition score, and the liveweight in grazing dairy cows.

Chapter 3

Validation of an accelerometer sensor-based collar for monitoring grazing and rumination behaviours in grazing dairy cows

3.1.Abstract

This study evaluated the accuracy of a sensor-based device (AfiCollar) to automatically monitor and record the grazing and rumination behaviours of grazing dairy cows on a real-time basis. Multiparous spring-calved dairy cows (*n = 48*) wearing the AfiCollar were selected for the visual observation of their grazing and rumination behaviours. The total observation period was 36 days, divided into four recording periods performed at different times of the year, using 12 cows in each period. Each recording period consisted of nine daily observation sessions (three days a week for three consecutive weeks). A continuous behaviour monitoring protocol was followed to visually observe four cows at a time for each daily observation session, from 9:00 a.m. to 5:00 p.m. Overall, 144 observations were collected, and the data were presented as behaviour activity per daily observation session. The behaviours visually observed were also recorded through an automated AfiCollar device on a real-time basis over the observation period. Automatic recordings and visual observations were compared with each other using Pearson's correlation coefficient (r), Concordance correlation coefficient (CCC), and linear regression. Compared to visual observation (VO), AfiCollar (AC) showed slightly higher (10%) grazing time and lower (4%) rumination time. AfiCollar results and VO results had strong associations with each other for grazing time (r = 0.91, CCC = 0.71) and rumination time (r = 0.89, CCC = 0.80). Regression analysis showed a significant linear relationship between AC and VO for grazing time (R^2 = 0.83, P < 0.05) and rumination time (R^2 = 0.78, P < 0.05). The relative prediction error (RPE) values for grazing time and rumination time were 0.17 and 0.40, respectively. Overall, the results indicated that AfiCollar is a reliable device to accurately monitor and record grazing and rumination behaviours of grazing dairy cows, although, some minor improvements can be made in algorithm calibrations to further improve its accuracy.

Keywords: AfiCollar; accelerometer sensor; grazing dairy cows; grazing behaviour; rumination behaviour

3.2.Introduction

Grazing and rumination are predominant behaviour activities in cattle, in terms of the daily allocated time, as cows, on average, spend 90–95% of their daily time grazing, ruminating, and resting (Kilgour 2012). Grazing is the natural feed intake behaviour in cows and chewing of cud (rumination) is the most important activity after grazing (Realini et al. 1999). The grazing behaviour of cows affects their ability to consume the optimal quantity of herbage (Stakelum and Dillon 2003); hence, influencing their milk production (DeVries et al. 2003). Moreover, it has been suggested by previous studies that dry matter intake (DMI) from grazed herbage is regulated by the time spent grazing and intake rate (Gibb 1998; Taweel et al. 2004; Dillon 2007). Similarly, rumination has been associated with nutrition and health in dairy cows (Krause et al. 2002; Radostits et al. 2006). Thus, measuring grazing and rumination behaviours can be a potential management tool to facilitate improved health, welfare, and productivity in dairy cows (Molfino et al. 2017; Werner et al. 2018). Measuring those behaviours is also potentially important for the management of pasture and feed availability (Meisser et al. 2014).

In previous decades, measuring behaviour mostly relied on visual observation or video recording, whereas those methods are very time-consuming, labour-intensive, and subject to human error (Elischer et al. 2013; Theurer et al. 2013). Therefore, an automated system for monitoring the behaviour of dairy cows became an important requirement for dairy production systems. That need paved the path for new approaches to developing an automated system to resolve the problem. Owing to the advancements in precision livestock farming (PLF), various sensors monitoring grazing and rumination behaviours have been manufactured over the past two decades. Those PLF tools are easy to handle and have less labour input and human interference (Andriamandroso et al. 2016). The first automated system to record jaw movements was developed for sheep, which consisted of a silicon tube packed with carbon granules that could be fitted over the muzzle of the animal (Penning 1983). The system was further improved by later research to enable differentiation between mastication chews and prehension bites (Penning et al., 1984). Subsequently, a microcomputer-based system using a sensor with a digital recorder was initially developed (Brun et al. 1984) and later upgraded (Matsui and Okubo 1991; Matsui 1993). The sensors currently available can potentially distinguish jaw movements, and respective algorithms exist to interpret them into chews and bites (Ungar and Rutter 2006). Data recorded using these sensors have been reported with 94% accuracy to record grazing time and rumination time (Clapham et al. 2011).

There are four types of behaviour monitoring sensors available voltage-detecting noseband pressure sensors, sound-detecting acoustic sensors, motion-detecting accelerometer sensors, and electrical signals detecting electromyographic sensors. The potential disadvantage of pressure and acoustic sensors is tightening the halter on individual animals generates different pressure values in pressure sensors, and disturbance by environmental noise leads to misclassifications of behaviour signals by acoustic sensors (Almeida et al. 2013). Therefore, considering more recent accelerometer sensors is more practical in an outdoor-based farm. An accelerometer sensor is a type of electronic device able to convert physical acceleration, such as motion or gravity into waveform as an output signal. It can detect and calculate both static (due to gravity) and dynamic (due to animal movements) accelerations, as well as a low-frequency component of the acceleration (Brown et al. 2013; Tani et al. 2013). A 1-axis accelerometer sensor was first presented to monitor eating and ruminating behaviours in cattle (Oudshoorn et al. 2013). Technology was further improved, and the 3-axis (x, y, z) accelerometer sensor was used subsequently to monitor the eating behaviour of cows on a pasture (Werner et al. 2019). Accelerometer sensors offer up to 90% functional accuracy (Almeida et al. 2013).

AfiCollar (AC), developed by Afimilk Ltd. Kibbutz Afikim 1514800, Israel, is an automated device used to monitor and record eating and rumination behaviours on a real-time basis. The AfiCollar device is equipped with a triaxial accelerometer sensor allowing the identification and classification of eating and rumination behaviours based on the patterns of the animal's head movements (Konka et al. 2014). The collar has a built-in integrated algorithm to calculate and classify eating time and rumination time by using the raw data. The behaviour data are transmitted to a wireless-based farm station once the animal wearing the AfiCollar comes under the range of the base station. The data are then manually downloaded from the computer attached to the base station. The main advantages of the collar device are its robust mechanical design and its ability to continuously monitor and record individual animal behaviour for several months; moreover, it operates with almost no human interference.

The AfiCollar device has been tested for measuring eating and rumination behaviours in the indoor dairy production system (Merenda et al. 2019). The collar device has not been validated for grazing dairy cows. The primary objective of this study was to validate the collar device by evaluating its accuracy in monitoring and recording grazing and rumination behaviours of dairy cows with voluntary movements in a pasture grazing condition.

3.3. Materials and methods

3.3.1. Experimental animals and their diet

A group of multiparous spring-calved lactating dairy cows (*n = 48*) fitted with AfiCollar devices were selected for the visual observation of their grazing and rumination behaviours. The cows were kept in a grazing-based system on a New Zealand-based farm. The cows included in the study had a 16.3 ± 4.4 L per day milk yield, 465 ± 54 kg body weight, and 4.6 ± 0.4 body condition score. Breeds of the cows were Jersey, Holstein-Friesian, and KiwiCross (a crossbreed of Holstein-Friesian and Jersey). The cows were in different lactations (1st, 2nd, 3rd), and were milked once a day at 6:00 a.m. The cows were fed on pasture mainly consisting of ryegrass (*Lolium perenne*) mixed with red clover (*Trifolium pratense*) and white clover (Trifolium repens) and allocated a dry matter intake of ~20 kg per cow per day. The cows were kept in the same grazing paddock (2.08 ha) for 24 hours (except milking time from 6:00 to 8:00 a.m.) and had ad libitum access to a water supply.

3.3.2. Behaviour observation

Specific behaviour activities of cows observed were grazing (cow actively looking for grass while walking with the head down, including biting and chewing pasture) and rumination (cow starts to regurgitate the chewed bolus in the mouth for re-mastication and ends once the bolus is swallowed), as defined in a previous study (Pereira et al. 2018).

The total period of valid observation was 36 days divided into 4 recording periods that were conducted at different times of the year (Table 3.1) to cover most of the lactation period. At the time of each recording period, cows were at a different stage of lactation (different days in milk). Days in milk are the number of days for a cow since calving. Each recording period was allocated a sequence of 9 continuous daily observation sessions. Each observation session consisted of 8 hours per day, from 9:00 a.m. to 5:00 p.m. to cover maximum daylight hours. Each observation session was performed for three weeks with three consecutive days per week. Out of the selected 48 cows, 12 cows were included in each recording period. A set of 4 cows was observed at a time for 3 consecutive daily observation sessions per week with a set of 4 other cows for the next daily observation sessions for the next week and so on. The observation was performed by a single trained observer following a continuous behaviour recording protocol (Stakelum and Dillon 2003). The cows being observed were the only cows in the grazing paddock and were observed by the same observer throughout the observation period (Lawrence and Lin 1989; Benaissa et al. 2019).

Table 3. 1. Time of year for the visual observation sessions and their duration, and behaviour activities observed during the recording periods.

Recording Period	Duration		Observation Sessions	Behaviour Observed
	From	To		
1	19 December 2019	28 February 2020	9 (72 h)	Grazing and rumination
2	30 September 2020	16 October 2020	9 (72 h)	Grazing and rumination
3	2 December 2020	18 December 2020	9 (72 h)	Grazing and rumination
4	8 February 2021	5 March 2021	9 (72 h)	Grazing and rumination

(Note: each observation session consisted of 8 h per daily recording, so, 9 × 8 = 72)

The cows were observed by the observer from ~30 m. Four time-synchronised stopwatches were used (one for each cow) to record grazing time and rumination time in the form of minutes spent per hour (min/h) by the cow on specific behaviour activity. At the start of each behaviour activity, a stopwatch was started to run the timer counting the minutes spent on that behaviour activity. The timer remained running until the behaviour activity was stopped or switched to a different behaviour activity. The timer was paused when the cow paused the behaviour activity or went to drink water for example. The stopwatches were reset once the hour ended and started again for the next consecutive hour. Minute-per-hour spent on grazing and rumination were obtained separately for each hour. The per-hour grazing time and rumination time per cow for eight hours were totalled to calculate grazing time and rumination time per daily observation session. The data collected through visual observation were presented as grazing time and rumination time per daily observation session and manually stored in a Microsoft Excel spreadsheet (Microsoft Excel, version 2016).

3.3.3. Sensor-based collar for behaviour monitoring

The automated AfiCollar device consisted of a proprietary 3D (x, y, z) accelerometer sensor fitted within a box and positioned on the right side of the animal's neck. The accelerometer sensor of the collar device was able to effectively detect and measure the motion patterns in the three-axis. The sensor could identify and classify specific behaviour categories, such as grazing, and rumination based on patterns of head movements. The behaviour data collected by the sensor were analysed by the collar device using built-in generic algorithms and produced as minute-per-hour (min/h) behaviour counts (per-hour grazing time and rumination time). The data collected by the AfiCollar device were wirelessly transmitted to a base station through Wi-Fi while cows were in the range of ~500 m. The data were manually downloaded from the computer attached to the base station in a Microsoft Excel spreadsheet (Microsoft Excel, version 2016). The minute-per-hour behaviour counts per daily observation session (8 h) by the collar device were used to manually calculate total grazing time and rumination time per daily observation session.

Each cow being observed was fitted with an AfiCollar device around the neck, which was worn by the cow throughout the observation period. Each collar device was time synchronised and activated by Afimilk's herd management software (Afimilk mySilent Herdsman, Afimilk Ltd. Kibbutz Afikim 1514800, Israel) before being placed on the experimental animals. The AfiCollar device continuously monitored and recorded the time spent by the cows grazing and ruminating on a real-time basis.

3.3.4. Data preparation and statistical analysis

A total of 144 observations (48 cows × 3 daily observation sessions per cow) were separately collected through both AfiCollar and visual observation over the observation period. The data recorded through the AfiCollar device, and the data obtained through visual observation were coupled with each other. Both recorded and observed outputs were presented as the total minutes each cow spent on grazing and rumination activities per daily observation session.

To investigate the levels of correlation and agreement between observed and recorded outputs, Pearson's correlation coefficient (r) and concordance correlation coefficient (CCC) were calculated respectively for both grazing time and rumination time as indicated by Landis and Koch (1977). The values of r were calculated using SAS (version 9.4) and the value of CCC was calculated following the equation as suggested by (Lawrence and Lin 1989). The interpretations of r and CCC were classified as negligible = 0.0–0.3, low = 0.3–0.5, moderate = 0.5–0.7, high = 0.7–0.9, and very high = 0.9–1.00. Mean bias (MB) was also calculated to examine the mean difference in grazing time and rumination time between the AfiCollar device and visual observation. Relative prediction error (RPE) values were calculated (Stergiadis et al. 2016) to evaluate the accuracy of the AfiCollar device to record grazing time and rumination time using the following equation (Burfeind et al. 2011):

$$RPE = \left(\frac{\sqrt{MPSE}}{Am}\right) \times 100$$

where $MPSE$ is the mean square prediction error and Am is the mean of the observed counts for each behaviour

To further investigate the associations between visual observation and automatic recording, linear regression analysis was performed in SAS (version 9.4) with R-squared (R^2) values reported for both grazing time and rumination time (Hessle 2009).

3.4. Results

3.4.1. Comparison of AfiCollar and visual observation

3.4.1.1. Grazing behaviour

The comparison was made between the behaviour results recorded through AfiCollar (AC) and the results obtained through visual observation (VO) and details are presented in Table 3.2. The mean time spent grazing per cow per daily observation session recorded through AC was 373 min while that obtained through VO was 325 min. The mean bias of grazing time between AC results and VO results was 48 min. Compared to VO results, AC results showed higher grazing time (10% on average). AC results and VO results had a good association (Figure 3.1), showing a strong correlation and high level of agreement (r = 0.91, CCC = 0.71) between each other with an RPE value of 0.14. Regression analysis (Table 3.3) showed VO result had a significant linear relationship with AC results ($R^2 = 0.83$, $p < 0.05$). The intercept and slope for grazing time were significantly different from zero ($p < 0.05$).

Table 3. 2. Comparison of grazing time and rumination time, mean bias (MB), percentage mean bias, Pearson's correlation coefficient (r), concordance correlation coefficient (CCC), and relative prediction error (RPE) of behaviour data recorded by AfiCollar (AC) and collected with visual observation (VO). (*n = 144*).

Behaviour	**AC (min)**	**VO (min)**	**MB (min)**	**Bias[1] (%)**	**r**	**CCC**	**RPE**
Grazing time	373 ± 78.9	325 ± 62.9	48	10	0.91	0.72	0.18
Rumination time	39 ± 40.9	56 ± 42.1	17	04	0.89	0.80	0.40

[1] Bias (%) represents mean percentage bias and it was calculated as AC (min)/480 − VO (min)/480 × 100, where 480 is the total time (8 hrs.) per daily observation session.

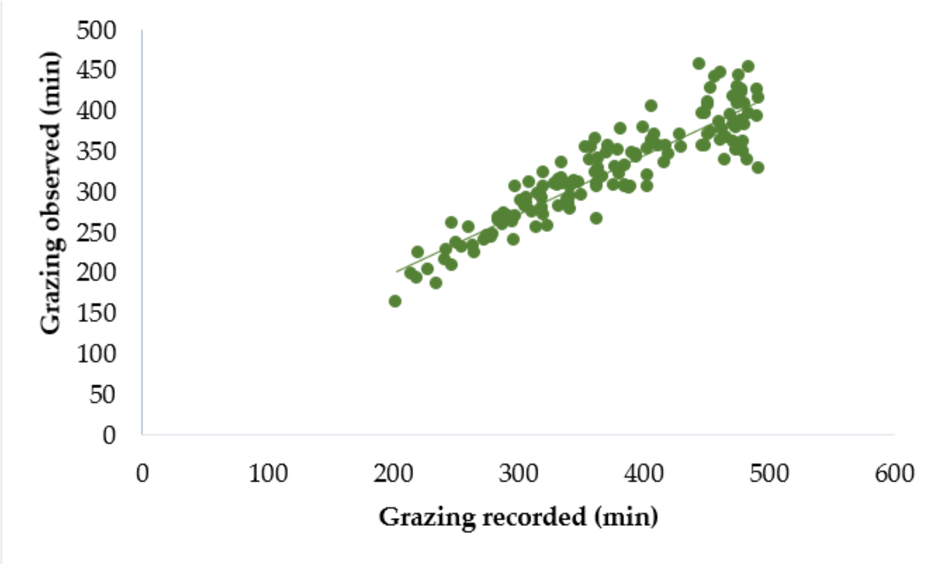

Figure 3.1. Relationship between grazing time recorded through AfiCollar device and grazing time obtained through visual observation per daily observation session.

Table 3.3. Regression analysis results between the AfiCollar and visual observation for grazing time and rumination time.

	Grazing Time	**Rumination Time**
R^2	0.83 ($p < 0.0001$)	0.78 ($p < 0.0001$)
Slope (SEM, *p*)	0.72 (0.02, $p < 0.0001$)	0.90 (0.04, $p < 0.0001$)
Intercept (SEM, *p*)	54.3 (10.5, $p < 0.0001$)	20.9(2.31, $p < 0.0001$)

(The regression model between visual observation (on Y-axis) and AfiCollar (X-axis) measurements (min/observation) are presented with the coefficients of determination (R^2), the slopes, and the intercepts with standard errors of the mean (SEM) and P-value. The significance level for the p-value was set at 0.05).

The sensitivity, specificity, and accuracy values for AfiCollar to monitor grazing and rumination behaviours we also calculated and are presented in Table 3.4.

Table 3. 4. Regression analysis results between the AfiCollar and visual observation for grazing time and rumination time.

Behaviour	Sensitivity (%)	Specificity (%)	Accuracy (%)
Grazing time	97.6	71.91	86.98
Rumination time	70.29	69.45	86.00

Note: These values were calculated using per-hour data.

3.4.1.2. Rumination behaviour

The comparison was made between the behaviour results recorded through AC and results obtained through VO and details are shown in Table 3.2. The mean rumination time per cow, per daily observation session recorded through AC, was 39 min, whereas that obtained through VO was 56 min. Compared to the VO results, AC results showed lower rumination time (4% on average). The mean bias of rumination time per daily observation session calculated between the two methods was 17 min. The AC results and VO results had a good association (Figure 3.2), showing a strong correlation and level agreement (r = 0.89, CCC = 0.80) between each other with an RPE value of 0.40. Some of the cows (*n = 15*) were not found ruminating both in AC and VO results during some of the daily observation sessions. Moreover, for some of the observation sessions, rumination activity was obtained through VO results, but not produced by AC results. Regression analysis (Table 3.3) showed that the VO results had a significant linear relationship with the AC results ($R^2 = 0.78$, $p < 0.05$). The intercept and slope for rumination time were significantly different from zero ($p < 0.05$).

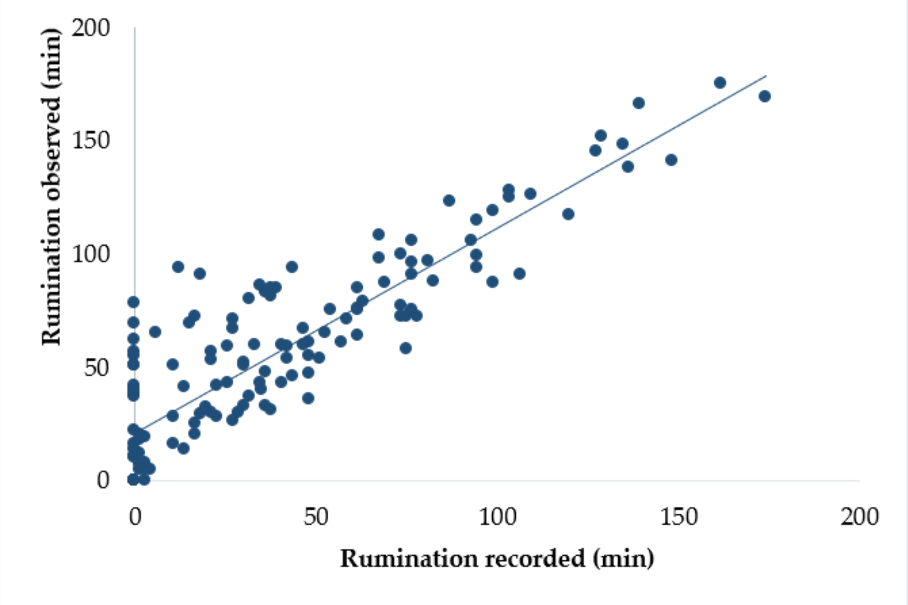

Figure 3.2. Relationship between rumination time recorded through the AfiCollar device and rumination time obtained through visual observation per daily observation session.

3.5. Discussion

This study validated the accuracy of a triaxial accelerometer sensor-based automated device called AfiCollar, designed to monitor and record eating and rumination behaviours on a real-time basis. The collar device was earlier tested in an indoor dairy system (Merenda et al. 2019) and reported to have 87% accuracy in recording the eating and rumination behaviours of dairy cows. However, in the present study, the collar device was evaluated to monitor and record the grazing and rumination behaviours of dairy cows in a pasture-based system on a New Zealand-based farm.

Consistent behaviour counts were found between automatic recording through the AfiCollar and visual observation throughout the observation period. The estimation of mean grazing time per daily observation session through AC was slightly higher than that of VO, with a mean bias of 48 min (10%). In a grazing-based system, dairy cows have freedom of movement, and they keep moving between the feeding patches in search of quality feed (Schütz et al. 2010). Therefore, the frequency of movements in a grazing-based system is higher than that in a confined indoor system. Moreover, during the visual observation for the current study, cows were found with a high frequency of movements, spending more time selecting grazing patches and moving around without performing grazing activity. The AfiCollar device is equipped with an accelerometer-based sensor that is designed to detect motion patterns. The sensor can identify and categorise specific behaviour categories based on the motion patterns of the animal's head. The accelerometer-based sensor in the collar device possibly considered all those movements by the cows with their heads down to select grazing patches as true grazing activity. The built-in algorithms in the collar device possibly calculated the time spent on those movements with no grazing activity by cows as grazing time. The higher grazing time recorded by AC compared to VO was probably due to the interpretation of those false positive grazing movements as true grazing activity.

For the rumination behaviour, a lower rumination time was recorded through AC than that indicated by VO, with a mean bias of 17 min (4%). Rumination time between AC and VO mainly differed in the recording performed during the hot summer season. Cows were expected to be feeling heat stress as they were observed performing rumination activity mostly in a standing posture. It was noted previously that as temperature increases in hot summer, cows stand more and lie down less (Palacio et al. 2015). Moreover, pastured cows are exposed to fly attacks during the summer, exacerbated by increased heat, as reported in a previous study (Ternman et al. 2018). The cows were also observed frequently performing random head movements to get rid of flies around the lower abdomen and udder areas that are common on pasture in the summer season. The collar uses an accelerometer-based sensor that might have considered and interpreted those random head movements performed by the cows during the standing posture as grazing activity, whereas the cow was performing rumination. The sudden and frequent random head movement probably would have interrupted the threshold of specific movement patterns for rumination behaviour identified by the sensor. Afterwards, the collar might have started counting the head movements into grazing time. Similarly, rumination activity was observed during a few observation sessions but not recorded by the collar. These findings further suggest that the threshold of the sensor and the algorithms used by the collar could be improved in terms of precision to truly identify and interpret the patterns of head movements reflecting specific behaviour activity. A recent study has suggested including leg movement patterns as well to optimize the threshold of behaviour monitoring sensors and readjust the algorithms for grazing-based systems (Cullen et al. 2023). Some cows ($n = 15$) were found with no rumination activity in both AC and VO results during some of the observation days. As previously reported, the maximum rumination activity by dairy cows is performed during the night while resting (Borchers et al. 2016). This might be the possible reason for zero rumination during the observation period, which was during the daytime (from 9:00 a.m. to 5:00 p.m.). On the other hand, some cows were recorded with zero or no rumination activity but were observed performing rumination activity. This occurred during the observation performed in the summer season as explained above. This might be because of atmospheric patterns and high-temperature humidity index, which affected the behaviour of dairy cows. The behaviour variation due to high temperature was reflected in the outputs recorded through AC. This will be further investigated.

The strong correlation between AC results and VO results for grazing (r = 0.91) and rumination (r = 0.89) indicated the high accuracy of the collar to monitor grazing and rumination behaviours of grazing dairy cows. The correlation values were consistent with the findings of previous studies that used accelerometer sensor-based collars. A previous study (Neethirajan et al. 2017) reported the correlation values for grazing (r = 0.88) and rumination (r = 0.72) between observed and recorded results using an ear-tag accelerometer-based sensor (Cow Manager Sensor, Agis Automatisering BV, Harmelen, the Netherlands), which identified the specific behaviour based on both ear and head movements. Another study reported a high correlation between observed and recorded results for grazing behaviour (r = 0.90) and rumination behaviour (r = 0.80) in grazing dairy cows (Stakelum and Dillon 2003). The device used in that study was a neck-mounted behaviour and activity monitoring collar (SCR HR-LDn; SCR Engineers, Netanya, Israel), which had a three-axis accelerometer sensor to generate data and, a microprocessor to calculate (utilizing specifically developed algorithms) grazing and rumination behaviours. The consistent correlation values between visual observation and automatic measurements in the current study with that of previous studies suggested the reliability of the AfiCollar device to effectively monitor the grazing and rumination behaviours of grazing dairy cows.

Concordance correlation coefficient (CCC) values between AC and VO were high for both grazing (CCC = 0.71) and rumination (CCC = 0.80). However, the value for rumination was higher than that of grazing. Those values based on the agreement between recorded and observed datasets further explained the reliability of the collar to accurately record grazing and rumination behaviours of grazing dairy cows. The CCC values for grazing and rumination agreed with the CCC values reported by previous studies. Another study (Benaissa et al. 2019) reported a slightly higher CCC value for grazing (CCC = 0.88) and a slightly lower CCC value for rumination (CCC = 0.71) compared to CCC values in the current study. Another study used an accelerometer sensor-based device called CowManager SensOor (Agis, Harmelen, Netherlands) and reported CCC = 0.82 for eating and CCC = 0.59 for rumination in dairy cows (Allain et al. 2014). Moreover, the relative prediction error for rumination (0.40) was higher than that for grazing (0.18). This indicated that the precision of the collar device for monitoring grazing behaviour was higher than that of rumination behaviour.

Regression analysis further verified a strong relationship between observed and recorded results for both grazing and rumination. High R^2 values were found between AC results and VO results in the current study for grazing (0.83) and rumination (0.78). High R^2 values indicated the efficiency of the collar to monitor and record behaviours in a grazing-based system. A previous study (Zehner et al. 2012) found a range of R^2 values from 0.69 to 0.93 between recorded and observed results for the grazing behaviour of dairy cows. They used Kenz Lifecorder+® (LC+; Suzuken Co. Ltd., Nagoya, Japan) which was developed to monitor uniaxial acceleration. Similarly, another study has found an R^2 value (0.79) for rumination consistent with the value in the current study (Zehner et al. 2012). A range of R^2 values (from 0.22 to 0.79) between recorded and observed data for the rumination behaviour in different aged day cows has been reported (Hessle 2009). Their study used the Hi-Tag electronic rumination-monitoring system (SCR Engineers Ltd., Netanya, Israel). Highly consistent with the previous studies, R^2 values for both behaviours in the current study further proved the reliability and accuracy of the AfiCollar to monitor the behaviour of grazing dairy cows.

3.6. Conclusion

This study evaluated a triaxial accelerometer sensor-based automated device (AfiCollar) for dairy cows to monitor and record their grazing and rumination behaviours in a grazing-based system on a real-time basis. The AfiCollar device showed a strong correlation and high agreement with visual observation. Based on associations between automatic recording and visual observation, the AfiCollar device proved to be a useful and reliable tool to accurately monitor and record the grazing and rumination behaviours of grazing dairy cows on a pasture on a real-time basis. The collar slightly overestimated grazing time and underestimated rumination time. This was possible because of the effects of the weather (high temperature) on the behaviour of dairy cows, which was reflected in behaviour outputs by the collar device. Minor modifications are suggested in algorithms to improve the identification and characterization of cow head movements for a more precise interpretation of the specific behaviour. Also, the inclusion of leg impressions might be crucial to set the threshold of AfiCollar for monitoring grazing and rumination in grazing dairy cows.

Chapter 4

Variations in the 24 hours temporal patterns and time budgets in grazing, ruminating and idling behaviours in grazing dairy cows

4.1.Abstract

This study investigated the variations in the temporal distribution and the per cent length of time spent grazing, ruminating, and idling by grazing dairy cows over 24 hours. Spring calved lactating dairy cows (*n = 54*) from three breeds, Holstein-Friesian (HFR), Jersey (JE), and Holstein-Friesian/Jersey crossbreed, KiwiCross (KC) in different lactations (1st, 2nd, 3rd) and with different breeding worth index values (103<BW>151) selected. The study was conducted for a whole lactation season. The cows were managed through a rotational grazing system and milked once a day at 5:00 hrs. The cows grazed mainly pasture and consumed additional feeds (maize silage and turnips)) in summer and autumn seasons. An automated device, AfiCollar was used to monitor and record the time (min/h) spent grazing and ruminating by the individual cows throughout the lactation period (~270 days). A repeated measure design with PROC MIXED was applied considering the effects of breed, lactation number, the hour of the day, season, and supplementary feed to evaluate the difference in grazing time (min/h) and rumination time (min/h). Hourly behaviour patterns based on the mean values of grazing and rumination behaviours for each hour over 24 hours were demonstrated for each breed, lactation number, season, and supplementary feed. Idling time (min/h) was calculated as the time left after grazing and rumination. Behavioural (grazing, rumination, and idling) means for the breed, lactation number, season and feed were considered as representative of their time budgets across 24 hours. The mean time spent under grazing, ruminating, and idling were expressed as a percentage (%) of 24 hours used for each behaviour (time budget). Regardless of the season and supplementary feed, cows spent most of the daytime grazing and most of the night-time ruminating. Grazing activity remained consistently high throughout the day with two peaks around dawn and dusk. Rumination activity increased gradually from the late evening and remained high until early morning, except for a short grazing peak around midnight. Grazing and ruminating patterns were similar between different breed and lactation groups, however, JE cows grazed slightly longer than HFR and KC, and first lactation cows also grazed slightly longer than those in higher lactations. The onset and cessation of grazing activity by the cows were adjusted according to varying day lengths by season. Cows finished grazing activity earlier when they consumed additional supplements and silage along with pasture. Cows from different breed groups and lactations spent most of their 24-hour period grazing followed by ruminating and idling. Season and supplementary feed potentially caused variations in behaviour time budgets. Variations in behaviour time budgets were more apparent in the autumn season when cows were about to be dried off and received supplement feeds. As informing about the pasture and additional feed demands by different animals within a day and

over lactation, these findings should support improving measures for animal welfare and pasture management in varying environmental and/or managemental conditions.

Keywords: automated behaviour monitoring, behaviour patterns, behaviour time budgets, Grazing dairy cows, individual animal data

4.2. Introduction

Cows are naturally motivated to carry out certain behaviour activities throughout 24 hours forming repetitive patterns. Over 24 hours, a cow engages in periods of grazing, ruminating, and idling. These activities are predominant in pasture-based grazing cows, and they spend 90–95% of their daily time grazing, ruminating, and resting (Kilgour, 2012). Cows in a pasture-based system do not graze continuously, their crepuscular grazing patterns are distributed in discrete events or "meals" with clear peaks around dawn (after milking) and dusk (Shabi et al., 2005; von Keyserlingk & Weary, 2010). A grazing event (or a meal) is the collection of grazing bouts (Metz, 1975), and the cumulative grazing events over 24 hours, therefore, represent the overall time budget specified for grazing (Gibb 1998) per day. Rumination is another important activity performed by ruminants after grazing. Like grazing, time budget and the pattern of rumination activity in pasture-grazing dairy cows are circadian but flexible (Gregorini et al. 2006). The behaviour patterns represent benchmarked routines, and the time budgets indicate a net response of cows to their environment over 24 hours. Any prolonged deviations in those patterns due to environmental and/or management constraints can result in negative consequences for animal productivity and health (Dittrich et al., 2019). Determining the behaviour patterns and time budgets therefore can help to depict a balance in behaviour activities and to evaluate any deviations in animals' natural behaviour. Also, obtaining this information for grazing dairy cows can further serve as a foundation to develop management strategies, and to improve welfare without interfering with their natural behaviour.

In New Zealand, dairy production mainly relies on the grazing of pasture, and cows only receive supplementary feeds if required. New Zealand dairy herds are mainly populated with Holstein-Friesian, Jersey, and Crossbreed of Holstein-Friesian/Jersey (KiwiCross) breeds. Climatic conditions and weather in New Zealand are variable and exhibit a four-season pattern. Under those temperate free-range conditions, grazing ruminants generally exhibit a daily frequency of three to five grazing events (Gibb 1998). The frequency of grazing fluctuates with the current physiological state of the animal, grazing methods, and the environment (Gregorini 2012). The choice for a behavioural activity is determined by the current state of the animal and its environment (Mangel and Clark 1986). Those decisions ascertain how grazing cows invest their time in eating to address their metabolic and nutrient requirements. The metabolic, diurnal, and seasonal rhythms of grazing and ruminating patterns in grazing dairy cows are influenced by the quality and quantity of pasture, weather, daylight hours, and theoretical food requirements (Corbett 1953; deVries and Daleboudt 1994). On the other hand, grazing and rumination are interdependent and the potential factors that can alter the rumination pattern are the quality of diet and time spent consuming it (Pearce 1965; Schirmann et al. 2012); as the time budget specified by a cow for ruminating is diet dependent. Grazing and rumination patterns in grazing dairy cows are also modulated by the addition of supplement feeds and the timing of providing the supplements (Al-Marashdeh et al. 2018). Variations in the behaviour patterns and their time budgets could be due to the production level of animals as well; for instance, high-producing cows are expected to spend a longer period grazing to fulfil their energy requirements compared to low-producing cows. Similarly, variations in behaviours might exist in cows of different breeds due to physiological and anatomical differences, and in cows with different years of lactation due to varying energy requirements.

An intriguing question evolves about how to describe the varying behaviour patterns in grazing dairy cows and what happens at the individual animal level in the paddock. For example, how do cows of different breeds in different lactation years pattern their daily behaviour activities? What changes occur in grazing cows' behaviour patterns and time budgets in response to seasonal variations? Moreover, are there any changes occurring in the behaviour patterns and time budget of pasture-fed cows when receiving additional supplementary feeds? Some studies have explored the behaviour patterns and time budgets in grazing dairy cows (Sheahan et al. 2011; Jochims et al. 2020). Whereas, neither of those studies collected data for long periods such as over a complete lactation season for a few consecutive lactations. One of the potential reasons has been the lack of technology to record those behaviours in individual animals. Most of the research has relied on the use of visual observations to record different behaviours in grazing dairy cows which is a time-consuming procedure. Precision Livestock Farming (PLF) offers sensors monitoring the individual animal's behaviour on a real-time basis. Various tools such as collar devices have been developed, validated, and applied to monitor behaviours in grazing cows (Frost et al. 1997; Schirmann et al. 2012; Elischer et al. 2013; Iqbal et al. 2021).

How grazing dairy cows distribute their behaviour patterns over 24 hours and how the frequency of behaviour varies in different cow breeds and lactation groups during different seasons with different supplementary feeds is important in understanding their grazing process. Understanding the behaviour patterns and time budgets, and their variations at the individual animal level is an essential tool to improve overall management strategies and especially grazing management for pasture-based dairy cows. Furthermore, the temporal distribution, duration, and intensity of grazing events can also help improve the nutrient supply to grazing cows. This information can be applied to manage pasture allowance and feed resources for day-to-day and even within a day throughout the lactation period. However, there is little literature concerning these effects. Therefore, the primary objective of this study was to examine the variations in behaviour patterns and time budgets over 24 hours in lactating grazing dairy cows from different breed groups and lactation years, during different seasons, and when fed with different supplements.

4.3. Materials and methods

4.3.1. Ethical statement

The study was carried out at Dairy unit 1, Massey University, Palmerston North, New Zealand (Latitude: -41.3009, Longitude: 174.7720). Approval (Protocol No. 18/58) for the care and handling protocols of animals was received from the Animal Ethics Committee, Massey University, New Zealand.

4.3.2. Grazing conditions

The study was performed at Dairy Unit 1, Massey University, Palmerston North, New Zealand (Latitude: -41.3009, Longitude: 174.7720). Dairy unit 1 is a pasture-based, once-a-day milking dairy farm operated through a rotational grazing scheme with a spring calving system. The farm area consists of 142.7 hectares and is divided into 63 paddocks. The local climate is of a temperate type with four seasons classified as spring (September to November), summer (December to February), autumn (March to May), and winter (June to August). The annual average temperature in the area over the study period was ~16°C (8-24°C) with an annual rainfall of ~960 mm (NIWA 2022).

4.3.3. Grazing animals

Pasture grazing, and spring calving lactating dairy cows ($n = 54$) used in the study were a subset of the whole herd ($n = \sim 260$). The selection of cows was based on their breed type, lactation number within each breed, and breeding worth (BW) index value. Breeding worth is an index that ranks the genetic potential of the animal to produce profitable progeny and is expressed in dollars ($) (Harris 1998). Eighteen (n =18) cows from each of the three breeds, Holstein-Friesian, Jersey, and Holstein-Friesian/Jersey Crossbreed (KiwiCross) were included in the group. The cows included in each breed group were from different lactations (1st, 2nd, and 3rd) with six cows (n = 6) from each lactation. The cows within each lactation had varying genetic merit (103<BW>151) for the farm profit. The cows were kept in grazing paddocks throughout their lactation period except when brought to the milking shed (~ two hours per milking).

4.3.4. Feeding the experimental animals

The feed requirements for the pasture grazing cows were established by the farm manager based on the feed requirement table by Dairy New Zealand (DairyNZ 2022a). However, the actual intakes of neither the grass nor supplements were measured. The cows mainly grazed pasture of perennial ryegrass (*Lolium perenne L.*) mixed with red clover (*Trifolium pretense*) and white clover (*Trifolium repens*). To meet energy requirements and to cope with the seasonal changes in pasture quality and production (Machado et al. 2005), cows were additionally fed with supplements including maize (*Zea mays*) silage and turnips (*Brassica rapa subsp. rapa*) during summer and autumn seasons. Replacing good quality pasture with an alternative feed source or 'balancing pasture' is not considered advantageous; therefore, supplements are only used to provide energy when there is insufficient pasture available, especially during summer and autumn. Supplementary feeds are used when quality pasture is less available, to fill the feed deficits and to support the cows to maintain energy intake and production (DairyNZ 2022b). Moreover, the purpose of providing supplements to milking cows in autumn is also to achieve calving body condition score targets, if the feeds are not supplemented, cows are more prone to lose body condition score as quality pasture is insufficient at that time of the year (DairyNZ 2022b). Maize silage and turnips (bulbs and leaves in situ) were fed around midday in the paddock. The supplementary feeds were provided in equal allowance per cow and were equally accessible to each cow. The cows had *ad libitum* access to drinking water in each paddock.

4.3.5. Behaviour recording

An automated device, AfiCollar (Afimilk Ltd. Kibbutz Afikim, 1514800, Israel) was used in this study to monitor and record the time spent grazing and ruminating by the grazing dairy cows over the lactation period. The device has been validated for measuring grazing and rumination behaviours in grazing dairy cows (Iqbal et al. 2021). The device continuously monitored and recorded the minute-by-minute behaviours of the cows for 24 hours on a real-time basis. The AfiCollar device had a triaxial (x, y, z) accelerometer-based sensor in a box attached to the collar and positioned on the right side of the animal's neck. The sensor could identify and classify specific behaviour categories such as grazing, and rumination based on the patterns of the animal's head movements. The data collected by the sensor were analysed by the collar device using built-in generic algorithms and produced as minute-per-hour (min/h) behaviour counts (grazing time and rumination time). The data collected by the AfiCollar device were wirelessly transmitted to a base station through Wi-Fi while cows were in the range of ~500 meters. The data transmission took place once per day when cows were in the shed for milking. The data were downloaded in a Microsoft Excel spreadsheet (Version 2016) from the computer attached to the base station.

4.3.6. Data collection and preparation

This study collected grazing time (min/h) and rumination time (min/h) of grazing dairy cows over the lactation period (2018-2019). The lactation period of dairy cows usually ranges from August to April of the next year (~ 270 days) following the typical spring calving system in New Zealand. The AfiCollar device was fitted to the individual cow after the calving event, and it was kept by the cow throughout the lactation period until drying off. The data collection started once the cow calved and ended when the cow was dried off. Minutes per hour spent grazing and rumination by each cow were collected for the individual hour throughout the lactation seasons, organized, and used as such to perform analysis. The data for the individual animals were separately sorted in Microsoft Excel spreadsheets (Version 2016). The overall number of observations registered and used for analysis was 269318.

4.3.7. Data analysis

4.3.7.1. Behaviour patterns

To determine the hourly patterns for grazing and rumination behaviours, the data were summarized and expressed as minutes utilized for each behaviour within an individual hour over 24 hours. Effects of breed and lactation number of cow, the hour of the day, season, and supplementary feed within the season were evaluated on hourly patterns of grazing and rumination behaviours. A repeated measure design using PROC MIXED with breed × lactation number (with three levels each), individual cow within the breed and lactation number, hour of the day, season, and supplementary feeding within the season was performed in SAS (version 9.4, SAS Institute Inc. Cary, NC). The model investigated the differences in grazing time and rumination time within each hour over 24 hours, as recently used by another study (Jochims et al. 2020). Grazing time (min/h) and rumination time (min/h) were the main dependent variables. Breed and lactation numbers were the main fixed effects in the model. Hour of the day was added as repeated measures on the subject cow to evaluate its effect on hourly behaviour patterns. Lactation length covered three seasons (spring, summer, and autumn), the season was added in as a fixed factor to test its effect on grazing and rumination times. Cows received different supplementary feeds in the summer and autumn seasons, so, the supplementary feeding nested within the season was added as a fixed effect in the model. Individual cow with breed and lactation number was used as a random effect in the model. The least-square means of grazing and rumination times (min/h) for each hour over 24 hours were plotted in a line chart using Microsoft Excel (version 2016).

4.3.7.2. Behaviour time budgets

Before this analysis, idling time was added as a new variable and defined as the time when the animal was neither grazing nor ruminating (Forbes 1988). Idling time (min/h) was manually calculated for the individual cow for each hour by subtracting the total minutes spent grazing and ruminating from 60 (total minutes in an hour). The behaviour data collected for the individual cow for the individual hour over 24 hours were further classified and sorted by breed, lactation number, season, and supplementary feeding within the season.

Means of minutes per hour spent grazing, rumination, and idling for 24 hours were considered as the average time utilised for each behaviour activity across 24 hours. The behavioural means (min/h) for the breed, lactation number, season and feed within the season were considered to calculate the proportion of 24 hours (24-hour time budget) utilized for grazing, rumination, and idling. The mean time budget values were expressed in percentages.

4.4. Results

4.4.1. Grazing and rumination patterns

Hour of the day had a significant effect on the hourly grazing and rumination behaviour patterns of grazing cows (Table 4.1). The overall temporal distributions of grazing and rumination activities over 24 hours in grazing dairy cows are shown in Fig 4.1. Regardless of the season, supplementary feed type, breed type, and lactation number, grazing dairy cows spent most of their daytime grazing and most of the night-time ruminating. Grazing activity started early in the morning, gradually increased, and remained high throughout the day with a decline in the evening. The intensity of grazing (The minutes spent grazing within an hour) was higher, especially in the morning and in the late afternoon until evening. The evening grazing peak was slightly higher than the morning one. Grazing activity remained low over the night hours except for a short peak around midnight. In contrast to grazing, rumination activity in grazing dairy cows gradually increased from the late evening and consistently remained high until the early morning when cows were brought to the milking shed (Fig 1). Rumination activity remained low throughout the daytime.

Table 4. 1. P values for the effects of breed, lactation, season, feed within the season, and their interactions on grazing time (min/h) and rumination time (min/h) using a mixed effects model with the cow (*n = 54*) as a random factor.

Effect	P Value	
	Grazing time (min/h)	**Rumination time (min/h)**
Breed	0.0738	0.3334
Lactation	0.8242	0.5131
Breed*lactation	0.0839	0.9339
Hour	<.0001	<.0001
Season	<.0001	<.0001
Feed (Season)	<.0001	<.0001
Breed*Season	<.0001	<.0001
Lactation*season	<.0001	<.0001
Breed*Hour	<.0001	<.0001
Lactation*Hour	<.0001	<.0001
Season*Hour	<.0001	<.0001
Breed*Lactation*Season	<.0001	<.0001

(The significance of the P value was set at 0.05. * Indicates interaction.)

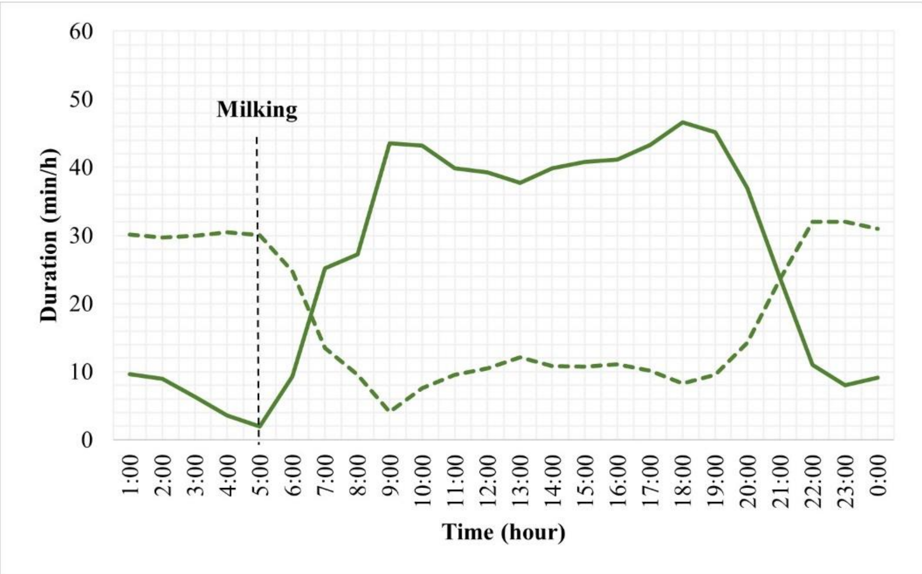

Figure 4. 1. Duration of grazing and rumination behaviours for each hour over 24 hours in grazing dairy cows (*n = 54*). (Compact line shows grazing activity and the dotted line shows rumination activity).

The temporal patterns of grazing and rumination behaviours over 24 hours were similar among cows from different breeds (Fig 4.2) with no significant differences (Table 1). Jersey (JE) cows grazed longer with more consistent activity compared to Holstein-Friesian (HFR) and KiwiCross (KC) cows. JE cows' morning and evening grazing peaks were one hour later than that of HFR cows. HFR cows showed slightly elevated rumination activity after the morning grazing peak. The temporal patterns of grazing and rumination behaviours over 24 hours were similar among cows in different lactations (Table 4.1), although, the first lactation cows showed more intense and longer grazing activity compared to cows in 2nd or 3rd lactations (Fig 4.3). Standard errors of means for the breed and lactation number for different hours of the day are shown in Table 4.2.

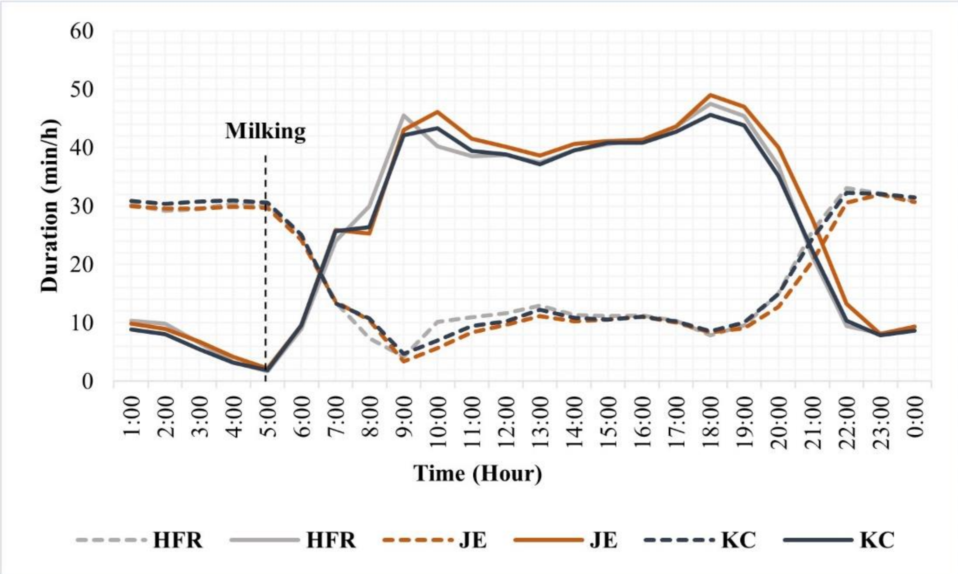

Figure 4. 2. Duration of grazing and rumination behaviours for each hour over 24 hours in different breeds of grazing dairy cows (*n = 54*). Compact lines show grazing activity and dotted lines show rumination activity. HFR = Holstein-Friesian, JE = Jersey, and KC = KiwiCross.

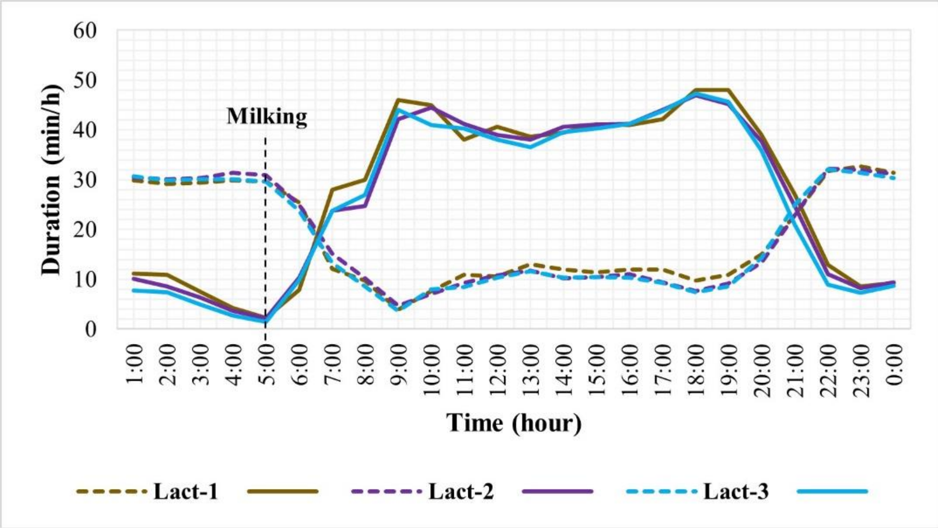

Figure 4. 3. Duration of grazing and rumination behaviours for each hour over 24 hours in grazing dairy cows (*n = 54*) in different lactations. Compact lines show grazing activity and dotted lines show rumination activity. Lact-1, Lact-2, and Lact-3 represent first, second, and third lactation cows respectively.

Table 4. 2. Means and Standard errors of means (SEM) for per-hour grazing time (min/h) and rumination time (min/h) for each hour over 24 hours.

	Grazing time		Rumination time	
Hour	**Mean**	**SEM**	**Mean**	**SEM**
0:59	10.3	0.14	30.6	0.13
1:59	9.4	0.14	30.2	0.13
2:59	6.6	0.12	30.6	0.12
3:59	3.8	0.09	31.0	0.12
4:59	2.0	0.06	30.8	0.12
5:59	10.4	0.12	24.7	0.12
6:59	24.1	0.14	14.4	0.11
7:59	26.7	0.15	10.4	0.10
8:59	42.4	0.17	4.7	0.08
9:59	41.4	0.20	8.5	0.13
10:59	38.8	0.20	9.9	0.13
11:59	39.5	0.18	10.5	0.13
12:59	37.9	0.19	12.4	0.14
13:59	39.5	0.18	11.2	0.13
14:59	39.8	0.17	11.6	0.13
15:59	40.7	0.17	11.6	0.13
16:59	42.6	0.17	11.0	0.13
17:59	46.2	0.16	8.7	0.12
18:59	45.6	0.16	9.4	0.12
19:59	38.0	0.21	13.9	0.15
20:59	25.6	0.20	22.7	0.15
21:59	12.2	0.15	32.0	0.13
22:59	8.7	0.14	32.1	0.13
23:59	9.7	0.14	31.3	0.13

Note: This table is linked to Fig 4.1.

Table 4. 3. Means and Standard errors of means (SEM) for per hour grazing time (min/h) and rumination time (min/h) for Holstein-Friesian (HFR), Jersey (JE), and KiwiCross (KC) breeds for each hour over 24 hours period.

	Grazing time						Rumination time					
	HFR		JE		KC		HFR		JE		KC	
Hour	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
0:59	9.8	0.30	9.7	0.31	8.3	0.24	30.4	0.28	30.0	0.29	31.1	0.22
1:59	10.1	0.30	9.4	0.30	8.3	0.23	29.2	0.28	29.4	0.28	30.3	0.21
2:59	7.1	0.26	7.5	0.26	5.9	0.20	29.5	0.27	29.3	0.28	30.8	0.21
3:59	3.8	0.19	4.8	0.20	3.4	0.15	30.6	0.26	29.7	0.26	31.1	0.20
4:59	1.9	0.13	2.4	0.13	1.9	0.10	30.1	0.25	29.5	0.25	30.8	0.19
5:59	9.9	0.20	10.6	0.20	10.3	0.15	24.9	0.25	24.0	0.26	25.0	0.20
6:59	24.2	0.29	26.4	0.30	25.8	0.23	13.9	0.23	13.3	0.23	13.6	0.17
7:59	29.8	0.29	26.0	0.29	26.7	0.22	7.8	0.19	10.4	0.20	10.9	0.15
8:59	44.5	0.35	42.2	0.36	41.4	0.27	4.8	0.18	4.1	0.19	5.4	0.14
9:59	39.0	0.39	44.5	0.40	42.0	0.31	11.1	0.26	6.6	0.26	7.6	0.20
10:59	37.4	0.41	39.8	0.42	38.3	0.32	11.5	0.27	9.0	0.28	9.8	0.21
11:59	40.3	0.40	41.3	0.41	40.3	0.32	10.7	0.28	9.0	0.29	9.4	0.22
12:59	38.0	0.40	38.7	0.41	37.6	0.31	12.7	0.29	11.1	0.30	11.9	0.23
13:59	38.9	0.39	39.5	0.40	38.8	0.30	11.3	0.28	10.3	0.29	10.7	0.22
14:59	41.1	0.38	41.4	0.39	41.2	0.29	10.8	0.28	10.1	0.29	10.2	0.22
15:59	40.9	0.37	40.9	0.38	40.3	0.29	11.6	0.28	11.4	0.29	11.3	0.22
16:59	43.8	0.37	43.4	0.37	42.8	0.28	10.4	0.28	10.2	0.29	10.2	0.22
17:59	47.9	0.35	46.9	0.36	46.1	0.27	7.8	0.27	8.2	0.28	8.3	0.21
18:59	45.3	0.34	46.3	0.36	44.0	0.27	9.7	0.27	9.0	0.28	9.9	0.21
19:59	36.0	0.41	38.1	0.43	34.7	0.32	15.3	0.30	12.9	0.32	14.9	0.23
20:59	20.6	0.35	27.1	0.36	21.9	0.27	26.0	0.29	20.6	0.30	24.5	0.22
21:59	9.5	0.30	13.2	0.31	10.2	0.23	32.4	0.28	30.2	0.29	31.8	0.22
22:59	8.5	0.28	8.4	0.28	8.1	0.22	31.9	0.27	31.6	0.28	31.7	0.21
23:59	10.3	0.29	10.7	0.30	9.7	0.23	30.2	0.27	29.9	0.28	30.8	0.21

Note: This table is linked to Fig 4.2.

Table 4. 4. Means and Standard errors of means (SEM) for per hour grazing time (min/h) and rumination time (min/h) for First lactation (Lact-1), second lactation (Lac-2), and third lactation (Lact-3) dairy cows for each hour over 24 hours period.

Grazing time						Rumination time					
Lact-1		Lact-2		Lact-3		Lact-1		Lact-2		Lact-3	
Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
10.8	0.26	9.5	0.28	7.5	0.31	29.9	0.24	30.7	0.26	30.9	0.28
11.2	0.26	8.7	0.28	7.9	0.30	29.0	0.24	30.1	0.26	29.8	0.28
8.2	0.22	6.7	0.24	5.7	0.26	29.3	0.23	30.2	0.25	30.0	0.28
4.5	0.17	3.9	0.18	3.5	0.20	30.1	0.22	31.4	0.24	29.9	0.26
2.2	0.11	2.0	0.12	1.9	0.13	29.9	0.21	31.0	0.23	31.0	0.23
8.7	0.17	10.7	0.18	11.3	0.20	25.3	0.22	24.9	0.24	23.5	0.26
28.3	0.25	23.8	0.28	24.2	0.30	12.3	0.19	15.2	0.21	13.2	0.23
30.6	0.25	25.1	0.27	26.8	0.29	9.9	0.17	10.3	0.18	8.9	0.20
44.1	0.31	41.0	0.33	43.1	0.36	4.5	0.16	5.5	0.17	4.4	0.19
42.4	0.34	43.1	0.36	40.1	0.40	8.6	0.22	7.9	0.24	8.9	0.26
36.3	0.35	40.2	0.37	39.0	0.42	11.6	0.24	9.6	0.25	9.1	0.28
41.9	0.35	40.7	0.37	39.3	0.41	9.7	0.25	9.7	0.26	9.6	0.29
39.1	0.35	38.5	0.37	36.7	0.41	12.6	0.26	11.5	0.27	11.5	0.30
38.5	0.34	39.9	0.36	38.9	0.40	11.9	0.25	10.1	0.26	10.2	0.29
41.4	0.33	41.5	0.35	40.9	0.38	11.1	0.25	10.0	0.26	9.9	0.29
40.4	0.33	40.8	0.34	40.9	0.38	12.3	0.25	11.3	0.26	10.7	0.29
42.3	0.32	43.8	0.34	44.0	0.37	11.9	0.25	9.6	0.26	9.3	0.29
46.0	0.30	47.2	0.32	47.7	0.36	9.5	0.23	7.5	0.24	7.2	0.28
44.7	0.30	45.3	0.31	45.6	0.36	10.8	0.24	9.0	0.25	8.8	0.28
36.6	0.36	37.5	0.38	34.8	0.42	15.0	0.27	13.3	0.28	14.8	0.31
25.3	0.31	24.4	0.33	19.9	0.36	22.8	0.25	22.8	0.27	25.5	0.29
12.9	0.26	11.0	0.28	9.0	0.31	31.1	0.24	32.0	0.26	31.4	0.29
9.0	0.24	8.2	0.26	7.9	0.28	32.4	0.23	32.0	0.25	30.9	0.27
10.4	0.25	10.3	0.27	10.0	0.30	30.7	0.24	30.6	0.26	29.6	0.28

Note: This table is linked to Fig 4.3.

The temporal distribution for grazing and ruminating behaviours over 24 hours during different seasons greatly varied (Table 4.1, Fig 4.4). The behaviour patterns varied according to the seasonally varying day length or daylight hours. Grazing activity in dairy cows started and finished earlier in autumn, whereas it finished later in spring and summer with a two-hour difference. Grazing activity was more consistent with an early morning steep line and intense peak in autumn. Rumination activity during the daytime was slightly higher in spring compared to autumn and summer.

The temporal patterns of grazing and rumination behaviours over 24 hours varied with varying supplementary feeds (Table 4.1, Fig 4.5). Grazing was more consistent with less resting interval when cows grazed on pasture or chicory compared to when they consumed turnips, silage, and supplements as additional feeds. When fed turnips, cows showed more intense, continuous, and longer grazing activity until late in the evening. Whereas cows always finished grazing earlier in the evening when they consumed supplements or silage as additional feeds. Rumination activity was higher during daylight hours when cows grazed solely pasture or chicory compared to that for other feed types. Standard errors of means for seasons and feeds are shown in Table 4.3.

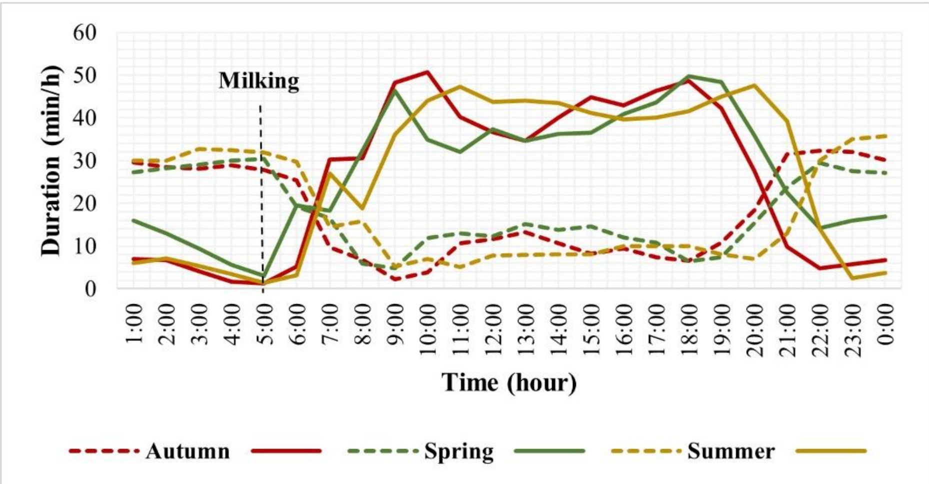

Figure 4. 4. Duration of grazing and rumination for each hour 24-hours in grazing dairy cows (*n = 54*) for different seasons of the experimental period. (Compact lines show grazing activity and dotted lines show rumination activity).

Table 4. 5. Means and Standard errors of means (SEM) for per-hour grazing time (min/h) and rumination time (min/h) in grazing dairy cows for spring, summer, and autumn seasons for each hour over 24 hours period.

Grazing time						Rumination time					
Spring		Summer		Autumn		Spring		Summer		Autumn	
Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
15	0.42	6	0.23	7	0.32	28	0.39	34	0.21	30	0.29
14	0.41	7	0.22	7	0.31	28	0.38	33	0.21	29	0.29
11	0.35	5	0.19	4	0.27	29	0.38	33	0.20	28	0.28
7	0.27	3	0.15	2	0.20	30	0.36	32	0.19	29	0.27
3	0.18	1	0.10	1	0.14	30	0.35	32	0.19	28	0.26
22	0.27	3	0.15	5	0.20	18	0.35	30	0.19	26	0.26
19	0.41	27	0.22	30	0.31	17	0.31	14	0.17	9	0.24
33	0.41	19	0.21	30	0.29	6	0.28	16	0.14	7	0.20
44	0.48	36	0.26	48	0.38	7	0.25	5	0.13	2	0.19
32	0.51	43	0.30	50	0.43	14	0.34	7	0.20	4	0.28
28	0.54	47	0.32	40	0.43	15	0.36	5	0.22	11	0.29
41	0.58	44	0.31	37	0.41	10	0.41	8	0.22	11	0.29
35	0.56	45	0.32	35	0.41	15	0.41	7	0.23	13	0.30
33	0.53	44	0.30	40	0.41	14	0.38	8	0.22	10	0.29
38	0.52	41	0.29	45	0.40	13	0.38	10	0.21	8	0.30
40	0.51	39	0.28	43	0.40	13	0.39	12	0.21	9	0.30
44	0.50	40	0.27	46	0.39	11	0.38	13	0.21	7	0.30
51	0.49	41	0.25	48	0.36	6	0.38	12	0.20	7	0.28
49	0.49	45	0.26	42	0.35	7	0.38	11	0.20	11	0.28
34	0.55	47	0.32	28	0.42	16	0.41	9	0.24	18	0.31
20	0.48	40	0.28	10	0.36	25	0.40	15	0.23	31	0.30
14	0.41	14	0.23	4	0.32	28	0.39	34	0.21	33	0.30
17	0.38	2	0.21	5	0.29	27	0.37	37	0.20	32	0.28
21	0.40	4	0.22	6	0.31	25	0.38	36	0.21	30	0.29

Note: This table is linked to Fig 4.4.

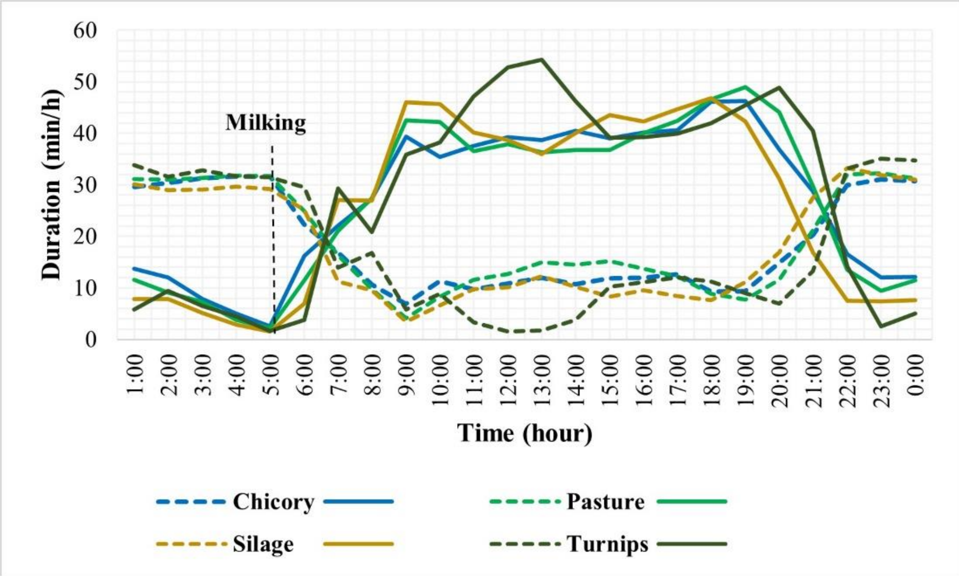

Figure 4. 5. Duration of grazing and rumination behaviour for each hour over 24 hours in grazing dairy cows (*n = 54*) consuming different feeds. (Compact lines show grazing activity and dotted lines show rumination activity).

Table 4. 6. Means and Standard errors of means (SEM) for per hour grazing time (min/h) and rumination time (min/h) in grazing dairy cows for Chicory, Pasture, Silage, and Turnips for each hour over 24 hours period.

Grazing time								**Rumination time**							
Chicory		**Pasture**		**Silage**		**Turnips**		**Chicory**		**Pasture**		**Silage**		**Turnips**	
Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
13	0.36	10	0.29	6	0.32	8	0.50	26	0.33	29	0.27	30	0.29	34	0.46
8	0.39	7	0.44	16	0.63	14	1.44	28	0.33	30	0.26	29	0.29	27	1.34
6	0.38	9	0.25	4	0.27	6	0.42	29	0.32	31	0.26	29	0.32	33	0.45
6	0.23	5	0.18	3	0.26	8	0.94	31	0.30	31	0.25	29	0.54	30	1.25
3	0.15	3	0.13	1	0.18	5	0.64	30	0.29	32	0.53	30	0.33	32	0.41
14	0.23	14	0.19	5	0.20	19	0.95	17	0.29	23	0.24	14	0.53	20	1.22
29	0.44	28	0.42	23	0.61	31	0.49	15	0.34	15	0.32	9	0.24	13	0.38
33	0.34	32	0.28	19	0.37	39	1.45	6	0.23	6	0.19	10	0.40	8	0.31
45	0.42	47	0.34	43	0.47	40	1.67	7	0.22	4	0.18	7	0.37	5	0.29
41	0.59	51	0.59	43	0.51	39	0.64	9	0.39	4	0.39	4	0.28	8	0.42
46	0.62	44	0.59	40	0.43	50	0.72	6	0.42	7	0.40	4	0.38	2	0.48
40	0.60	41	0.55	36	0.37	51	0.72	11	0.42	10	0.39	6	0.38	2	0.50
44	0.62	40	0.57	35	0.41	56	0.75	9	0.45	12	0.41	13	0.30	1	0.54
47	0.61	36	0.55	40	0.41	48	0.68	7	0.44	15	0.39	10	0.29	3	0.49
44	0.58	39	0.53	45	0.40	41	1.82	8	0.43	13	0.39	7	0.38	10	0.46
43	0.43	43	0.53	43	0.40	40	0.62	10	0.33	12	0.40	10	0.61	11	0.46
42	0.43	42	0.35	50	0.77	42	1.73	12	0.33	13	0.27	7	0.30	12	0.46
49	0.40	48	0.32	48	0.36	54	1.73	7	0.31	8	0.25	3	0.54	4	1.33
43	0.50	50	0.32	42	0.35	57	1.75	8	0.31	7	0.26	11	0.28	10	0.44
47	0.63	46	0.58	28	0.42	49	0.71	9	0.47	11	0.43	18	0.31	7	0.53
21	0.41	26	0.33	10	0.71	23	1.68	12	0.46	16	0.42	28	0.58	12	0.51
15	0.35	12	0.29	6	0.40	15	0.50	29	0.33	31	0.40	33	0.30	34	0.47
3	0.42	12	0.27	5	0.29	1	0.46	27	0.32	30	0.26	36	0.36	36	0.45
4	0.43	4	0.41	4	0.39	2	0.48	36	0.41	36	0.38	35	0.37	36	0.46

Note: This table is linked to Fig 4.5.

4.4.2. Grazing, rumination, and idling time budgets

Irrespective of breed, lactation number, season, and supplementary feed, cows spent most of their time grazing followed by ruminating and idling over 24 hours (Fig 4.6) The 24-hour time budget for grazing between Holstein-Friesian (HFR), Jersey (JE), and KiwiCross (KC) cows remained similar. The 24-hour time budgets for ruminating and idling behaviours were similar in HFR, JE, and KC cows (Fig 4.7). The 24-hour time budgets for grazing and idling behaviours between cows with different lactation numbers were similar (Fig 4.8). However, there was a slight increase in the idling time budget and a decrease in the grazing time budget in the cows with consecutive higher lactation. The rumination time budget remained similar in the cows of different lactation numbers throughout the study period.

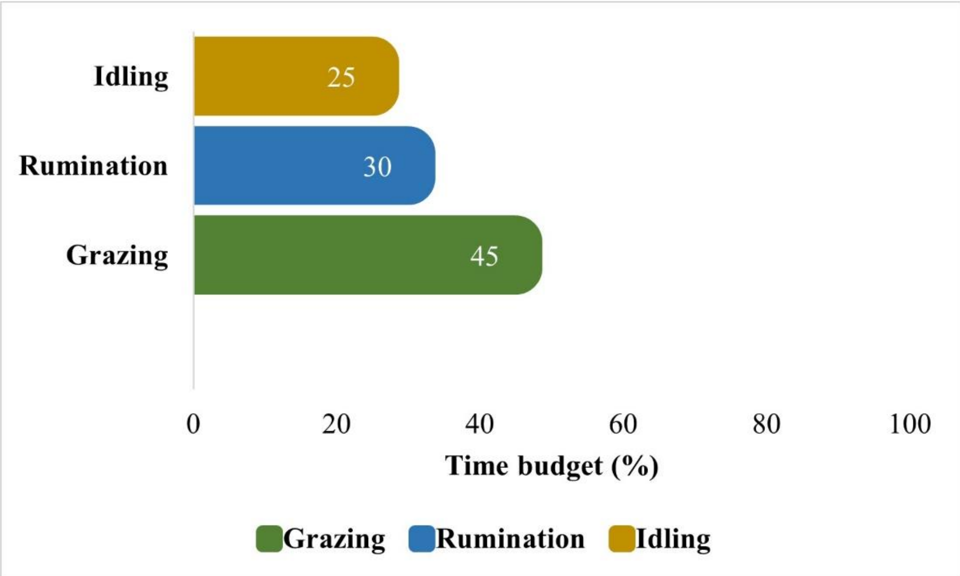

Figure 4. 6. The overall 24-hour time budgets for grazing, rumination, and idling behaviours in grazing dairy cows (n = 54). (This figure is based on the overall least square means of each behaviour (grazing, rumination, idling) over 24 hours across the whole lactation period.

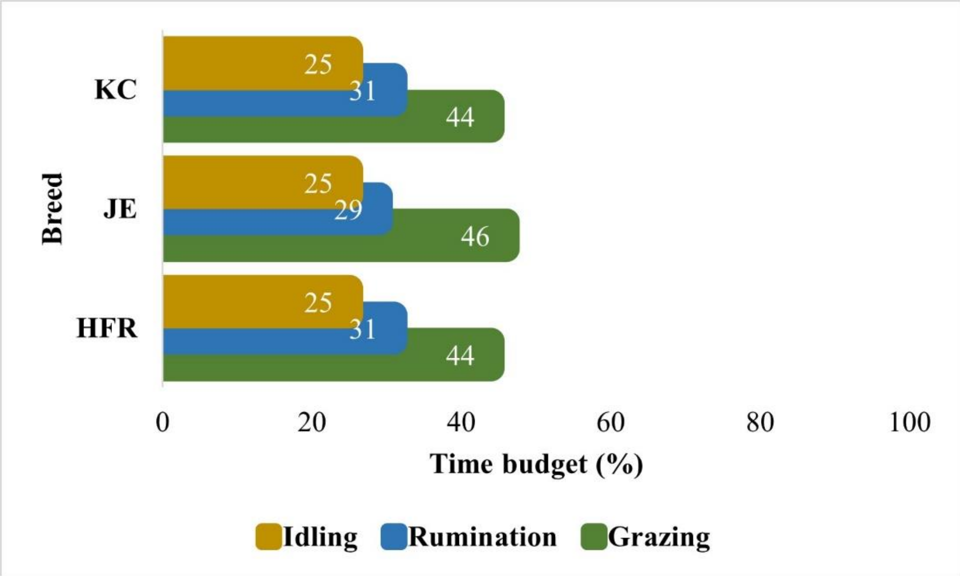

Figure 4. 7. 24-hour time budgets for grazing, ruminating, and idling behaviours in grazing dairy cows (*n* = *54*) breed. (HFR = Holstein-Friesian, JE = Jersey, KC = KiwiCross).

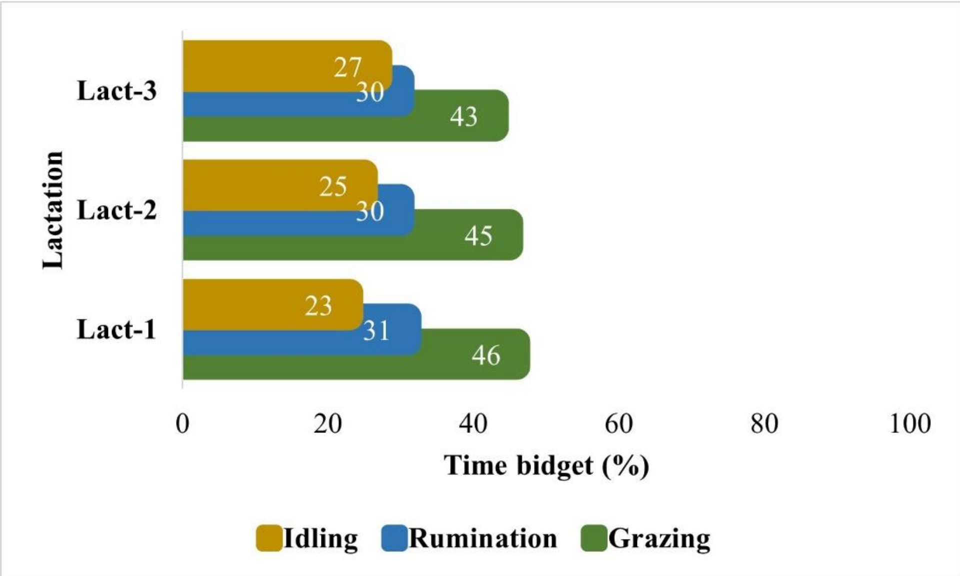

Figure 4. 8. 24-hour time budgets for grazing, ruminating, and idling behaviours in grazing dairy cows (*n* = *54*) in different lactations. (Lact-1, Lact-2, and Lact-3 represent cows in first, second, and third lactations respectively).

The 24-hour time budgets of grazing dairy cows for grazing, rumination and idling greatly varied during different seasons (Fig 4.9). Cows spent most of their time grazing and ruminating in all seasons, however grazing and ruminating time budgets declined from spring towards autumn. The idling time budget increased from spring to autumn, the idling time budget was highest in autumn and lowest in spring throughout the study period. The 24-hour time budgets for grazing, ruminating, and idling behaviours varied when cows consumed supplement feeds in addition to pasture (Fig 4.10). The grazing time budget was similar when cows grazed on pasture and chicory. However, the grazing time budget was relatively higher for turnips and the idling time budget was relatively higher when cows received silage. The rumination time budget did not much vary for different feeds. However, the Idling time budget was comparatively lower when cows received turnips and longer when they consumed silage.

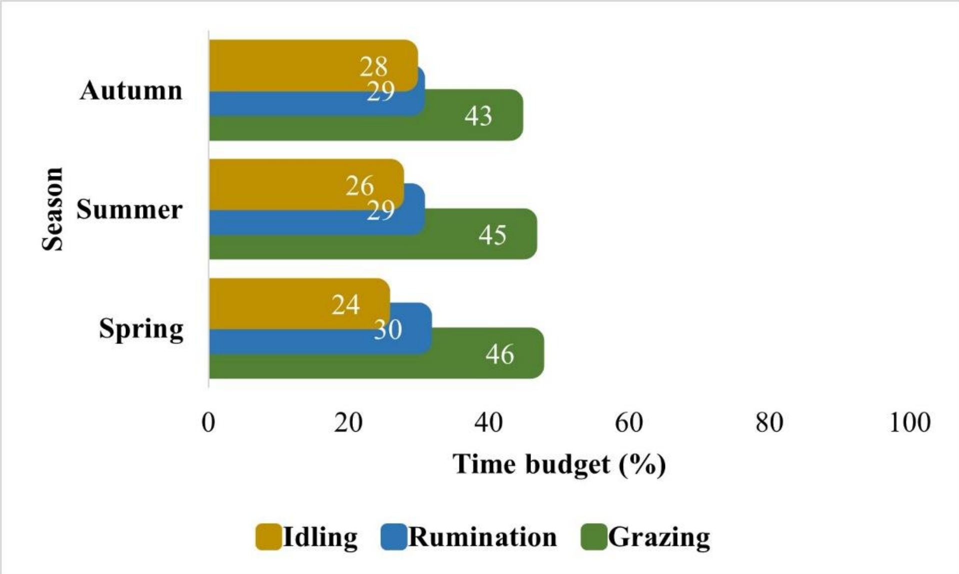

Figure 4. 9. 24-hour time budgets for grazing, ruminating, and idling behaviours in grazing dairy cows (n = 54) in different seasons (*n = 54*) over the experimental period.

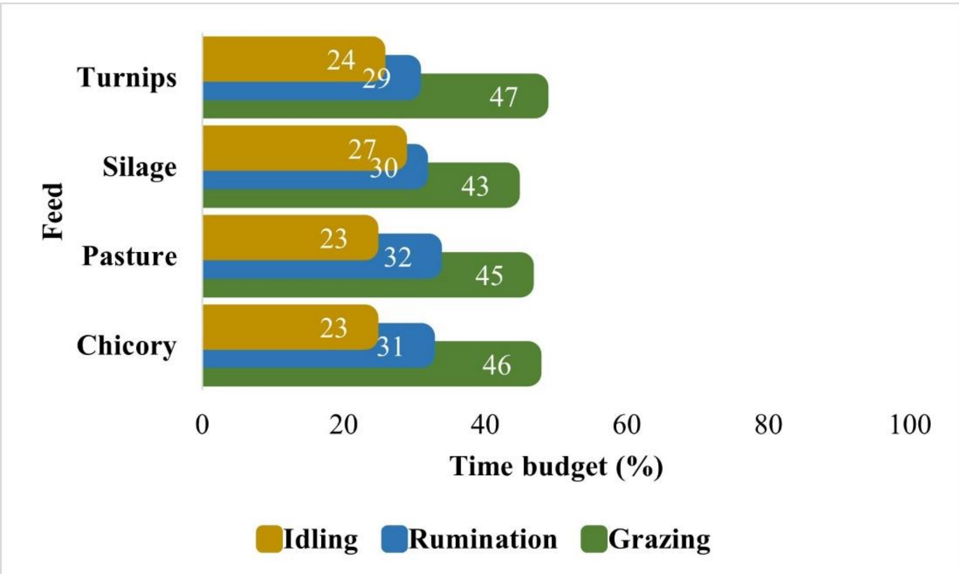

Figure 4. 10. 24-hour time budgets for grazing, ruminating, and idling behaviours in grazing dairy cows (n = 54) when fed with different supplementary feeds.

4.5. Discussions

This study examined the trends and variations in the temporal patterns of grazing and ruminating behaviours and their time budgets over 24 hours in grazing dairy cows. The study was unique as it used a large behaviour data set collected longitudinally over three consecutive lactation seasons. Grazing and rumination behaviours were measured using an automated collar device (AfiCollar). All cows of different breeds were kept as one herd in the same pasture; therefore, the herding instinct of cattle may have influenced the differences in behaviours among breeds. Similarly, season and supplementary feeding were linked with each other in a way that supplementary feed was confounded within the season. Therefore, the confounding may have partly influenced the effects of season and supplementary feeds.

Regardless of breed type, lactation number, season, and supplementary feed, pasture-grazing dairy cows spent most of the daylight hours grazing and most of the night hours ruminating; there was a short-lived grazing peak around midnight. The grazing intensity was highest in the morning after milking and, in the evening, before the start of the dark period. Previous studies have reported similar findings where most of the grazing activity occurred immediately following the milking and remained high throughout the day with a smaller peak around midnight (Hughes and Reid 1951; Orr et al. 200; Gibb et al. 2002). The higher intensity of grazing in the morning and evening in the current study was consistent with the previous reports. Dairy cows in New Zealand tend to exhibit a cyclic pattern of behaviour and the temporal distribution of grazing and rumination periods largely depends upon milking time and the time of sunrise and sunset (Brumby 1959; Krysl and Hess 1993). When the sun is close to the horizon during sunrise and sunset periods, the different ratio of shorter and longer wavelengths compared to that at mid-day has been suggested to have a stimulatory effect on appetite (Linnane et al. 2001; Gregorini et al. 2006;). In addition, the natural evacuation of digesta from the gut leads to the smallest ruminal pool size early in the morning and could potentially generate hunger explaining the high motivation to graze at sunrise. The dusk grazing event in the current study was slightly more intense than that of the dawn. Orr et al. (1997) and Gibb (1998) have already noted that the dusk grazing event is the longest and most intense. Cows spent 25% and 40% of their daily grazing time during dawn and dusk respectively with a higher bite rate and bite mass for the latter (Taweel et al. 2004). Moreover, the physical characteristics of pasture and environmental conditions may also contribute to this grazing pattern (Jochims et al. 2020). Moreover, the intense desire for grazing by pasture grazing cows in the evening is to maximize intake, when herbage is at its peak nutritive value, and to provide optimum feed for digestion during the night (Taweel et al. 2004). Thus, diurnal changes in herbage quality might also be playing a role in driving the intense, extended grazing event at dusk. Moreover, grazing activity predominantly occurs during the daytime because of thermal comfort and the photoperiod effect (Hogan et al. 1987; Gibb et al. 1998; Linnane et al. 2001). Phillips and Schofield (1989) found increased numbers of feeding bouts when cows were provided extra light during short days, and Rutter et al. (2002) noted a disruption in the grazing pattern of dairy cows during a total solar eclipse. Thus, the absence of presence of light significantly affects grazing activity in grazing dairy cows. Findings of a study by Champion et al. (1994) suggested that warmer environmental temperature is the reason most of the grazing activity occurs during the daytime, as the temperature is relatively colder at night. However, grazing events over the night are also essential for the cows to retain their metabolic heat production through rumen fermentation (Forbes 2007). The shorter, and less intense grazing event occurring at night contributes about 10-15% to the daily grazing time and approximately 10% to the daily herbage intake (Stobbs 1977; Krysl and Hess 1993). In addition, the distribution of rumination time by grazing dairy cows over 24 hours in the current study showed that most rumination occurred at night-time. However, a few short-lived rumination events during the daytime were also found. These findings were supported by previous studies (Newman et al. 1995; Prins 1996; Houtman and Dill 1998). Albright (1993) noted that cows performed most of the rumination activity at night while resting. Moreover, (Ternman et al. 2018; Ternman et al. 2019) reported that rumination activity in grazing dairy cows predominantly occurred at night but it was recorded both during the day and night. Rumination is a natural behaviour of cattle and the most important activity in the ruminants after grazing (Realini et al. 1999). Rumination tends to follow a daily pattern and cows spend a larger proportion of time ruminating at night and after intense feeding. Moreover, rumination is more likely to occur when cows are lying down, making it important to ensure that dairy cows have adequate, comfortable space.

Holstein-Friesian, Jersey, and KiwiCross breeds showed similar grazing and ruminating patterns over 24 hours. Miller Wood-Gush (1991) reported that when grazing, cattle often synchronize their behaviour in a way that animals as a group feed, ruminate, and rest at the same time. The synchronization of behaviour has also been observed in indoor-housed cows (Curtis and Houpt 1983). Although grazing patterns were similar between breeds, JE cows showed slightly longer grazing activity compared to HFR and KC cows. Studies suggest that the eating and rumination patterns of Jerseys are different from those of larger dairy breeds

(HFR) in a manner consistent with greater intake capacity and rate of digesta passage (Welch et al. 1970; Aikman et al. 2008). Also, grazing frequency and bite mass are influenced by the constraints due to the anatomy of the animal including mouth and body size (Rook 2000). Jersey cows have short stature with a small body and mouth size; therefore, JE cows' bite mass is smaller. Due to smaller bite mass JE cows take a longer time to fulfil their feed demands (Dürst et al. 1993; Rook 2000). The current study found a short-term rumination period after an intensive morning grazing peak in HFR cows; this has been previously reported (Sheahan et al. 2011). A possible explanation for this could be the release of neuroendocrine factors secreted in response to the presence of food in the digestive tract (Faverdin 1999), which is implicated as a satiety factor. The release of several neuroendocrine proteins associated with a hunger or satiety role coincides with the beginning or cessation of a meal (Roche et al. 2008).

The overall temporal patterns of grazing and rumination over 24 hours were similar between grazing dairy cows in different lactations. However, the continuous and more intense grazing activity during daylight hours by first lactation cows can be justified as they have a smaller body size, take smaller bites, and eat slower, hence graze longer compared to mature cows to address their nutritional demands. Furthermore, first-lactation cows are still in a growing phase and need additional energy to support growth in addition to energy for maintenance requirements (Grant and Albright 2001).

The current study found variations in the onset and cessation of grazing activity for varying day lengths during different seasons. Grazing activity occurred mainly during daylight during different times of the year, but the day length changed the grazing patterns. This might be a consequence of the interaction of photoperiod and environmental temperatures. Rhind et al. (2002) noted that seasonal variations in photoperiod affect grazing behaviour and resultant herbage intake. Compared to longer days in spring and summer, cows finished their grazing activity earlier during shorter days in autumn with relatively more intense grazing peaks. This can be justified as cows had the higher motivation to fill their rumen before the start of nightfall. Cows also adjusted the intensity of their grazing activity according to the day length; it was more vigorous during the short days in autumn than on long days in spring or summer. The backward shift of grazing peaks in autumn was also partly due to the absence of daylight savings that was observed during Spring and Summer. Sheahan et al. (2011) also reported that animals adapted their grazing habit according to day length and started early during short days so, they have more grass intake to address their satiety needs. An adaptation based on the variation in day length could be an increase in the duration of grazing events and a decrease in the number of meals during short days or an increase in the number of mealtimes at night (Gregorini et al. 2006); However, the duration of the grazing event remains constant regardless of the actual time of sunset (Rutter et al. 2002). Moreover, the different grazing peaks during different seasons demonstrate the ability of animals to adapt their ingestive activity in daylight, reserving most rumination and rest activities for periods of darkness to maintain their welfare. It is also due to adaptation to avoid predation and to cope with reduced eyesight during the night. Furthermore, the midnight grazing peak was slightly longer during spring. The temperature distribution over 24 hours is different, especially in different seasons. spring season is cooler with an average temperature of 19^{o}C compared to summer (25^{o}C) and autumn (21^{o}C). Forbes (2007) suggested that grazing events over the night are also necessary for the animals to maintain their metabolic heat production (by rumen fermentation) during cool seasons. Therefore, to maintain their welfare, animals distributed their grazing activity differently overnight during different seasons. In addition, rumination activity after the morning peak in spring was higher compared to that in summer. There is a natural drive for rumination after intense grazing, therefore, the cows were taking rest after the morning grazing peak and ruminating a little while resting. Also, after the first meal (morning grazing peak), animals decrease the time spent grazing, probably because of rumen filling (Demment et al. 1995). This was consistent with a recent study by Jochims et al. (2020) where animals showed higher rumination activity during the day in spring compared to that in summer.

The cows mainly grazed pasture over the lactation period, however, different supplements were fed in different seasons at different times of day to address the feed demands. Therefore, the time of day when the supplement is fed would most likely have the greatest impact on grazing behaviour rather than the supplement itself in the current study. Variations in the temporal distributions of grazing and rumination patterns were also linked with the different supplementary feeds consumed by animals during different seasons. The variations in grazing and rumination activities were high when animals consumed silage, supplements, and turnips along with pasture. Supplement and silage were usually fed to cows in summer as additional feeds to fulfil their energy demands as pasture quality was low at that time. Although the days were longer in summer, the cows finished their grazing activity earlier in the evening and started ruminating. It has already been reported that quantity, quality, and the timing of feeding supplements greatly influence the behaviour patterns of pasture-grazing cows (Heublein et al. 2017). Gregorini et al. (2006) suggested that the role of dawn grazing preference is certainly active in shaping the daily grazing pattern. As silage and supplements were fed to the cows at dawn after milking that might have supported the early fulfilment of nutritional requirements and motivated the early cessation of grazing activity. Cows received turnips during mid-day which resulted in the higher intensity of grazing in the afternoon as timing and delivery of fresh feed are highly stimulating factors for cows to perform grazing (DeVries and Von Keyserlingk 2005).

Time budgets for grazing, ruminating, and idling behaviour activities over 24 hours were quite similar between cows from different breed groups and cows in different lactations. The proportion of time spent chewing (grazing time plus rumination time) over 24 hours decreased and the amount of time spent idling increased in the cows with consecutive higher lactation numbers. Munksgaard et al. (2020) recently reported that cows in higher lactations spend more time lying compared to cows in early lactations. Another study by Sepúlveda-Varas et al. (2014) also reported the effect of parity with a higher proportion of time spent idling in higher-lactation cows compared to lower-lactation cows.

Seasonal variations in 24-hour time budgets in grazing dairy cows were prominent. The percentage of time spent grazing and ruminating altogether increased from spring (when animals calved, early lactation) reached the peak at the end of spring and started declining in summer. The grazing and ruminating time budget was further down and lowest in autumn when animals were ready to be dried off and received supplement feeds, whereas the proportion of time spent idling was just the opposite of chewing. Variations in behaviour time budgets were apparent in the autumn season when cows were about to be dried off, and during the time cows received supplements; this resulted in a higher amount of time spent idling. The amount of time spent idling was highest in autumn when most of the animals were about to be dried off and had less feed requirements, and the cows received supplement feeds as well. A study by Maselyne et al. (2017 reported a similar finding for lying time that is consistent with the results in this study. Both grazing and ruminating time budgets had higher values in spring and summer at the start and peak of the lactation period and reached a minimum level in autumn when animals were going to be dried off. DeVries et al. (2003) and Norring et al. (2014) have reported the same pattern in eating and ruminating time budgets in dairy cows. The time budgets for grazing and rumination did not vary when animals were fed on pasture, chicory, or silage, although, idling time was higher when animals consumed chicory, silage, and supplements. Compared with perennial ryegrass, as the dietary proportion of chicory increased, cows spent more time idling and less time ruminating, and increased ingestive mastications five and three times for chicory, respectively (Gregorini 2012). Variation in time budget was obvious when cows were fed on supplements. The lowest proportion of time spent chewing when cows received supplements was because their nutritional requirements were addressed by the energetic supplements so, they spent less time grazing and subsequently less time ruminating. Therefore, the proportion of time spent idling was highest when cows received supplements. Similar findings have already been reported (Sheahan et al. 2011; Hills et al. 2015).

4.6. Conclusion

Grazing dairy cows spend most of the daytime grazing to maximize energy intake and most of the nighttime ruminating the grazed herbage. Grazing activity appears to be high at dawn and dusk with the latter being more intense. Grazing and ruminating patterns are not different between different breed groups although, Jersey cows spend a relatively long time grazing and Holstein-Friesian cows spend a longer time ruminating. Cows in the first lactation graze continuously compared with those in higher lactations. Time of the day and seasonal variations suggested that grazing cows can adjust their behaviour patterns according to day lengths. The diurnal changes in herbage quality might also be playing a role in driving the behaviour patterns that need further exploration. Cows spend less time grazing and ultimately less time ruminating when pasture has been supplemented with additional feeds. Most of the time over 24 hours are spent grazing followed by ruminating and idling in dairy cows in a pasture-based system. Time budgets for the behaviour activities over 24 hours do not vary much between breed or lactation groups. Variations in time budgets were observed during different seasons and for different supplementary feeds. The analysis of daily behaviour patterns can help support predicting and addressing the behavioural needs of different animals in different climatic conditions by moulding the management practices according to the daily behavioural needs. Thus, using the temporal distribution in management strategies to drive the 24-hour supply of nutrients can be a potential tool in grazing management.

Chapter 5

Factors affecting grazing and rumination behaviours of dairy cows in a pasture-based system in New Zealand

5.1. Abstract

This study investigated the variation in daily time spent grazing and rumination in spring-calved grazing dairy cows (*n = 162*) of three breeds, Holstein-Friesian (HFR), Jersey (JE), and Holstein-Friesian/Jersey crossbreed, KiwiCross (KC) with different breeding worth index, and in different years of lactation (1st, 2nd, 3rd, 4th). The cows were managed through a rotational grazing system and milked once a day at 05:00 a.m. The cows grazed mainly pasture and received supplementary feeds depending on the season. Automated AfiCollar device continuously monitored and recorded grazing time and rumination time of the individual cows throughout the lactation period for three study years (Year-1, Year-2, Year-3) with 54 cows per year. A general linear mixed model fitted with breed × lactation year with days in milk (DIM), breeding worth (BW) index value, individual cow, season, and feed, and their interactions was performed in SAS. Variance partitioning was used to quantify the effect size of study factors and their interactions. Individual cows, DIM, and BW (except Year-3) had effects on grazing and rumination times throughout the study years. Grazing time and rumination time were different for different seasons due to varying supplementary feeds. Grazing time varied among breeds in Year-2 and Year-3, and among lactation years only in Year-1. Although rumination time differed among breeds in Year-3, it remained the same within different lactation years. Grazing time and rumination time had a negative relationship with each other, and their regression lines varied for different seasons. The total variance explained by the model in grazing time was 36–39%, mainly contributed by the individual cow (12–20%), season (5–12%), supplementary feed (2–6%), breed (1–5%), and lactation year (1–6%). The total variance explained in rumination was 40–41%, mainly contributed by the individual cow (16–24%), season (2–17%), supplementary feed (1–2%), breed (2–8%), and lactation year (~1%). These findings could contribute to improving the measures for feed resource management during different seasons over the lactation period for a mixed herd comprising JE, HFR and KC breeds in different years of lactation.

Keywords: Automatic behaviour monitoring, Grazing behaviour, Rumination behaviour, Pasture-based system, Individual animal data

5.2. Introduction

Grazing and rumination are predominant behaviours and provide key knowledge about the satiety needs, and how those demands are addressed, hence playing a pivotal role in the nutrition of grazing ruminants. Grazing regulates intake from the grazed herbage and rumination determines the digestive efficiency, health, and well-being of the animal (Phillips and Hecheimi 1989; Dillon 2007). Grazing dairy cows allocate 90–95% of their daily time to grazing, ruminating, and resting (Kilgour 2012). They normally exhibit four major periods of grazing occupying a total of seven to eight hours and a similar period for rumination; they spend the rest of the day resting or idling (Brumby 1959). The times spent grazing and ruminating are the main indicators for pasture management and animal welfare (Gonçalves et al. 2009). In addition, behavioural decisions made by animals result in variations in intake rate (Newman et al. 1994) and affect animals' milk production; as the amount of nutrients consumed drives milk production (Veerkamp et al. 2002; Waghorn and Clark 2004). Previous studies have also suggested possible associations between the grazing time of a cow with its milk production level (Illius 1989; Funston et al. 1991). Thus, the knowledge obtained through studying grazing and rumination behaviours can be applied to effectively address animals' demands for pasture or additional feeds and to improve animal welfare and productivity in a grazing-based system (Carvalho 2013).

Time spent grazing is dependent on multiple factors including nutritional requirements, feed availability, feed quality (such as NDF, particle size, flavour, smell), feed type (forage vs silage vs concentrate), temporal (time of the year or day), animal (lactation stage, size, appetite), social (co-grazing vs competition), and climatic (temperature, rainfall, wind) effects (Arnold 1985; Harb and Campling 1985; Doyle et al. 1986; Sowell et al. 1999; Ginane et al. 2011; Nørgaard et al. 2011; Schirmann et al. 2012; Heublein et al. 2017; Beauchemin 2018). Positive sensory stimulations including taste, smell, and palatability trigger grazing motivation that mostly results in higher intake and subsequently higher milk yield (Albright 1993; Llonch et al. 2018). The animal's motivation to eat is further stimulated by the sight and sound of other nearby eating animals (Ginane et al. 2015). Thus, not only appetite or satiety but also hedonic and motivational factors linked with food also affect grazing behaviour (Ginane et al. 2015). In addition, inherent differences in grazing and rumination behaviours exist among cows differing in intake capacity and production efficiency (Bao et al. 1992); high-producing cows generally require a longer period of grazing to fulfil their nutritional requirements. Likewise, varying milk production levels of dairy cows due to different lactation years and different stages (early, mid, late) within a lactation influence feed demand, and are expected to have effects on grazing and rumination times (Huzzey et al. 2006; Vijayakumar et al. 2017). Young cows in the first year of lactation have different feed demands and hence different behaviour than mature cows in higher lactations. Variations in the quality of pasture and the type of pasture consumed during various seasons are additional factors impacting herbage intake (Lambert and Litherland 2000; Sheahan et al. 2011; Romanzin et al. 2018), and therefore expected to influence grazing and rumination times (O'Driscoll et al. 2010). Grazing dairy cows are fed supplements to address their energy and protein demands when quality pasture is less available which is also believed to be modulating their grazing time and rumination time (Al-Marashdeh et al. 2018).

New Zealand dairy herds are primarily populated with three breeds, Holstein-Friesian (HFR), Jersey (JE), and KiwiCross (KC, Crossbreed of Holstein-Friesian/Jersey). Cows rely mainly on grazing pasture as a major dietary component and receive additional supplementary feeds when the availability of quality pasture is compromised due to dry weather conditions. In a grazing system, animal behaviour is more unpredictable as animals must adapt to constantly changing sward and weather conditions (Kamphuis et al. 2012). Therefore, behavioural variations are potentially difficult to identify in grazing animals. Moreover, in a grazing system, the average behaviour of the whole herd is expressed as an indicator of the external and/or internal drivers of each animal in the herd; this is because measuring individual animals' behaviour has been a challenge in the past, whereas individual animals vary in expressing distinct and consistent behaviour (Meagher et al. 2017). Recent advances in sensor-based Precision Livestock Farming (PLF) tools offer opportunities to automatically monitor and record grazing and rumination behaviours of individual animals on a real-time basis (Berckmans 2014; Hostiou et al. 2014; Andriamandroso et al. 2016). Over the last decade, growing appeals for PLF devices have increased the number of studies describing the eating and ruminating behaviours of dairy cows (Henriksen et al. 2019; Munksgaard et al. 2020). However, studies focusing on New Zealand cows are limited in the literature to date. For example, a previous study explored differences in grazing and rumination behaviours of individual dairy cow breeds (Prendiville et al. 2010), but their study did not account for other factors including lactation year/parity of cow, season, and supplementary feeds consumed by animals.

Grant and Albright (2000) concluded that management-related factors including grouping strategy, feeding system, quality of the feed consumed, as well as social hierarchy and competition for feed and water, all influenced the feeding behaviour of indoor cattle. However, these aspects remain unexplored in New Zealand's grazing-based dairy system. For instance, how do cows differ in their grazing and ruminating behaviours when kept as a single herd in which animals of different breeds in different lactation years graze together? Do animals with varying breeding worth indexes vary in their grazing and ruminating behaviours? How do different days in milk over the lactation period affect grazing and rumination behaviours? How do seasonal variations and feeding supplements influence behaviours? What are the most substantial sources of variance in grazing and rumination behaviours? Furthermore, grazing time and the subsequent time required for rumination are partially interdependent and are limited or prolonged by each other. Thus, a longer grazing time may result in higher intake and, hence may require a longer rumination time to process the ingested feed. However, a negative association might exist at some levels, as cows cannot graze and ruminate at the same time. In that scenario, is grazing time driving rumination time even if the cows are consuming additional supplementary feeds? A comprehensive understanding of these mechanistic connections is essential in a pasture-based system to develop strategies to optimize dairy cow production through better management of pasture and feed availability (Demment et al. 1995; Meisser et al. 2014). Understanding variation in the behaviours among cows of different breeds and lactation years, and consuming different supplementary feeds in different seasons should contribute to creating tailored management that better meets the needs of different animals on the farm. This information could also help select better and more profitable replacements.

The quantity of feed required to reach the satiety needs varies greatly and depends on age (or lactation year), state of production (days in milk) and breed (Llonch et al., 2018). Thus, we hypothesized that the times spent grazing and ruminating should vary among dairy cows of different breeds, breeding worth index, and lactation year due to varying levels of production (days in milk) and feed demands. We further hypothesized that grazing dairy cows change their grazing and rumination times in varying conditions related to different seasons that affect pasture quality (Lambert and Litherland 2000), and when animals are fed supplements (Romanzin et al. 2018). As grazing partially drives rumination, we also, assumed that grazing time and rumination time are related, and the strength of this relationship varies depending on the breed and lactation year of the cow, and seasons. Therefore, the objectives of this study were to explore the variation in grazing and rumination times over the lactation period in grazing dairy cows, considering the effects of breed, lactation year, and their interaction while accounting for breeding worth index, days in milk, and supplementary feeds. This study also evaluated the relationship between grazing time and rumination time, and if the strength of the relationship varies as affected by breed, lactation year, and season/supplementary feedings. This study further evaluated the magnitude of variance in grazing and rumination times explained by different study factors and their interactions.

5.3. Materials and methods

5.3.1. Grazing conditions

The study was performed at Dairy Unit 1, Massey University, Palmerston North, New Zealand (Latitude: −41.3009, Longitude: 174.7720). Dairy unit 1 is a pasture-based, once-a-day milking dairy farm operated through a rotational grazing scheme with a spring calving system. The farm area consists of 142.7 hectares and is divided into 63 paddocks. The local climate is of a temperate type with four seasons classified as spring (September to November), summer (December to February), autumn (March to May), and winter (June to August). The annual average temperature in the area over the study period was ~16 °C (8–24 °C) with an annual rainfall of ~960 mm (NIWA 2022).

5.3.2. Grazing animals

Spring-calved, lactating and pasture-grazing dairy cows (*n = 162*) were used in the current study. Study cows were a subset of the whole herd (*n = ~260*) at the farm, they grazed together along with the other cows and altogether managed as one herd. The study period consisted of three years, a subgroup of 54 cows was randomly selected each year (*54 × 3 = 162*). The cows were not completely independent in the three study years because some of them were used more than once by random resampling within the available cows. The selection of cows was based on their breed, lactation year, and breeding worth (BW) index value. The cows selected each study year were of three breeds, Holstein-Friesian (HFR), Jersey (JE), and Holstein-Friesian/Jersey Crossbreed (KiwiCross) with 18 cows of each breed (*18 × 3 = 54*). Those 18 cows in each breed category were of 3 different lactation years (with 6 cows of each lactation year, *6 × 3 = 18*). The cows were either in 1^{st}, 2^{nd}, 3^{rd}, or 4^{th} lactation years. The 6 cows within each lactation year had different breeding worth index values (103 < BW > 151). Breeding Worth (BW) is the index used to rank cows and bulls on their expected ability to breed profitable, efficient replacements. BW is calculated by combining breeding values (An estimate of a cow or bull's genetic merit for a trait) with the appropriate economic values (An estimate of the future dollar value of a unit change in each trait) for each trait and adding them all together. The cows were altogether kept in the same grazing paddocks all the time throughout their lactation period (~270 days) except when brought to the milking shed at 05:00 a.m. Cows were rotated from one paddock to another based on the natural grass production and growth cycle.

5.3.3. Feeding of animals

The feeding regimes of the cows over three study years are shown in Table 5.1. The feed requirements for the pasture grazing cows were established by the farm manager based on the feed requirement table by DairyNZ (2022). The cows mainly grazed pasture of perennial ryegrass (*Lolium perenne L.*) mixed with red clover (*Trifolium pretense*) and white clover (Trifolium repens). Besides pasture, cows grazed chicory (*Cichorium intybus*) as well in the spring season. To meet energy requirements and to cope with the seasonal changes in pasture quality and production (Machado et al. 2005), cows were additionally fed with supplements including maize (*Zea mays*) silage, corn gluten (*Zea mays L.*), tapioca (*Manihot esculenta*), turnips (*Brassica rapa subsp. rapa*), and distillers' grains during summer and autumn seasons. Replacing good quality pasture with an alternative feed source or 'balancing pasture' is not considered advantageous; therefore, supplements are only used to provide energy when there is insufficient pasture available, especially during summer and autumn. Supplementary feeds are used when quality pasture is less available, to fill the feed deficits and to support the cows to maintain energy intake and production (DairyNZ, 2022). Moreover, the purpose of providing supplements to milking cows in autumn is also to achieve calving body condition score (BCS) targets, if the feeds are not supplemented, cows are more prone to lose due to quality pasture being insufficient at that time of the year. Distillers' Grains (DG), corn gluten (CG), and tapioca were usually fed in the feeding area near the milking shed after milking, whereases, maize silage (MS), grass silage (GS), and turnips were fed around midday in the paddock. CG and DG were fed in the form of pellets, tapioca in the form of ground meal, and turnips bulbs, and leaves were fed in situ. The supplementary feeds were provided in equal amounts to all cows and were equally accessible to each cow. However, the actual intakes of either the grass or supplements were not measured. The cows had ad libitum access to drinking water in each paddock.

Table 5. 1. Seasonal feeding regimes for grazing dairy cows during the study period.

Season	Year-1	Year-2	Year-3
Spring	Pasture, Chicory	Pasture, Chicory	Pasture, Chicory
Summer	Pasture, Turnips, GS	Pasture, Turnips, DG, Tapioca	Pasture, Turnips, GS
Autumn	Pasture, GS	Pasture, MS, DG, Tapioca	Pasture, MS, DG, Tapioca, CG

(Year-1, Year-2, and Year-3 represent the lactation period between 2018–2019, 2019–2020, and 2020–2021, respectively. GS = Grass silage, DG = Distillers' grain, MS = Maize silage, CG = Corn gluten).

5.3.4. Behaviour recording

An automated device, AfiCollar (Afimilk Ltd. Kibbutz Afikim, Israel, 1514800) was used to continuously monitor and record the time spent grazing and ruminating by the cows. The collar device was validated for measuring grazing and rumination behaviours in grazing dairy cows (Iqbal et al. 2021). The AfiCollar device monitored and recorded the minute-by-minute behaviour for consecutive 24 hours throughout the lactation period for three study years. The collar device had a triaxial (x, y, z) accelerometer-based sensor that was fitted within a box attached to the collar and positioned on the right side of the animal's neck. The sensor could identify and classify specific behaviour categories such as grazing, and rumination based on the patterns of the animal's head movements. The data collected by the sensor were analysed by the collar device using built-in generic algorithms and produced as min/h behaviour counts (grazing time and rumination time). The data collected by the AfiCollar device were recorded and subsequently transmitted wirelessly to a base station through Wi-Fi while cows were in the range of ~500 meters. The data for the individual cows were manually downloaded in a Microsoft Excel spreadsheet (Version 2016, Microsoft corporation, Redmond, Washington, USA. Retrieved from https://office.microsoft.com/excel) from the computer attached to the base station, and separately sorted.

5.3.5. Data collection and preparation

The grazing time and rumination time of the individual cows were recorded over the lactation period for three consecutive years (2018 to 2021). The lactation period of the cows usually spanned between August to April of the next year (~270 days), following the typical New Zealand spring calving system. The lactation period covered spring, summer, and autumn seasons, while cows were at the dry stage in winter. Data were collected only when cows were lactating, thus no data were collected in winter. Data collection for each cow in each study year started once the cow calved and ended when it was dried off. The lactation period for 2018–2019 was named Year-1, the lactation period for 2019–2020 was named Year-2, and the lactation period for 2020–2021 was named Year-3.

The frequencies of behaviour activities summarized by the AfiCollar device were minutes within an hour (min/h) utilized for grazing and rumination. The minutes per 24 hours (min/day) spent grazing and rumination were manually calculated using the min/h data. Daily grazing time (min/day) and rumination time (min/day) of the individual cows along with their progressing days in milk (DIM, from the day of calving until the day of drying off) and BW index value were sorted separately for each year over the study period. The data collected were further classified into different breeds, lactation years, and seasons.

5.3.6. Data analysis

5.3.6.1. Variation in grazing and rumination behaviours

A general linear mixed model fitted in a factorial design with breed × lactation year and their interaction while accounting for days in milk, breeding worth index, individual cow, season, feeding regime within the season, and their interactions was performed in SAS version 9.4 (SAS Institute Inc. Cary, NC) to test the differences in grazing and rumination times. Grazing time and rumination time were the main dependent variables. Breed, lactation year, and their interaction were the main fixed effects, while individual cows nested within breed and lactation year were included as a random effect in the model. As lactation length ranged from August to April next year and covered three seasons (spring, summer, and autumn), the season was included in the model as a fixed factor to test its effect as well as its interaction with the other fixed effect on grazing and rumination times. Cows received different supplementary feeds during different seasons in each study year, so, the feeding regime nested within the season was added as a fixed effect in the model. The calving date was different for each cow; therefore, DIM was added as a continuous covariate in the model. The BW index value, one of the ranking variables for the study cows was also added as a covariate in the model. The interactions between the covariates (DIM, BW) and the fixed effects including breed, lactation year, and season were also included in the model to test if the relationship between covariates and grazing/rumination varied between the fixed effects.

To further determine the relative effect size or strength of various study factors and their interactions, variance partitioning was used considering the type I sum of squares values of study factors and their interactions. The significance and effect size of the study factors were assessed separately for each study year because the study years differed in supplementary feeds as well as the lactation year of the study cows. The model used in this study is given below:

$$Y_{ijklmn} = \mu + A_i + B_j + A_i \times B_j + C_k (A_i \times B_j) + D_l + E_m (D_l) + A_i \times D_l + B_j \times D_l + A_i \times B_j \times D_l + X_i + Y_j + X_i \times A_i + Y_j \times A_i + X_i \times B_j + Y_j \times B_j + X_i \times A_i \times B_j + Y_j \times A_i \times B_j + X_i \times D_l + Y_j \times D_l$$

Where: Y_{ijklmn} is the kth observation in the i_{th} treatment group A and j_{th} treatment group B and so on; μ is a general mean; A_i, B_j represent the fixed effects of breed and lactation year; A_i x B_j represent interaction between breed and lactation year; C_k (A_i x B_j) is random effect of cow within breed and lactation year; D_l is fixed effect of season; E_m (D_l) is supplementary feed within season; A_i x D_l is interaction between breed and season; B_j x D_l is interaction between lactation year and season; A_i x B_j x D_l is interaction between breed, lactation year and season; X_i + Y_j are covariates as BW and DIM; Xi x Ai is interaction between BW and breed; Y_j x A_i is interaction between DIM and breed; X_i x B_j is interaction between BW and lactation year; Y_j x B_j is interaction between DIM and lactation year; X_i x A_i x B_j is interaction between BW, breed and lactation year; Y_j x A_i x B_j is interaction between DIM, breed and lactation year; X_i x D_l is interaction between BW and season; Y_j x D_l is interaction between DIM and season.

5.3.6.2.Relationship between grazing and rumination

The relationship between grazing time and rumination time and the possible differences in the regression lines between grazing and rumination after accounting for different fixed effects were investigated with the same model. Grazing time was added as a covariate and rumination time as a dependent variable in the model. The interactions of grazing time with the breed, lactation year, and season were included in the model to test their significance for rumination time. Moreover, variance partitioning was used considering the type I sum of squares values to determine the effect size of the grazing time and its interactions with the breed, lactation year, and season on rumination time.

5.4.Results

5.4.1. Variation in grazing behaviour

Grazing time differed among the individual cows within breed and lactation year throughout the study period (Table 5.1). Grazing time varied due to seasons and the feeding regimes within different seasons throughout the study period. The daily time spent grazing was longest in spring, it was reduced in summer and reached to minimum in autumn. Grazing time was affected by the breeding worth (BW) index and days in milk (DIM) of the cows (Fig 5.1, Fig

5.2). Grazing time varied among different breeds in Year-2 and Year-3, although, the breed effect was not significant in Year-1 of the study period. Jersey (JE) cows grazed longest followed by Holstein-Friesian (HFR), and KiwiCross (KC) among the three breeds. Grazing time varied among cows depending on their lactation year in Year-1 but not in Year-2 and Year-3 of the study period with a decrease in the cows in higher lactation years. Breed and lactation year showed no statistical interaction for grazing time. Breed (except Year-3) and lactation year (all study years) had interactions with the season (Fig 5.3, Fig 5.4), and the trend of a gradual decrease in grazing time from spring to autumn was evident for each breed and each lactation year. Jersey cows among the breeds and first lactation cows remained the longest grazers in spring, summer, and autumn. The effect of BW depended on the breed in Year-1 and Year-2, while BW and lactation year never jointly influenced grazing time. Days in milk had statistical interaction with lactation year in Year-1 and Year-2, while DIM showed no interaction with breed.

The analysis further showed that the total amount of variance in grazing time explained by the model for Year-1, Year-2, and Year-3 of the study period was 35.6%, 39.4%, and 39.3% respectively (Table 5.2). The effects of individual cows (Year-1 = 16.77%, Year-2 = 20.6%, Year-3 = 12.36%), season (Year-1 = 5.60%, Year-2 = 8.59%, Year-3 = 12.18%), and feed (Year-1 = 2.50%, Year-2 = 3.67%, Year-3 = 6.30%) consistently remained the factors explaining most of the variance in grazing time. Breed accounted for 1.71%, 3.80%, and 5.76% of the variance in grazing time in Year-1, Year-2, and Year-3, respectively. Lactation year of the cows in Year-1 explained 6.3% of the variance in grazing time and 1.75% and 1.23% in Year-2 and Year-3 respectively. The interaction of breed and lactation year did not explain much of the variance (1.5%) and both DIM and BW described <1% of the variance in grazing time. The statistical interactions of different factors included in the study design explained the least amount of variance (<1%) in grazing time.

Table 5. 2. Least square means (LSMean) and standard errors of means (SEM) of grazing time (min/day) for the effects of breed, lactation year and season, and P values and the variance (%) explained by breed, lactation year, cow within breed and lactation year, season, feed within the season, breeding worth (BW) index, days in milk (DIM), and their interactions in three consecutive years of the study period using a mixed effects model with the cow (*n = 54*) as a random factor, and BW and DIMas continuous covariates.

Grazing time (min/day)						
Effect	**Year-1**		**Year-2**		**Year-3**	
Breed	**LSMean**	**SEM**	**LSMean**	**SEM**	**LSMean**	**SEM**
HFR	667	4.1	634	3.3	632	6.3
JE	669	3.7	658	4.1	668	6.4
KC	658	1.8	634	1.8	629	6.4
Lactation year						
1st	692	3.6	-	-	-	-
2nd	657	3.0	663	2.9	652	7.9
3rd	645	3.4	637	5.8	635	8.5
4th	-	-	627	2.5	628	4.7
Season						
Spring	681	2.0	675	4.9	651	6.5
Summer	673	2.9	647	5.2	666	6.3
Autumn	639	3.8	604	5.0	598	6.8
P Value and explained variance (%)						
Breed	0.1298	1.71	0.037	3.80	0.0002	5.76
lactation	0.0012	6.34	0.2034	1.75	0.1135	1.23
Cow (Breed*Lactation)	<.0001	16.77	<.0001	20.06	<.0001	12.36
Season	<.0001	5.60	<.0001	8.59	<.0001	12.18
Feed (Season)	<.0001	2.50	<.0001	3.67	<.0001	6.30
Breed*Lactation	0.4443	1.52	0.9933	0.12	0.9243	0.24
Breed*Season	0.0002	0.13	<.0001	0.22	0.0925	0.04
Lactation*Season	<.0001	0.24	0.0243	0.07	<.0001	0.13
Breed*Lactation*Season	0.0054	0.13	0.3072	0.06	<.0001	0.17
Breeding worth (BW)	0.0346	0.03	<.0001	0.18	0.0157	0.03
Days in milk (DIM)	0.0215	0.03	<.0001	0.24	<.0001	0.47
BW*Breed	0.0009	0.08	0.0009	0.09	0.4885	0.01
DIM*Breed	0.1658	0.02	0.9926	0.00	0.5631	0.01
BW*Lactation	0.6196	0.01	0.1694	0.02	0.1402	0.02
DIM*Lactation	0.0002	0.10	0.0099	0.06	0.2067	0.02
BW*Breed*Lactation	<.0001	0.20	0.0107	0.09	0.0301	0.05
DIM*Breed*Lactation	0.0319	0.06	<.0001	0.19	0.0874	0.04
BW*Season	0.0003	0.09	0.0791	0.03	0.0087	0.05
DIM*Season	0.0025	0.07	<.0001	0.16	<.0001	0.20
Total variance (%)	**-**	**35.60**	**-**	**39.42**	**-**	**39.28**

(Note: LSMeans that do not share a common letter are significantly different for the significance level set at the P-value of 0.05. HFR= Holstein-Friesian, JE= Jersey, KC = KiwiCross. P represents the P-value for the level of significance and Var. represents the variance in grazing time explained by the individual effects and their interactions included in the model. * Indicates an interaction between study factors).

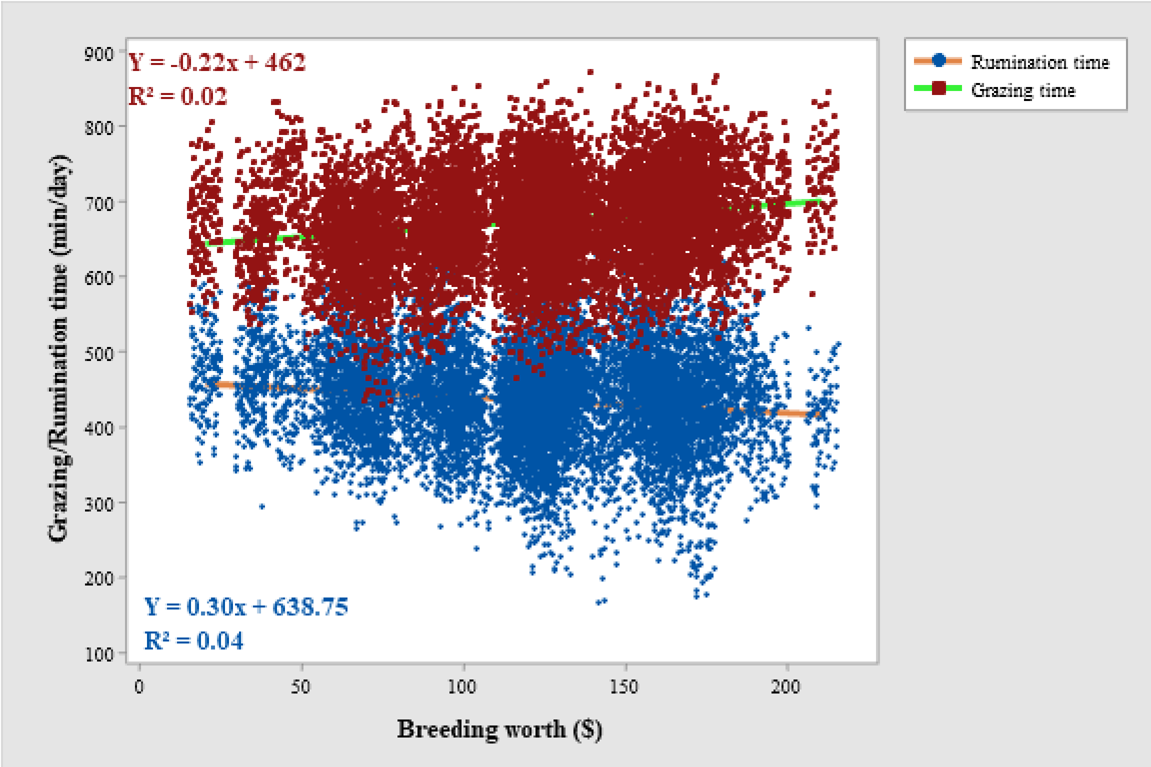

Figure 5. 1. Scatterplot of grazing time (min/day) and rumination time (min/day) with breeding worth index value ($) of grazing dairy cows across the lactation period for Year-1 of the study period.

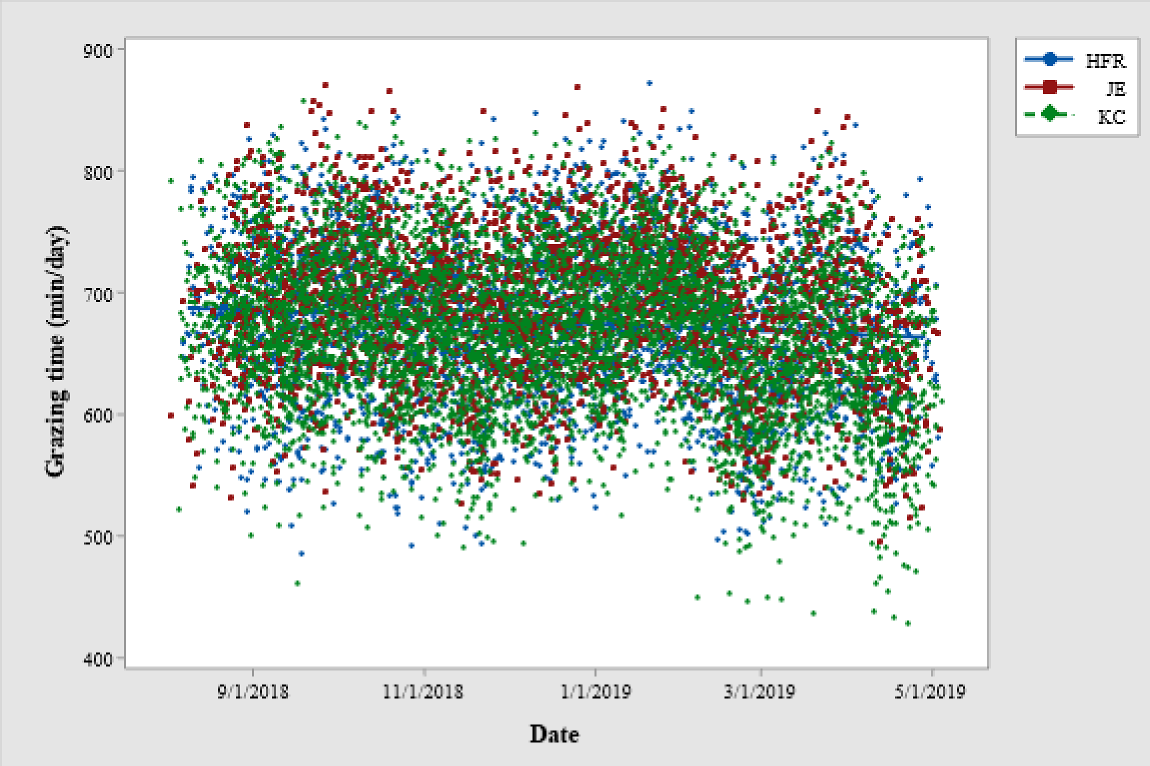

Figure 5. 2. Scatterplot between date and grazing time (min/day) for Holstein-Friesian (HFR), Jersey (JE) and KiwiCross (KC) cows across the lactation period for Year-1 of the study period. (The scatterplot is based on the raw values of grazing time).

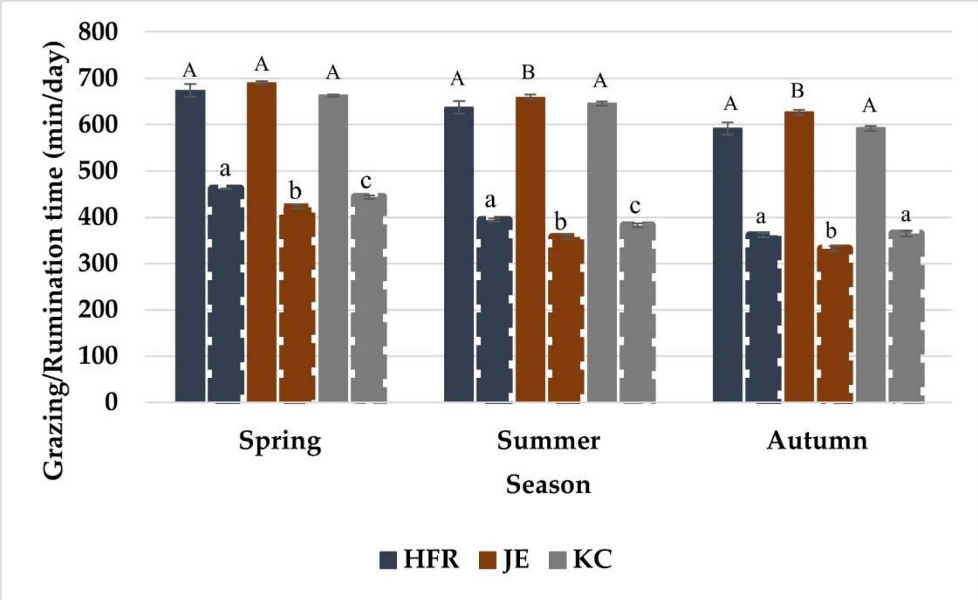

Figure 5. 3. Grazing time (min/day) and rumination time (min/day) of Holstein-Friesian (HFR), Jersey (JE) and KiwiCross (KC) cows across three seasons over the lactation period for Year-1 of the study period. Compact bars show grazing time and dotted bars show rumination time. Error bars represent standard error. Letters on each bar show significant differences between bars, capital letters for grazing time and small letters for rumination time.

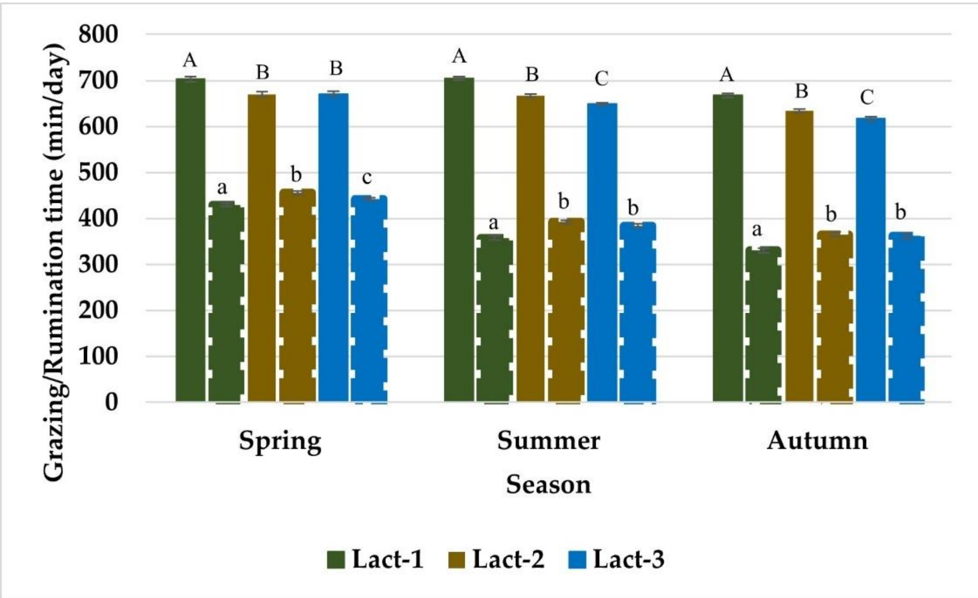

Figure 5. 4. Grazing time (min/day) and rumination time (min/day) of dairy cows in lactation year 1 (lact-1), lactation year 2 (lact-2) and lactation year 3 (lact-3) across three seasons over the lactation period for Year-1. Compact bars show grazing time and dotted bars show rumination time. Error bars represent standard error. Letters on each bar show significant differences between bars, capital letters for grazing time and small letters for rumination time.

5.4.2. Variation in rumination behaviour

Rumination time was affected by the individual cows within breed and lactation year in all study years (Table 5.2). Rumination time was different for different seasons in all study years which was related to varying feeding regimes within each season. Rumination time was affected by DIM in all study years while the genetic merit (BW) effect was only observed in Year-2 and Year-3 (Fig 5.1, Fig 5.5). Rumination time did not vary among breeds except for Year-3. Rumination time remained shortest for JE cows and longest for HFR cows throughout the study years. Rumination time did not differ in cows in different lactation years in all study years. Breed and lactation year showed no statistical interaction for rumination time while both breed (except Year-3) and lactation year (all study years) showed interactions with the season (Fig 5.2, Fig 5.3). The overall trend of a gradual decrease in rumination time from spring to autumn was evident for each breed and lactation year. Holstein-Friesians remained the longest ruminator among the breeds, and first lactation cows remained the shortest ruminators among lactation years in spring, summer, and autumn in all study years. Breeding worth showed interaction with the breed in Year-1 and Year-3 while interaction with lactation year in all study years. Days in milk showed an interaction with breed and lactation year in all study years.

The analysis further showed that the study factors and their interactions tested in the model explained 40.02%, 43.01%, and 40.0% of the total variance in rumination time in Year-1, Year-2, and Year-3 respectively (Table 5.2). Individual cow (Year-1 = 24.03%, Year-2 = 14.54%, Year-3 = 16.07%), season (Year-1 = 2.31%, Year-2 = 16.98%, Year-3 = 7.41%), and feeding regime within the season (Year-1 = 1.70%, Year-2 = 2.11%, Year-3 = 1.64%) explained the maximum amount of variance in rumination time. DIM described 0.12%, 0.05%, and 0.36% while BW accounted for 0.71%, 0.79%, and 0.81% of the variance in rumination time in Year-1, Year-2, and Year-3, respectively. Breed effect accounted for 2.19%, 1.78%, and 8.54% while lactation year accounted for 1.77%, 0.05%, and 0.98% of the variance in rumination time in Year-1, Year-2, and Year-3, respectively. Breed and lactation year interaction explained only up to 0.2% variance. The statistical interactions of different factors included in the study design explained the least amount of variance (<1%) in rumination time.

Table 5.3. Least square means (LSMeans) and standard errors of means (SEM) of rumination time (min/day) for the effects of breed, lactation year and season, and P values and the variance (%) explained by breed, lactation year, cow within the breed and lactation year, season, feed within the season, breeding worth (BW) index, days in milk (DIM), and their interactions in three consecutive years of the stiudy period using a mixed effects model with the cow (*n = 54*) as a random factor, and BW and DIM as continuous covariates.

Rumination time (min/day)						
Effect	**Year-1**		**Year-2**		**Year-3**	
Breed	**LSMean**	**SEM**	**LSMean**	**SEM**	**LSMean**	**SEM**
HFR	405	4.0	373	5.6	441	5.6
JE	370	3.6	334	4.8	372	2.9
KC	397	1.7	367	2.2	377	4.9
Lactation year						
1st	372	3.5	-	-	-	-
2nd	404	2.9	371	3.4	381	8.8
3rd	396	3.3	390	6.8	375	9.5
4th	-	-	313	4.7	434	6.3
Season						
Spring	442	2.0	417	5.7	469	7.2
Summer	378	2.9	385	6.1	388	7.0
Autumn	353	3.7	272	5.9	333	7.6
P Value and explained variance (%)						
Breed	0.1605	2.19	0.1116	1.78	<.0001	8.54
Lactation	0.2256	1.77	0.936	0.05	0.258	0.98
Cow (Breed*Lactation)	<.0001	24.03	<.0001	14.54	<.0001	16.07
Season	<.0001	2.31	<.0001	16.98	<.0001	7.41
Feed (Season)	<.0001	1.7	<.0001	2.11	<.0001	1.64
Breed*Lactation	0.8699	0.21	0.725	0.02	0.6768	0.05
Breed*Season	0.0002	0.23	0.0839	0.08	<.0001	0.62
Lactation*Season	<.0001	0.23	0.422	2.57	0.0413	0.01
Breed*Lactation*Season	<.0001	3.5	0.1377	1.49	<.0001	2.54
Breeding worth (BW)	<.0001	0.71	<.0001	0.79	0.0966	0.81
Das in milk (DIM)	<.0001	0.12	<.0001	0.05	<.0001	0.36
BW*Breed	0.0021	0.07	0.305	0.02	0.0209	0.04
DIM*Breed	0.0028	0.07	<.0001	0.27	<.0001	0.1
BW*Lactation	0.0007	0.08	<.0001	0.14	0.0004	0.08
DIM*Lactation	<.0001	0.52	0.0035	0.07	0.0027	0.06
BW*Breed*Lactation	0.1997	0.03	<.0001	0.35	<.0001	0.12
DIM*Breed*Lactation	<.0001	0.22	<.0001	0.15	0.0244	0.05
BW*Season	0.0022	0.07	0.0233	0.05	0.8963	0.01
DIM*Season	<.0001	2.04	<.0001	1.51	<.0001	0.52
Total variance (%)	-	**40.02**	-	**43.01**	-	**40.0**

(Note: LSMeans that do not share a common letter are significantly different for the significance level set at the P-value of 0.05. HFR= Holstein-Friesian, JE= Jersey, KC = KiwiCross. P represents the P-value for the level of significance and Var. represents the variance in grazing time explained by the individual effects and their interactions included in the model. * Indicates an interaction between study factors.)

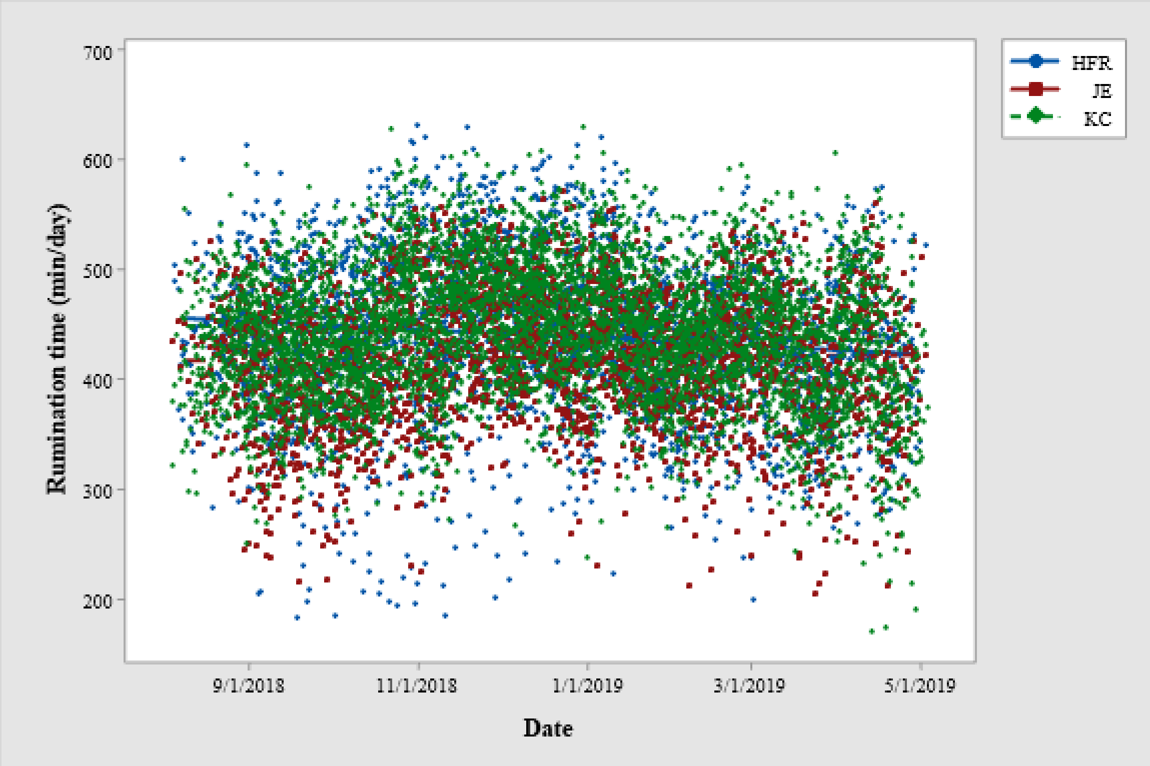

Figure 5. 5. Scatterplot between date and rumination time (min/day) for Holstein-Friesian (HFR), Jersey (JE) and KiwiCross (KC) cows across the lactation period for Year-1 of the study period. (The scatterplot is based on the raw values of rumination time).

5.4.3. Variation in the relationship between grazing and rumination

Grazing time overall affected rumination time in all study years (Table 4), and there was a negative relationship between both variables (Fig 5.6). The regression line between grazing time and rumination time among breeds remained the same, while the regression line differed among lactation years in Year-1. The regression line between grazing and rumination varied in different seasons in Year-1 and Year-3. The statistical interactions of grazing time for rumination time were non-significant with DIM (except in Year-1) and BW (except in Year-2).

The total amount of variance in rumination time explained by grazing time as a covariate in the model was 5.14%, 2.17%, and 2.14% in Year-1, Year-2, and Year-3 respectively (Table 4). In other words, the addition of grazing time in the model improved the percentage variance explained in rumination time i.e., for Year-1 from 1 38.02 to 43.76, for Year-2 from 41.5 to 44.35, and for Year-3 39.5 to 42.4. The amount of variance in rumination time explained by the interaction of grazing time with the breed, lactation year, season, and other covariates included in the study (e.g., DIM, BW) was very low (<1%) in all study years.

Table 5. 4. P values and the variance explained for the linear relationship between grazing time and rumination time while accounting for the effects of breed, lactation year, cow within breed and lactation year, season, supplementary feeds within the season, breeding worth (BW) index, days in milk (DIM), and their interactions using a mixed-effects model with the cow (*n = 54*) as a random factor, and BW, DIM, and grazing time (GT) as continuous covariates.

Rumination time (min/day)						
	P-Value and explained variance (%)					
Effect	**Year-1**		**Year-2**		**Year-3**	
Breed	0.1605	2.19	0.1116	1.78	<.0001	8.54
Lactation	0.2256	1.77	0.936	0.05	0.258	0.98
Cow (Breed*Lactation)	<.0001	24.03	<.0001	14.54	<.0001	16.07
Season	<.0001	2.31	<.0001	16.98	<.0001	7.41
Feed (Season)	<.0001	1.70	<.0001	2.11	<.0001	1.64
Breed*Lactation	0.8699	0.71	0.725	0.79	0.6768	0.81
Breed*Season	<.0001	0.12	0.0713	0.05	<.0001	0.36
Lactation*Season	<.0001	0.21	0.3961	0.02	0.0339	0.05
Breed*Lactation*Season	<.0001	0.23	0.1147	0.08	<.0001	0.62
Grazing time (GT)	<.0001	5.54	<.0001	2.17	<.0001	2.14
Breeding worth (BW)	<.0001	0.19	<.0001	2.84	0.0305	0.02
Days in Milk (DIM)	<.0001	3.31	<.0001	1.75	<.0001	2.98
BW*Breed	0.0084	0.05	0.0993	0.03	0.0309	0.03
DIM*Breed	0.0013	0.07	<.0001	0.27	<.0001	0.10
GT*Breed	0.0722	0.03	0.0959	0.03	0.6516	0.00
BW*Lactation	0.0011	0.07	<.0001	0.12	<.0001	0.09
DIM*Lactation	<.0001	0.47	0.0014	0.08	0.0072	0.04
GT*Lactation	<.0001	0.13	0.0385	0.04	0.1136	0.02
BW*Breed*Lactation	0.0056	0.07	<.0001	0.32	<.0001	0.12
DIM*Breed*Lactation	<.0001	0.24	0.0027	0.10	0.0089	0.06
GT*Breed*Lactation	0.3848	0.02	0.0024	0.10	0.0311	0.05
GT*BW	0.4776	0.00	0.0008	0.07	0.2159	0.01
GT*DIM	<.0001	0.30	0.3699	0.00	0.1728	0.01
GT*Season	<.0001	0.30	0.9713	0.00	<.0001	0.12
Total variance (%)	**-**	**43.76**	**-**	**44.35**	**-**	**42.40**

(P represents the P-value for the level of significance and Var. represents the variance in grazing time explained by the individual effects and their interactions included in the model. The significance level of the P-value was set at 0.05. * Indicates an interaction between study factors).

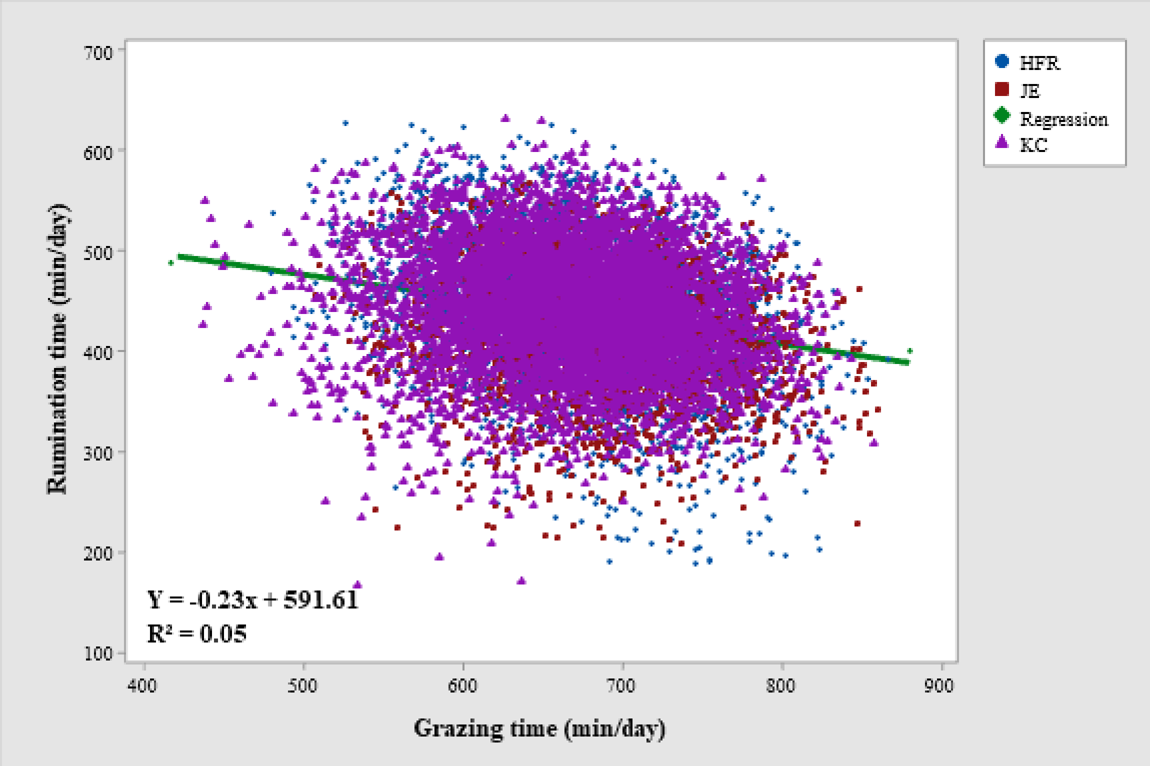

Figure 5. 6. Scatterplot between grazing time (min/day) and rumination time (min/day) for Holstein-Friesian (HFR), Jersey (JE) and KiwiCross (KC) cows across the lactation period in Year-1 of the study period. (The scatterplot is based on the raw values of grazing time and rumination time).

5.5.Discussion

The current study evaluated the variation in grazing time and rumination time and their relationship as affected by breed, lactation year, breeding worth (BW) index, and days in milk (DIM) of the individual cow, season, supplementary feeding, and their interactions. In the current study, the cows were managed altogether with other (non-study) cows as a single herd, like normal on farms in New Zealand. Thus, interactions among the cows within different breeds or lactation years, and the effect of herd size cannot be excluded but were not the focus of this study. Furthermore, the feeding regimes (i.e., herbage from pasture and supplementary feeds) differed among the study years, like the lactation year of the cows, this may explain variation in the results among different years (Year-1, Year-2, Year-3) of the study period, and this was the reason for analysing the dataset separately for each study year.

Grazing and rumination times varied among the individual cows in all years of the study period. The analysis further indicated that individual cows within breed and lactation years have been the main contributors to the variance in grazing time (12–20%) and rumination time (14–24%).

This might be due to the variability in grazing and digestive efficiencies, genetic potential, or individual traits of each study cow (Prendiville et al. 2010). Variation in the individuals' behaviour describes variation in their personality traits (Müller and von Keyserlingk 2006). For example, animals that are under highly competitive pressure may exhibit different ingestion behaviours to those with less competition. The foraging behaviour of grazing animals is not a simple process, but rather an outcome of interactions between feed and the animal itself (Villalba et al. 2015). Several animal-related factors influence their diet selection, bite mass and bite rate (Boval and Sauvant 2019), such as the mechanism of harvesting food; cows mainly use their tongue to harvest forage and they have a large mouth for a large bite. Animals tend to choose a diet of higher quality; for example, they select clover over grass and leaves over the stem and dead material (Litherland and Lambert 2007). Moreover, grazing management practices, the state of the grazed pasture, pasture availability and the quality or composition of pasture have significant effects on the selection of herbage by the animal (Lambert et al. 1986; Poppi et al. 1987). Furthermore, previous experience (e.g., previous feeding regime), the physiological status of the animals, and the digestive processes also influence their drive for grazing and choice of pasture (Hill et al. 2009). These findings emphasize that it is crucial to consider individual dairy cows when making management decisions; this could be done by grouping similar animals within a herd and managing them together. This study considered a few animal-related factors such as breed, lactation year, and breeding worth. Some other characters such as grazing efficacy, nonvisual traits, and social status of the individual animal in the herd were not studied and can be further explored in terms of their effects on grazing and rumination behaviours.

The season greatly influenced and explained 5-12% of the variance in the grazing time of dairy cows. The cows used in the current study calved in spring following the normal calving pattern in the New Zealand dairy system. Grazing time tended to increase during the initial weeks of the lactation period in spring, reduced in summer and further declined towards the end of lactation in autumn. These findings were consistent with a recent study that found a significant effect of season on grazing time in lactating dairy cows (Jochims et al. 2020). Few other studies also observed a significant effect of season on grazing time and comparatively longer grazing time at the initial weeks of lactation in spring than that in summer or autumn (DeVries et al. 2003; Munksgaard et al. 2020). It has been reported that both milk yield and herbage intake (indicated by grazing time) increase during the first few weeks of lactation, and gradually decrease towards the end of lactation (Bossen et al. 2009). Furthermore, both herbage intake and time spent grazing in dairy cows increase during the early lactation and decline towards the end of lactation, going parallel with the milk production curve (Kertz et al. 1991). The decline in grazing time in summer in the current study could be potentially due to the high-temperature humidity index that could have induced heat stress and resulted in reduced grazing time (Kidane et al. 2018). Additionally, dry summer affects the pasture quality and leaves the grass mostly rich in fibre content. Reports state, that when fed a moderate to a high-fibre diet, cows avoid consuming long particles and decrease their eating time per meal, but usually increase the number of meals per day (Kröger et al. 2019). Thus, the shorter grazing time in the cows in summer was most probably due to heat stress in cows and the drought effect on pasture; however, this is a hypothesis and needs to be tested by upcoming studies. Moreover, cows were fed additional supplements to address their nutritional demands during summer which would also have caused a reduction in grazing time. Grazing time gradually decreased to a further level in autumn. The even shorter grazing time during autumn was because the cows were at the end of the lactation period and were going to be dried off. Additionally, their nutritional demands were addressed by the additional supplementary feeds mainly during summer and autumn as these seasons are dry and potentially influence pasture quality (low ME and a high proportion of dead tissue) and availability in New Zealand (Litherland et al. 2002). The cows had lower feed demands in autumn and thus spent less time grazing. It has also been reported that grazing behaviour such as sward selection, time spent grazing, and consumption rate is affected by pasture management, type and quality of pasture, and supplementation (Lopes et al. 2013). The difference in grazing time was not large when cows consumed chicory, silage, or solely pasture. Whereas there was a reduction in grazing time (~60 min/day) when supplements were fed to the cows in autumn. The same effect, a reduction in the grazing time of 8.5 min per cow per day (overall 63 min per cow per day) for each kilogram of supplement consumed has been reported (Wright et al. 2016). Another study reported 54 54-minute reduction in the grazing time when fed with 14 kg of supplement per cow per day (Arachchige et al. 2013). Thus, the overall pattern and length of grazing time in different seasons and for different feeds found in the current study are consistent with the previous reports. However, the supplementary feeds were provided to all the animals at the same time so there is a probability that some animals might have consumed more or less than the required and this might have resultantly affected their grazing and rumination times. These findings inform the varying requirements for grazing and rumination behavioural needs over the lactation period and could be considered for making feed management decisions for grazing cows.

Season significantly affected rumination time and explained 2–17% of the variance in it in the current study. The effect of season was potentially linked to the supplementary feeds provided to the cows within different seasons as the type and quality of diet affect rumination time (Doyle et al. 1986), and the stage of lactation. The time spent rumination directly depends on the time spent eating, and the feed quality and type. Therefore, the effect of season on the variation in grazing time was further reflected in the variation in rumination time as well. Moreover, rumination time showed a seasonal curve parallel with the grazing time. These findings were consistent with a previous study (Jochims et al. 2020) that reported a similar trend in rumination time during different seasons except that rumination time continued increasing until the end of summer. Whereas in the current study, rumination time declined in summer, which is hypothesized to be potentially impacted by heat stress caused by the high-temperature humidity index (Moallem et al. 2010); although, this was not measured. The seasonal effect on variation in rumination time was also possibly related to the varying feeding regimes in each season. As grazing time was also reduced in summer which implies that animals had less feed to be processed through rumination activity; it resulted in a reduction in rumination time. Moreover, rumination time was lowest when supplementary feed was included in the daily ration in autumn, which might also be an effect of supplement feeds, however, it needs further exploration.

Grazing time among Jersey, Holstein-Friesian (HFR), and Crossbreed cows have been compared in a few previous studies with varying results. Similar grazing times among HFR, Crossbreed, and JE cows (646, 637, and 662 min/day) have been reported with a comparatively longer grazing time than HFR (171 vs. 129 min) when expressed as per 100 kg body weight (Prendiville et al. 2010). Similar findings have been reported by a recent study focusing on the effect of breed on the eating time of cows kept in the indoor system (Munksgaard et al. 2020). Higher daily eating time by JE (382 min) compared to that of HFR (360 min) in total mixed ration-fed lactating cows have been previously observed (Aikman et al. 2008). Furthermore, studies reporting significant differences in time spent grazing among different breeds with longer eating time by JE cows are also available (Wilson 2017). The bite mass is influenced by the constraints due to the anatomy including both the mouth and body size of the animal (Rook 2000). Therefore, higher grazing time in JE cows was probably due to their smaller physical size (short body and small stature) that only supported a smaller bite mass, and it took JE cows a longer time to fulfil their satiety needs. Additionally, lower bite mass and grass intake by JE cows compared to HFR cows have been reported (Prendiville et al. 2010) and higher feed intake per unit bodyweight (Grainger and Goddard 2007) which further justifies their grazing time to be longer. Thus, the difference in time spent grazing by cows of different breeds in the current study agrees with previous reports.

Rumination time was influenced by breed in only Year-3 of the study period with 8.53% of the variance in rumination time explained by the breed effect. The significance of the breed effect was relatively higher for both grazing and rumination in Year-3 which might be linked to consumption of different supplementary feeds and chewing behaviour or herbage intake with different nutritional demands for that study year. Significant differences in rumination time between Holstein-Friesian (10.4 hours/day) and Jersey cows (9.0 hours/day) with a similar quantity of intake have been reported; Holstein-Friesian cows spent more time (1.4 hours/day) ruminating (Aikman et al. 2008). Rumination time remained longest for HFR cows and shortest for JE cows in the current study. This was consistent with previous findings that reported lower rumination time in JE than in HFR (Aikman et al. 2008; Prendiville et al. 2010; Heublein et al. 2017). Smaller-sized JE cows have been observed to have smaller bolus sizes due to the anatomical influence on bolus movement during rumination (Prendiville et al. 2010). The study further suggested that inherent grazing and ruminating differences do exist between cows varying in intake capacity and production efficiency. Thus, the longer rumination time in HFR cows compared to JE cows can be explained by anatomical differences in the muzzle and incisor breadth between both breeds (Rook 2000).

Grazing time did not vary among cows in different lactation years except in Year-1 of the study period when first lactation cows were included as study animals. Moreover, lactation year explained the highest (6.3%) amount of the variance in grazing time in Year-1 compared to Year-2 (1.8%) and Year-3 (1.2%) when study cows were in their 2nd, 3rd, and 4th years of lactation, and the effect of lactation year was non-significant. Eating time in dairy cows was not influenced by age or lactation year in a previous study; However, their study reported more variation in the eating time of heifers than that of mature cows (Grandl et al. 2016). In addition, we found a decreasing trend in grazing time with an increase in the year of lactation; the first-lactation cows showed the longest grazing time followed by the cows in their second, third, and fourth lactations. A decline in eating time and the number of chews with advancing age in dairy cows has been reported (Grandl et al. 2016). Shorter chewing times per unit of feed-in multiparous cows compared with primiparous cows have also been previously observed (Dado and Allen 1994). First-lactation or young cows show different grazing behaviour than mature cows (cows in 2nd, 3rd, or 4th lactation years), as young cows have a smaller body size, take smaller bites, and eat more slowly, hence spending longer time eating compared to mature cows (Amaral-Phillips 2020). The first-lactation cows are still in the growing phase and need additional energy and protein to support growth and maintenance requirements. Their study further concluded that mature cows are socially more dominant, therefore, when housed together, younger cows eat (10 to 15%), and rest (20%) less than when housed separately (Konggaard and Krohn 1978; Grant and Albright 2001). In the current study, all the experimental animals from different breeds and in different lactation years were grazed together as a single herd in the same paddock. The smaller bites due to smaller size, additional growth demands and being socially influenced by mature cows in the herd were presumably the potential reasons for the longer grazing time in first-lactation cows. Social status and nutritional requirements of young cows were not the focus of this study, but they can be explored in the upcoming research.

Rumination time remained similar between cows in different lactation years throughout the study period. These findings need further exploration in terms of comparisons of grazing and digestive efficiencies between first-lactation cows and mature cows. Moreover, rumination time declined in cows with an increase in lactation year which might be due to the increased digestive efficiency of mature or multiparous cows for fibrous feed, this needs further exploration. The results were opposite to previous studies which found an increase in rumination time in multiparous cows (Maekawa et al. 2002; Bowman et al. 2003) and with no parity effect. The animals in those studies were kept indoors and fed on a concentrated diet. This was probably the main difference between those studies and the current study for contrasting trends of rumination time (pasture vs. total mixed ration), although the specific lactation years of the multiparous cows were not mentioned.

The findings in this study suggest that cows in early lactation require a comparatively longer time to graze and a larger allocation of pasture and/or supplementary feeds to address their satiety needs when they are grazing together with mature cows in a mixed herd. These findings should further help to manage the pasture and additional feed supply for a grazing herd with cows in different lactation years by splitting the animals into subgroups of similar individuals. Studies have reported the effects of season and diet on variation in grazing time in both indoor and outdoor dairy production systems (Sheahan et al. 2011; Wright et al. 2016). Irrespective of breed or year of lactation, cows showed a gradual reduction in grazing time from spring to autumn (from the start of lactation towards the end of lactation). These findings on the other hand reflect the overall trend in feed/pasture demand by dairy cows in different seasons over the lactation period. This information could be helpful to improve pasture management and utilization and additional feed supply on the farm effectively addressing the variable forage demand by the grazing cows in different seasons over the lactation period. This could be helpful to further improve animal productivity; consistent allocation of sufficient pasture daily can lead to approximately 10% increased milk yield (Fulkerson et al. 2005). Thus, an accurate indicator of pasture availability and the appropriate time to deliver additional feedstuff would be a potential feed management tool, particularly in a grass-based dairy system.

Days in milk and breeding worth index of the cows had effects on their grazing time and rumination time but the amount of the variance in grazing time and rumination time explained by BW (0.03–0.2%, 0.7–0.8%) and DIM (0.03–0.5%, 0.1–0.4%) was very low. The significant effect of BW and DIM might be due to some unknown reasons whereas, DIM and BW originally did not affect grazing and rumination. This was further verified by the magnitudes of the effect sizes of BW and DIM which were very low for both grazing and rumination. Grazing and ruminating times were similar in high BW ($146) and low BW ($40) indexed animals in a recent study (Al-Marashdeh et al. 2020). Another study by Rossi (2005) reported similar grazing times but a greater herbage intake rate for New Zealand dairy cows with modern genotypes (the 1990s) compared with those of an old genotype (the 1970s).

Grazing activity, to some extent, drives rumination activity, therefore, one of the objectives of the current study was to investigate the relationship between grazing time and rumination time and if this relationship varies for different breeds, lactation years, and seasons when animals are provided supplementary feeds. Grazing time and rumination time were significantly negatively correlated which is quite reasonable as when animals spend more time grazing, there is less time available for rumination. Longer periods of feed deprivation in grazing cows result in longer grazing bouts with higher intake along with a reduction in time left for rumination (Cazzuli 1999). Grazing time interacted with lactation year for rumination time only in Year-1 of the study period. The inclusion of primiparous cows in Year-1 of the study period and their different grazing times compared to mature cows explains this interaction. Whereas there was no statistical interaction between grazing time and breed for rumination time in Year-1. Furthermore, this joint effect of grazing time with lactation year on rumination time only in Year-1 of the study was probably because lactation year also affected grazing time in Year-1 of the current study (Table 2). The interaction of grazing time with season could be explained by the varying supplementary feeding within each season. Along with other study factors, grazing time explained 5.54%, 2.17%, and 2.14% of the additional variance in rumination time in Year-1, Year-2, and Year-3 of the study period, respectively. This further means that although rumination time is influenced by grazing time, the variation in rumination time is not solely explained by grazing time. Some other factors including feed efficiency, type of feed offered, quality of feed, and time of the supplement offered might be affecting rumination time.

5.6. Conclusion

The current study to our knowledge is the first study that provides insight into variation in grazing and rumination times and their relationship in grazing dairy cows considering the combined effects of breed, lactation year, individual cow, season, supplementary feeds, breeding worth index, and days in milk. The individual cow had the largest effect on variation in grazing and rumination behaviours. Minor differences existed between Jersey and Holstein-Friesian cows in grazing and rumination times with JE being the longest grazers and HFR being the longest ruminators. The length of time spent grazing and rumination gradually decreased in cows with an increase in the year of lactation, which indicates cows in their first lactation need more time to graze to address their satiety needs. Grazing time and rumination time increased at the start of lactation in spring and declined towards the end of lactation in autumn. Additionally, supplementary feeds greatly affected grazing and rumination times in a way that cows substantially reduced their time spent grazing and ruminating when additionally offered supplements. Although rumination has a relationship with grazing, the variation in rumination time is not solely explained by grazing time. With all the factors considered (individual cow, breed, lactation year, season, supplementary feed, and their interactions) in the current study, we could only explain 35 to 39% and 40 to41% of the variance in grazing time and rumination time, respectively, and 60-65% of the variance remained unexplained. Individual cows, season, and supplementary feeds were the factors explaining most of the variance in grazing and rumination behaviours.

Due to large variations in grazing and rumination behaviours among the individual cows, management decisions based on the individual animal in the herd are crucial and are expected to support improvement in animal productivity and welfare leading to farm profitability. Our findings further indicate how pasture utilization and additional feeds can be adjusted over the lactation period, depending on the nutritional demands of dairy cows of different breeds and lactation years to improve their health, welfare, and productivity. Thus, an accurate indicator of pasture availability and the appropriate time to deliver additional feedstuff would be a potential tool, particularly in a pasture-based dairy system in New Zealand. Including digestive, metabolic, and social behavioural parameters holds great potential to learn more about what further influences grazing and rumination behaviours. As there were no uniform control herds, there are still some questions that the study design did not allow testing. Furthermore, highlighted areas including additional grazing components (e.g., intake rate, bite mass, jaw movements, feed efficiency, social status, and other behavioural traits) and testing pasture quality are potential opportunities for future studies.

Chapter 6

Effects of grazing and rumination behaviours on productivity, liveweight and body condition score in spring-calving New Zealand dairy cows

6.1.Abstract

This study investigated the relationship of grazing and ruminating behaviours with performance in spring calving grazing dairy cows (*n = 162*) for three consecutive lactation periods (Year-1, Year-2, Year-3), with 54 cows each study year. The cows were of Holstein-Friesian (HFR), Jersey (JE), and Holstein-Friesian/Jersey Crossbreed (KiwiCross, KC) with 18 cows of each breed in either of three different lactation years (1st, 2nd, 3rd, 4th) with six cows of each lactation year. The cows had different genetic merit or breeding worth (BW) index values. The cows were managed through a rotational grazing scheme with once-a-day milking in the morning at 05:00 hrs. The cows mainly grazed pasture of perennial ryegrass (*Lolium perenne*) mixed with red clover (*Trifolium pretense*) and white clover (*Trifolium repens*) and received supplementary feeds including maize silage, corn gluten, tapioca, turnips, and distillers' grains in various seasons. This study used an automated AfiCollar device to continuously monitor and record the time spent grazing and ruminating by the cows on a real-time basis. Herd testing for milk yield (L), milk fat (kg), milk protein (kg), milk solids (kg), liveweight (kg) and body condition score of individual animals were performed once a month by Livestock Improvement Corporation (LIC). This study collected behaviour and performance data of individual grazing dairy cows over the lactation period (~270 days) for three consecutive years (Year-1, Year-2, Year-3). A general linear mixed model fitted with a factorial design of breed × lactation year with three levels each and their interaction while accounting for grazing time, rumination time of individual cows within the breed and lactation year, season, feed within the season, and their interactions to test the differences in milk yield, milk fat, milk protein, milk solids, liveweight (LW) and body condition score (BCS). Type I sum of squares values were used to quantify the magnitude of variance in the study variables explained by each of the study factors and their interactions. Breed influenced milk yield (MY), milk protein (MP) and liveweight (LW), while breed had no effects on milk fat (MF), milk solids (MS) and body condition score (BCS). Lactation year affected MY, MF, MP, and MS in all study years, while no effects on LW and BCS (except Year-1). The individual cow showed a significant effect for MY, MF, MP, MS, LW and BCS throughout the study years. The season affected MY, MF, MP, and MS in all study years, while the season affected LW in Year-1, and BCS in Year-1 and Year-2. Grazing time affected milk yield (MY), except Year-1 while it affected MF, MP, MS, LW and BCS throughout the study years. Rumination time affected MY, MF, MP, and MS in all study years while there were no effects of rumination time on LW and BCS. Breed and lactation showed no interaction with each other whereas both breed and lactation year showed interaction with the season for MY, MF, MP and MS. Breed and season showed no interaction for LW while lactation and season showed an interaction for LW but not for BCS. The variance in MY (Year-1=98%, Year-2=98%, Year-3=94%), MF (Year-1=98%, Year-2=96%, Year-3=92%), MP (Year-1=98%, Year-2=96%, Year-3=89%), MS (Year-1=98%, Year-2=96%, Year-3=91%), LW (Year-1=98%, Year-2=98%, Year-3=99%), and BCS (Year-1=94%, Year-2=90%, Year-3=88%) varied each study year. Grazing time explained up to 1-11%, 2-18%, 1-4%, 1-14 %, 4-22%, and 1-5% and rumination time explained 8-31% 5-19%, 5-22%, 5-21%, 1-9%, and 0-5% of the variance in MY, MF, MP, MS, LW, and BCS, respectively.

Keywords: Grazing time, rumination time, individual animal data, performance parameters

6.2. Introduction

Dairy production in New Zealand is reliant on grazing pasture which is the cheapest diet and the major source of nutrient supply for cows (O'kiely 1994; Holmes et al. 2002). A successful dairy system involves cows capable of consuming a large quantity of quality pasture and converting the ingested feed into high-quality milk (Buckley et al. 2005). However, the grazing system is characterized by low herbage intake which is considered a key factor limiting milk production in high-producing cows (Kolver and Muller 1998). Many factors related to the animal itself (e.g., breed and lactation) and pasture (such as quantity and nutritional value) influence the animal's ability to meet its nutritional requirements and cause significant variation between individuals in their nutritional requirements (Rutter et al. 2004; Prendiville et al. 2010; McEvoy et al. 2008). In pasture-based systems, dairy cows utilize more than 50% (up to 15 h per cow per day) of their daily time for grazing and ruminating (Vance et al. 2012; Iqbal et al. 2022). Herbage intake is expressed as the product of grazing time, biting rate, and bite mass and it is largely regulated by the time spent grazing (Rook 2000). Thus, animal grazing behaviour also has an important role to play in dictating the balance between both nutrient intake and energy expenditure with the energy available for milk production (Pollock et al. 2022).

Apart from the factors associated with the environment, grass, and management (Dillon 2007), milk production in a grazing-based system is also limited by animals' ability to consume enough herbage (Stakelum and Dillon 2003). For instance, behavioural decisions made by grazing animals result in variations in intake rate (Newman et al. 1994) and lead to differences in animals' milk production. Therefore, grazing behaviour may be not only affecting animals' herbage intake but also subsequently influencing animals' productivity; as the number of nutrients consumed drives milk production (Veerkamp et al. 2002; Waghorn and Clark 2004). Chilibroste et al. (2007) suggested that because of the effect of herbage intake on milk production, milk yield may be affected by the length of grazing time. Previous studies have suggested possible associations of grazing time with milk production level and liveweight in dairy cows (Illius 1989; Funston et al. 1991). Likewise, another study found a positive relationship between grazing behaviour and milk yield and the age of the animal (Bao et al. 1992). Another study reported that the performance of dairy cows is affected by the alterations in their grazing behaviour (Pérez-Ramirez et al. 2008). These findings further indicate that the influence of grazing behaviour on productivity may be as important as feed intake.

Milk production and its efficiency are affected not only by the amount and quality of pasture grazed by the cow but also by the way it is digested. In addition to grazing, rumination is also a key activity and a trait indicative of appropriate digestive operations in grazing ruminants. Rumination through regurgitation and remastication facilitates the accessibility of ingested forage to fermenting bacteria to enhance fibre digestibility (Llonch et al. 2018). The greater digestibility of dry matter then allows cows to consume more digestible energy, resulting in greater milk yields (Weiss et al. 2011). The time a cow spends ruminating has also been found positively associated with feed intake (Krause et al. 2002). However, the cows utilizing more time for rumination had less time for grazing and had less herbage intake (Schirmann et al. 2012. On the other hand, another study (Roche et al. 2006) suggested that feed intake is considered a measure of the body condition score (BCS) and liveweight (LW) because animals' feed demands are addressed based on their body weight; this may lead to an effect on grazing and rumination behaviour as well as on milk production and composition.

In a grazing system, animals adapt their behaviour accordingly to ever-changing sward and weather conditions (Kamphuis et al. 2012). The behaviour of cows kept in a grazing herd is usually expressed as an average behaviour of the whole herd and used as an indicator of the external and/or internal environments of animals. Whereas the managemental strategies based on the herd's average behaviour do not equally benefit all animals and might negatively impact the animals different from the average (Richter and Hintze 2019). For improvements in productivity and welfare of the individual animal in a herd, managemental strategies focusing on individual behavioural trends are essential. Measuring behaviour in individual grazing cows depends on the use of labour-intensive and indirect techniques such as visual measurements that have several sources of error (Rook 2000). Measuring the behaviour of individual dairy cows in a grazing-based system has been a challenge in the past as it typically involves a large group of grazing animals. The advanced Precision Livestock Farming (PLF) tool provides the opportunity to record the grazing and rumination behaviours of individual animals in the herd.

Understanding the impact of grazing and rumination behaviours on animal productivity could assist in improving the tailored management system based on behavioural responses. As a reflection of parameters such as efficiency or productivity, grazing behaviour has attracted considerable interest in recent years (Llonch et al. 2018). However, those studies have not investigated how individual animals' behaviour variability relates to their productivity, liveweight and body condition score at the same time. Likewise, little literature is published on the associations of BCS and LW with grazing time and rumination time. Thus, the primary objective of the current study was to investigate the relationship of grazing and rumination behaviours with milk production and composition, liveweight and body condition score.

6.3. Materials and methods

Materials and methods were the same as described in chapter 5 except for the following sections.

6.3.1. Performance data

Performance data were provided by Dairy Unit 1. Data collection for milk yield (L), milk fat (kg), milk protein (kg), and milk solids (kg) of the individual cows was performed by Livestock Improvement Corporation (LIC) through herd testing. Herd tests were conducted by LIC at Dairy Unit 1 once each month over the whole lactation period. Body Condition Score (BCS) of the individual animal was evaluated monthly by the farm staff using a 1 to 10 BCS scale (Macdonald and Roche 2004). Liveweight (LW) of the individual cows were collected monthly by the farm staff using automated Tru-test XR3000 WOW Scales (Tru-Test Pty Ltd., Sunnybank, Australia).

6.3.2. Data collection and preparation

This study collected grazing time (min/day) rumination time (min/day), milk yield (L), milk fat (kg), milk protein (kg) milk solids (kg), liveweight (kg) and body condition score of individual grazing dairy cows over the lactation period for three consecutive lactations (2018 to 2021). The lactation period of the cows ranged from August to April of the next year, amounting to approximately 270 days, following the typical spring calving system in New Zealand dairy cows. The lactation period covered spring, summer, and autumn seasons for data collection while no data were collected for winter as cows were in the dry stage. As data were collected only when cows were lactating, it started once the cow calved and ended when the cow was dried off. For convenience, the lactation period for 2018-19 was named Year-1, the lactation period for 2019-20 was named Year-2, and the lactation period for 2020-21 was named Year-3. The frequencies of behaviour activities summarized by the AfiCollar device were minutes specified for grazing and rumination by each cow within the hour (min/h). The min/h data were used to calculate minutes per 24 hours (min/day) spent grazing and rumination activities by the individual cow.

A database containing grazing and rumination times, milk production and composition, liveweight and body condition score data for a total of 162 dairy cows (54 cows per year) over three consecutive lactations was assembled. All the data collected were classified and sorted by breed, lactation year and season. Study years varied in supplementary feedings provided to animals as well as their lactation year, therefore, data were separately analysed for Year-1, Year-2, and Year-3 of the study period.

6.3.3. Statistical analysis

The significance and effect size of the study factors were assessed separately for each study year because the study years differed in supplementary feeds as well as the lactation year of the study cows. Monthly values of each performance variable were recorded for each animal, whereas monthly average values of behaviour variables for each animal were used to perform the analysis.

6.3.3.1. Correlation between behaviour and performance

Pearson's correlation coefficients were determined between behaviour (grazing time and rumination time) and performance parameters (Milk yield, milk fat, milk protein, milk solids, liveweight, and body condition score using PROC CORR in SAS (version 9.4, SAS Institute Inc. Cary, NC, USA).

6.3.3.2. Significance of study factors

A general linear model fitted in a factorial design with breed × lactation year (with three levels each) and their interaction while accounting for grazing time, rumination time, individual cow, season, and feed within the season, and their interactions were performed using PROC GLM in SAS (version 9.4, SAS Institute Inc. Cary, NC, USA) to test the differences in milk yield, milk fat, milk protein, milk solids, liveweight, and body condition score. Milk yield (MY), milk fat (MF), milk protein (MP), milk solids (MS), liveweight (LW), and body condition score (BCS) were the main dependent variables. Breed, lactation year, and their interaction were the main fixed effects, while individual cows nested within breed and lactation year were included as a random effect in the model. As lactation length ranged from August to April next year and covered three seasons (spring, summer, and autumn), the season was included as a fixed factor to test its effect as well as its interaction with the other fixed effect on the dependent variables. Cows received different supplementary feeds during different seasons in each study year, so, the feeding regime within the season was added as a fixed effect in the model. Grazing time (min/day) and rumination time (min/day) were added as continuous covariates in the model. The interactions between the covariates and the fixed effects were also included in the model to test if the relationship between covariates and dependent variables varied between the fixed effects. The model used in this study is given below:

$Yijklmn = \mu + Ai + Bj + Ai \times Bj + Ck (Ai \times Bj) + Dl + Em (Dl) + Ai \times Dl + Bj \times Dl + Ai \times Bj \times Dl + Xi + Yj + Xi \times Ai + Yj \times Ai + Xi \times Bj + Yj \times Bj + Xi \times Ai \times Bj + Yj \times Ai \times Bj + Xi \times Dl + Yj \times Dl$

Where: Yijklmn is the kth observation in the ith treatment group A and jth treatment group B and so on; μ is a general mean; Ai and Bj represent the fixed effects of breed and lactation year of the subject cow; Ai x Bj represent interaction between breed and lactation year; Ck (Ai x Bj) is random effect of cow within breed and lactation year; Dl is fixed effect of season; Em (Dl) is feed within season; Ai x Dl is interaction between breed and season; Bj x Dl is interaction between lactation year and season; Ai x Bj x Dl is interaction between breed, lactation year, and season; Xi + Yj are covariates as grazing time (GT) and rumination time (RT); Xi x Ai is interaction between GT and breed; Yj x Ai is interaction between RT and breed; Xi x Bj is interaction between GT and lactation year; Yj x Bj is interaction between RT and lactation year; Xi x Ai x Bj is interaction between GT, breed and lactation year; Yj x Ai x Bj is interaction between RT, breed and lactation year; Xi x Dl is interaction between GT and season; Yj x Dl is interaction between RT and season.

6.3.3.3.The relative effect size of study factors

To further determine the relative effect size or strength of various study factors and their interactions on milk yield, milk fat, milk protein, milk solids, liveweight and body condition score, variance partitioning was used considering the type I sum of squares (Type ISS) values of each study factor and their interactions. The significance and effect size of the study factors were assessed separately for each study year because the study years differed in the supplementary feeds as well as the lactation year of the study cows.

6.4.Results

6.4.1. Correlation between behaviour and performance

The correlation coefficient (r) values of grazing time (GT) and rumination time (RT) with Milk yield (MY), milk fat (MF), milk protein (MP), milk solids (MS), liveweight (LW), and body condition score (BCS) for different study years (Year-1, Year-2, and Year-3) are shown in Fig 1, Fig 2, and Fig 3. The r values of GT for MY were up to 0.34, MF was up to 0.43, MP was up to 0.22, MS was up to 0.39, LW was up to -0.47, and BCS was up to -0.24. The r values of RT with MY were up to 0.64, with MF up to 0.57, MP was up to 0.52, with MS was up to 0.57, with LW was up to 0.26, and with BCS was up to -0.26.

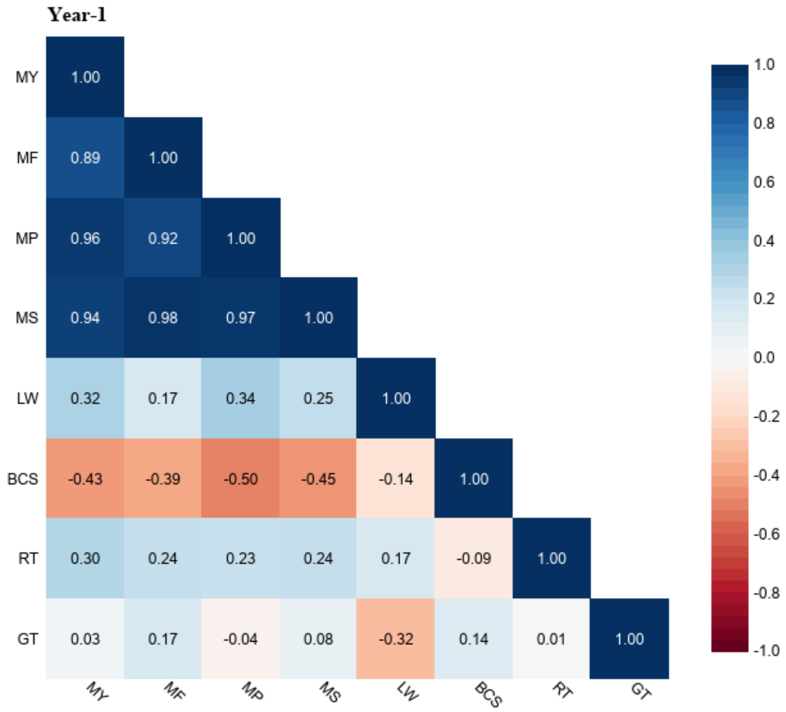

Figure 6. 1. Correlation coefficient (r) values of grazing time (GT) and rumination time (RT) with milk yield (MY), milk fat (MF), milk protein (MP), milk solids (MS), liveweight (LW), and body condition score (BCS) in grazing dairy cows (n = 54) for Year-1 of the study period.

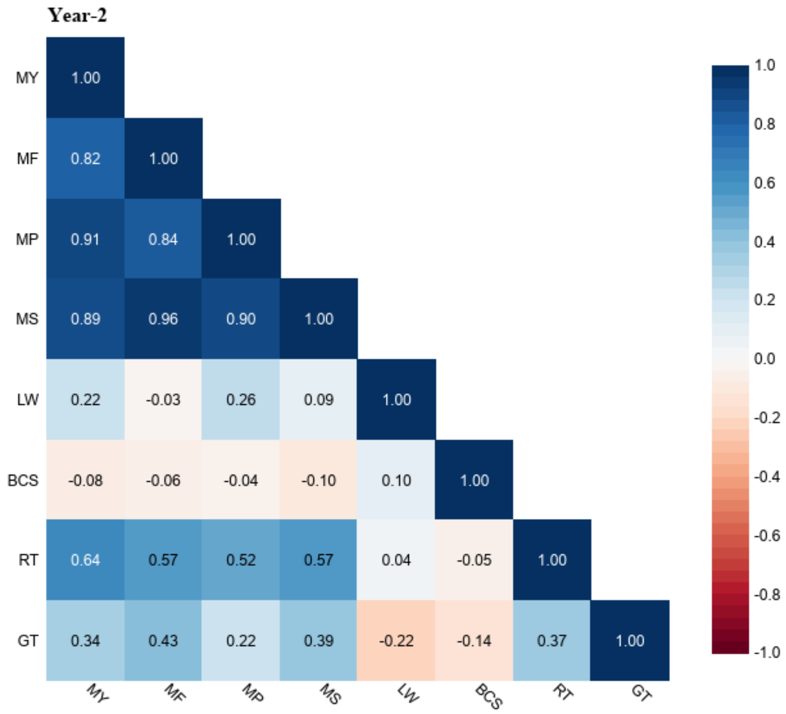

Figure 6. 2. Correlation coefficient (r) values of grazing time (GT) and rumination time (RT) with milk yield (MY), milk fat (MF), milk protein (MP), milk solids (MS), liveweight (LW), and body condition score (BCS) in grazing dairy cows (n = 54) for Year-2 of the study period.

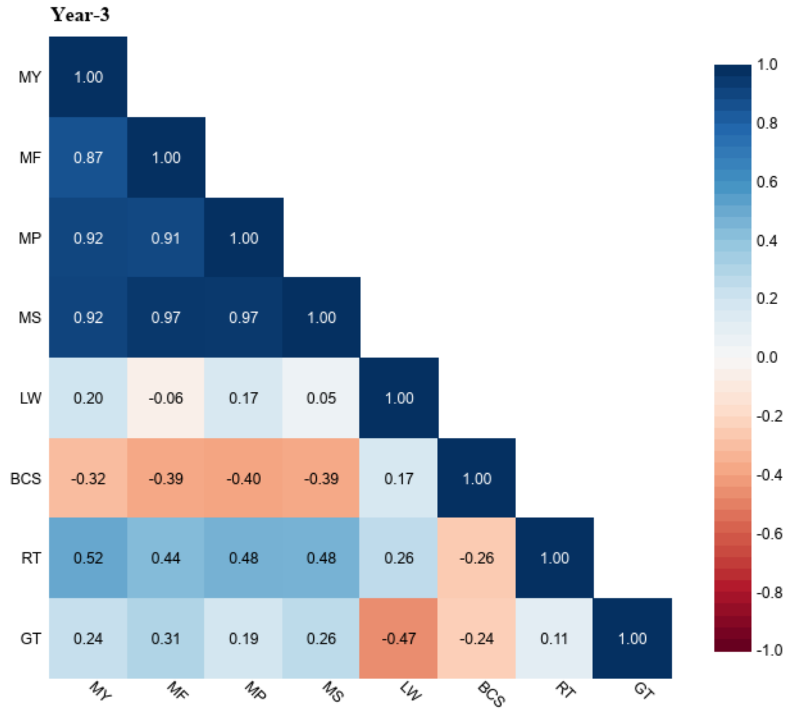

Figure 6. 3. Correlation coefficient (r) values of grazing time (GT) and rumination time (RT) with milk yield (MY), milk fat (MF), milk protein (MP), milk solids (MS), liveweight (LW), and body condition score (BCS) in grazing dairy cows (n = 54) for Year-3 of the study period.

6.4.2. Significance of study factors

The breed effect was significant for MY, MP, and MS while non-significant for MF in all study years (Table 2). The breed effect remained significant for LW (except Year-2) and non-significant for BCS throughout the study years. The lactation year of the cow affected MY (except Year-2), MF (except Year-2), MP, and MS in all study years. The lactation effect was significant for LW and BCS only for Year-1 while the lactation year had a non-significant effect on LW and BCS in Year-2 and Year-3. The individual cow showed a significant effect for MY, MF, MP, MS, LW and BCS throughout the study years. The season affected MY, MF, MP (except Year-3), and MS in all study years. Season effect was significant for LW in Year-1 and Year-3, and for BCS in all study years. Grazing time had a significant positive association with MY, MF, MP, and MS only in Year-1. Grazing time had significant negative associations with LW in Year-1 and Year-2, and a significant negative association with BCS in Year-1. Rumination time showed a non-significant positive relationship with MY, MF, MP, and MS in all study years. Rumination time showed a significant positive relationship with LW and a significant negative relationship with BCS in only Year-1.

Table 6. 1. Levels of significance for the effects of breed, lactation year, cow within breed and lactation year, season, grazing time (min/day), rumination time (min/day), and their interactions on milk yield (MY, kg), milk fat (MF, kg), milk protein (MP, kg), milk solids (MS, kg), body weight (BW, kg), and body condition score (BCS) in Year-1, Year-2, and Year-3 of the experimental period.

	Effect	MY	MF	MP	MS	LW	BCS
Year-1	Breed	<.0001	0.0928	0.0004	0.0099	<.0001	0.1943
	Lactation	<.0001	<.0001	<.0001	<.0001	0.0004	0.0016
	Breed*Lactation	0.6103	0.0152	0.2098	0.0794	0.6808	0.6083
	Cow (Breed*Lactation)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
	Season	<.0001	<.0001	<.0001	<.0001	<.0001	0.0069
	Breed*Season	<.0001	<.0001	<.0001	<.0001	0.0834	0.5703
	Lactation*Season	<.0001	<.0001	<.0001	<.0001	0.1433	0.1275
	Breed*Lactation*Season	0.0013	0.2445	0.001	0.0107	0.158	0.75
	Grazing time (GT)	0.6069	0.8613	0.4865	0.6469	0.1399	<.0001
	Rumination time (RT)	0.0006	0.1142	0.0002	0.0088	<.0001	<.0001
	GT*Breed	0.4151	0.555	0.7366	0.5865	0.5995	0.8538
	RT*Breed	0.9603	0.6733	0.9269	0.7391	0.0929	0.0062
	GT*Lactation	0.1791	0.1286	0.0968	0.0903	0.6007	0.26
	RT*Lactation	0.2795	0.0287	0.1017	0.0348	0.9772	0.0086
	GT*Breed*Lactation	0.6703	0.18	0.9336	0.4194	0.8389	0.3428
	RT*Breed*Lactation	0.872	0.1062	0.9941	0.2757	0.5758	0.5202
	GT*Season	0.097	0.3714	0.2212	0.197	0.7571	0.2369
	RT*Season	0.0006	0.0038	0.01	0.0023	0.6383	0.4979
Year-2	Breed	0.0008	0.1584	0.0008	0.063	0.1006	<.0001
	Lactation	0.2454	0.0649	0.001	0.0098	0.2707	0.0019
	Breed*Lactation	0.601	0.4003	0.2185	0.5301	0.6126	0.6004
	Cow (Breed*Lactation)	0.2046	<.0001	<.0001	<.0001	<.0001	<.0001
	Season	<.0001	<.0001	<.0001	<.0001	0.9682	<.0001
	Breed*Season	0.5202	0.855	0.2245	0.4826	0.0006	<.0001
	Lactation*Season	0.9745	0.0271	<.0001	0.0074	0.8667	0.0868
	Breed*Lactation*Season	0.999	0.753	0.6263	0.389	0.9241	0.9654

	Grazing time (GT)	0.8695	0.0135	0.4491	0.1072	0.2411	0.8792
	Rumination time (RT)	0.4331	<.0001	<.0001	<.0001	0.3698	<.0001
	GT*Breed	0.5909	0.0205	0.0738	0.0369	0.7243	0.6788
	RT*Breed	0.0372	0.7711	0.2159	0.4899	0.6765	0.5615
	GT*Lactation	0.7965	0.6607	0.8015	0.9012	0.8997	0.4296
	RT*Lactation	0.0765	0.2898	0.0012	0.041	0.7301	0.8893
	GT*Breed*Lactation	0.8774	0.7381	0.4065	0.335	0.011	0.4332
	RT*Breed*Lactation	0.3385	0.3191	0.8883	0.6116	0.9559	0.6469
	GT*Season	0.9697	0.2891	0.2719	0.1906	0.8476	0.9888
	RT*Season	0.8787	0.4612	0.5748	0.5064	0.6981	0.0782
Year-3	Breed	<.0001	0.1847	<.0001	0.0074	<.0001	0.2574
	Lactation	<.0001	0.0024	<.0001	<.0001	0.0548	0.0983
	Breed*Lactation	0.1113	0.8728	0.074	0.7516	0.0804	0.5466
	Cow (Breed*Lactation)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
	Season	<.0001	<.0001	0.7169	<.0001	<.0001	<.0001
	Breed*Season	0.0006	0.1997	<.0001	0.0587	0.0013	0.0086
	Lactation*Season	0.1699	0.0256	<.0001	0.0443	0.0096	0.3213
	Breed*Lactation*Season	0.7995	0.4294	0.2186	0.7791	0.3089	0.0434
	Grazing time (GT)	0.2241	0.1625	0.0725	0.157	0.6064	0.021
	Rumination time (RT)	0.6174	0.9158	0.9858	0.7935	0.6721	0.439
	GT*Breed	0.3362	0.9344	0.9192	0.849	0.1733	0.4619
	RT*Breed	0.9114	0.8007	0.22	0.6628	0.3825	0.2243
	GT*Lactation	0.0706	0.1758	0.5319	0.232	0.0616	0.4787
	RT*Lactation	0.2659	0.5029	0.217	0.4375	0.7408	0.2409
	GT*Breed*Lactation	0.6226	0.5694	0.737	0.4715	0.4671	0.5924
	RT*Breed*Lactation	0.5697	0.3574	0.765	0.3401	0.7327	0.8361
	GT*Season	<.0001	<.0001	0.0229	<.0001	0.0074	0.0007
	RT*Season	0.0013	0.048	0.306	0.0087	0.5375	0.9445

(The significance level is set at the P-value of 0.05. * Indicates an interaction between study factors).

Table 6. 2. Least square means ± Standard errors of milk yield (MY), milk fat (MF), milk protein (MP), liveweight (LW), and body condition score (BCS) for Holstien-Friesian (HFR), Jersey (JE), KiwiCross (KC) breeds, lactation years (1st, 2nd, 3rd) and seasons (spring, summer, autumn) in three study years.

	Effect	MY (L)	MF (Kg)	MP (Kg)	MS (Kg)	LW (Kg)	BCS
Year-1	**Breed**						
	HFR	17.28±1.70	0.74±0.08	0.62±0.06	1.36±0.13	537±16.48	4.0±0.26
	JE	12.65±1.01	0.71±0.05	0.54±0.04	1.26±0.08	424±9.74	4.88±0.15
	KC	14.23±0.33	0.75±0.02	0.59±0.01	1.34±0.03	489±3.24	4.57±0.05
	Lactation year						
	1st	10.92±0.55	0.61±0.03	0.44±0.02	1.06±0.04	446±5.33	4.90±0.08
	2nd	14.54±0.33	0.74±0.02	0.60±0.01	1.34±0.03	498±3.19	4.50±0.05
	3rd	18.69±1.92	0.85±0.09	0.72±0.07	1.57±0.15	506±18.54	4.05±0.29
	Season						
	Spring	16.97±0.45	0.89±0.02	0.64±0.02	1.53±0.03	469±4.32	4.64±0.07
	Summer	14.62±0.92	0.71±0.04	0.58±0.03	1.29±0.07	487±8.93	4.37±0.14
	Autumn	12.56±1.07	0.61±0.05	0.54±0.04	1.15±0.08	494±10.36	4.43±0.16
Year-2	**Breed**						
	HFR	18.86±0.44	0.84±0.03	0.71±0.02	1.61±0.04	542±3.93	4.13±0.07
	JE	13.22±0.47	0.80±0.03	0.55±0.02	1.45±0.04	461±4.17	4.42±0.08
	KC	16.41±0.27	0.86±0.02	0.68±0.01	1.59±0.02	514±2.43	4.49±0.05
	Lactation year						
	2nd	15.16±0.39	0.82±0.02	0.62±0.02	1.47±0.04	484±3.51	4.25±0.07
	3rd	16.34±0.27	0.81±0.02	0.67±0.01	1.52±0.02	535±2.41	4.46±0.04
	4th	17.00±0.49	0.87±0.03	0.65±0.02	1.66±0.04	497±4.38	4.33±0.08
	Season						
	Spring	20.36±0.74	1.04±0.04	0.83±0.03	1.83±0.07	500±6.55	4.46±0.12
	Summer	16.07±0.32	0.82±0.02	0.64±0.01	1.50±0.03	505±2.80	4.30±.05
	Autumn	12.06±0.64	0.63±0.04	0.48±0.03	1.31±0.06	512±5.72	4.27±0.11
Year-3	**Breed**						
	HFR	21.27±0.70	0.94±0.04	0.81±0.03	1.82±0.06	554±3.56	4.41±0.07
	JE	14.47±1.23	0.77±0.06	0.57±0.06	1.41±0.11	450±6.24	4.59±0.12
	KC	17.26±0.70	0.89±0.04	0.71±0.03	1.61±0.06	509±3.53	4.35±0.07
	Lactation year						
	2nd	14.46±0.77	0.75±0.04	0.59±0.04	1.35±0.07	484±3.93	4.48±0.08
	3rd	18.22±0.97	0.93±0.05	0.74±0.04	1.71±0.09	508±4.92	4.57±.10
	4th	20.31±0.97	0.92±0.05	0.760.04	1.78±0.09	522±4.90	4.30±0.10
	Season						
	Spring	22.10±0.79	1.08±0.04	0.84±0.042	1.95±0.07	499±3.98	4.46±0.08
	Summer	16.94±0.82	0.82±0.05	0.68±0.04	1.52±0.09	502±4.82	4.47±0.09
	Autumn	13.96±1.05	0.70±0.06	0.57±0.04	1.37±0.10	513±5.32	4.42±0.10

Note: The data is presented with Mean ± Standard error of the mean.

6.4.3. The relative effect size of study factors

Grazing time explained 0.11, 11.3%, 5.5% of the variance in milk yield, 2.90%, 18.18%, 9.46% of the variance in MF, 0.16%, 4.63%, 3.59% of the variance in MP, and 0.62%, 14.82%, 7.01% of the variance in MS in Year-1, Year-2, and Year-3, respectively (Table 3). Grazing time explained 9.96%, 4.89%, 22.14% of the variance in LW and 1.89%, 1.98% 5.93% of the variance in BCS in Year-1, Year-2, and Year-3 of the study period 'respectively'. Rumination time described 8.76%, 31.20%, 24.56% of the variance in MY, 5.73%, 19.48%, 16.68% of the variance in MF, 5.44%, 22.72%, 21.21% of the variance in MP, and 5.84%, 21.60%, 20.84% of the variance MS in Year-1, Year-2, and Year-3, respectively. Rumination time explained 2.96%, 1.85%, and 9.75% of the variance in LW and 0.85% 0.0%, and 5.51% of the variance in BCS in Year-1, Year-2, and Year-3 respectively. The variance in MY, MF, MP, MS, BW and BCS explained by interactions of different study factors and covariates was very low (<1%). Only lactation and season interactions explained up to 5% of the variance in milk yield and milk composition in Year-1and Year-2.

Table 6. 3. The magnitude of variance explained in milk yield (MY), milk fat (MF), milk protein (MP), milk solids (MS), liveweight (LW) and body condition score (BCS) by the effects of breed, lactation year, cow within breed and lactation year, season, and their interactions in three consecutive years using a mixed effects model with the individual cow (n = 54) as random factor and grazing time and rumination time as covariates.

	Effect	MY	MF	MP	MS	LW	BCS
Year-1	Breed	11.68	1.78	7.76	3.95	36	4.12
	Lactation	28.21	25.97	37.02	32.97	15.33	15.14
	Breed*Lactation	0.53	6.1	1.91	3.56	2.87	2.51
	Cow (Breed*Lactation)	15.18	18.43	18.41	18.43	36.67	39.79
	Season	27.24	31.93	17.62	26.23	1.49	0.24
	Feed (Season)	2.92	3.52	2.66	2.73	0.37	15.78
	Breed*Season	1.52	0.91	0.98	0.9	0.2	0.47
	Lactation*Season	4.58	2.9	5.05	3.77	0.16	0.85
	Breed*Lactation*Season	0.68	0.28	0.73	0.46	0.22	0.46
	Grazing time (GT)	0.32	0.23	0.17	0.2	0.01	0.15
	Rumination time (RT)	0.34	0.31	0.44	0.42	0.02	0.17
	GT*Breed	0.04	0.05	0.03	0.05	0.04	0.01

	RT*Breed	0.02	0.14	0.03	0.11	0.05	0.31
	GT*Lactation	0.09	0.07	0.07	0.06	0.04	0.13
	RT*Lactation	0.21	0.11	0.12	0.12	0.03	0.61
	GT*Breed*Lactation	0.16	0.17	0.12	0.16	0.05	0.31
	RT*Breed*Lactation	0.14	0.13	0.12	0.15	0.12	0.12
	GT*Season	0.03	0	0.05	0.03	0.12	0.34
	RT*Season	0	0.01	0	0	0.02	0.11
	GT +RT (%)	**1.35**	**1.22**	**1.15**	**1.3**	**0.5**	**2.26**
	Total (%)	**94.64**	**93.59**	**93.93**	**94.8**	**94.01**	**82.28**
Year-2	Breed	13.32	2.4	9.44	3.68	38.37	6.39
	Lactation	2.22	3.65	9	6.5	15.42	3.54
	Breed*Lactation	2.11	2.57	3.25	1.98	2.87	3.53
	Cow (Breed*Lactation)	27.37	22.22	19.33	22.17	37.14	46.96
	Season	27.22	40.48	32.98	37.75	1.7	0.01
	Feed (Season)	2.84	12.72	8.33	11.56	1.57	0.92
	Breed*Season	2.04	0.11	0.41	0.26	0.41	2.94
	Lactation*Season	0.31	0.89	1.92	1.07	0.12	0.18
	Breed*Lactation*Season	0.53	0.4	0.44	0.64	0.03	0.45
	Grazing time (GT)	0.02	0.49	0.04	0.2	0	0.2
	Rumination time (RT)	0.39	6.73	4.63	6.53	0.44	0.12
	GT*Breed	0.66	0.63	0.37	0.5	0.01	0.09
	RT*Breed	4.2	0.04	0.22	0.11	0.02	0.11
	GT*Lactation	0.29	0.07	0.03	0.02	0.02	0.03
	RT*Lactation	3.27	0.2	0.99	0.48	0	0.09
	GT*Breed*Lactation	0.76	0.16	0.28	0.34	0.05	1.93
	RT*Breed*Lactation	2.87	0.38	0.08	0.2	0.04	0.1
	GT*Season	0.04	0.2	0.19	0.25	0	0.05
	RT*Season	0.16	0.12	0.08	0.1	0.07	0.1
	GT +RT (%)	**12.66**	**9.02**	**6.91**	**8.73**	**0.65**	**2.82**
	Total (%)	**92.18**	**89.84**	**92.41**	**89.66**	**67.75**	**98.89**
Year-3	Breed	9.14	1.28	5.95	3.4	48.39	3.02
	Lactation	9.22	5.06	7.85	7.31	4.41	5.27

Breed*Lactation	1.57	0.45	1.05	0.59	6.35	3.35
Cow (Breed*Lactation)	8.84	16.45	13	13.95	31.99	48.54
Season	43.48	43.54	34.08	39.94	1.32	2.86
Feed (Season)	8.18	8.86	11.63	10.57	0.19	0.74
Breed*Season	1.09	0.42	0.78	0.61	0.29	1.07
Lactation*Season	0.36	0.76	1.03	0.68	0.21	0.37
Breed*Lactation*Season	0.22	0.55	0.2	0.33	0.14	1.2
Grazing time (GT)	0.12	0.2	0.16	0.31	0.02	0.12
Rumination time (RT)	0.28	0.32	0.53	0.5	0.02	0.04
GT*Breed	0.07	0.03	0.03	0	0.06	0.11
RT*Breed	0.2	0.24	0.2	0.2	0.01	0.21
GT*Lactation	0.57	0.28	0.19	0.38	0.08	0.16
RT*Lactation	0.26	0.17	0.43	0.3	0.01	0.3
GT*Breed*Lactation	0.16	0.16	0.29	0.24	0.06	0.19
RT*Breed*Lactation	0.11	0.19	0.34	0.18	0.03	0.09
GT*Season	0.52	0.52	0.8	0.86	0.11	0.92
RT*Season	0	0.09	0.01	0.04	0.02	0.01
GT + RT (%)	**2.29**	**2.2**	**2.98**	**3.01**	**0.42**	**2.15**
Total (%)	**84.72**	**79.77**	**78.59**	**80.42**	**93.79**	**69.18**

(GT + RT represents the variance (%) in milk and milk production and milk composition explained by grazing time, rumination time and their interactions with other study factors. The total represents the total amount of variance (%) explained by all study factors and their interactions).

6.5.Discussion

The current study evaluated the effects of grazing time and rumination time along with breed, lactation year, season, and feed within the season on production parameters (e.g., milk yield, milk fat, milk protein, milk solids, liveweight, and body condition score) in grazing dairy cows. The experimental cows were kept and managed together with other (non-study) cows as a single herd, like normally on farms in New Zealand. The feeding offered to animals was different among the individual study years and may explain variation in the results among different study years; this was the reason for analyzing the dataset separately for each year.

Breed and lactation year of the individual cows were among the factors that explained most of the variation in production parameters. These findings are consistent with the studies that have already reported significant differences in the production performance of the cows affiliated with different breeds within different parties, and for different stages of lactation (Edwards et al. 2014). This study also found that milk production and quality varied because of the season; the season of the year also represented different stages of lactation. Several factors contribute to the seasonal variations in milk such as type, availability, and quality of pasture (Auldist et al. 1996).

Grazing time was positively associated (r = 0.34) with milk yield (MY) and explained up to 0.32% of the variance in MY, although the relationship of GT with MY was significant for only Year-1. This further means that an increase in grazing time resulted in increased milk production and vice versa. Lathrop et al. (1988) have reported a positive relationship between milk production and grazing time. Bargo et al. (2002) found that high-producing cows grazed for a longer time per day and had greater bite rates and intake than those of low-producing cows. That study also found a positive relationship between the number of bites per day and milk yield (Bargo et al. 2002); a higher number of bites indirectly represents a long time spent grazing. Herbage intake is the outcome of time spent grazing, bite rate, and intake per bite (Spedding et al. 1966); therefore, animals grazing longer have the propensity for a higher number of bites, thereby, having a higher amount of pasture consumed (higher DMI) resulting in higher milk production. A continuous period of grazing activity provides a consistent supply of metabolites that have a positive effect on milk synthesis efficiency (Dalley et al. 2001) and resultantly bring a boost a milk yield. In addition, some reports have found no relationship between grazing behaviour and milk yield (Bao et al. 1992; Pollock et al. 2020).

Grazing time also showed effects on milk fat, protein, and solids. A previous study (Garcia-Rodriguez and Oregui 2003) found a significant effect of time at pasture on milk yield, fat, protein and liveweight. Grazing time had a significant effect (except Year-2) on milk yield with a positive correlation (r = up to 0.43) and explained up to 0.49% of the variance in milk fat. Shabi et al. (2005) also reported positive associations between time spent eating, and milk fat and protein. This is probably because eating time is linked with DMI which is highly correlated with feed conversion efficiency (r = 0.54 to 0.74) in dairy cattle (Meir et al., 2018). Continuous feeding with multiple meals per day has already been reported to increase milk fat yield, probably through the stabilization of ruminal fermentation (Rottman et al. 2014). Milk fat is the milk component most responsive to nutritional and environmental factors. This may be attributable to the dietary content consumed by the animals. Providing more frequent feeding might have resulted in a lower rumen pH, which likely led to the elevated milk fat yield in this study.

The effect of grazing time on milk protein was also significant in Year-1 with an r value up to 0.22 and explained 0.49% of the variance in milk protein. Previous study has suggested that feeding behaviour is less likely to influence milk protein due to having no significant association between the two variables (Macmillan et al. 2017). Milk protein concentration is generally associated with DMI and energy supply (Coulon and Rémond 1991), thus high protein content with longer time on pasture is reasonable (Nannig et al. 2018). This study found that grazing behaviour had a significant influence on milk solids production, aligned with total milk production. Higher milk solids contents have already been reported in grass-fed cows compared with TMR-fed cows (O'Callaghan et al. 2016).

Rumination time had a positive correlation with milk yield (r = up to 0.69) and explained up to 0.39% of the variance in milk yield. A weak correlation (r = 0.30) between both phenotypes has already been noted (Stone et al. 2017). Another study observed a positive association between rumination time and milk production in grazing dairy cows and reported improved feed intake and milk production with a longer rumination time (Watt et al. 2015). A positive relationship between rumination time and dry matter intake has also been found in dairy cows (Beauchemin 1991); a positive relationship between rumination time and milk production may be indirectly related to dry matter intake (Mikuła et al. 2021). Moreover, most of the rumination activity performed by grazing dairy cows is generally in a lying posture at nighttime. Due to a positive association between rumination and lying times (Llonch et al. 2018), rumination probably impacts milk production (Fregonesi et al. 2007).

Rumination time explained up to 6.73% of the variance in milk yield. Longer rumination time directly results in better rumen homeostasis and fibre microbial degradation leads to an increase in fat percentage (Zebeli et al. 2012). The cows had a greater probability of ruminating while producing milk of greater fat content (McWilliams et al. 2022). The authors hypothesized that cows who spend less time ruminating while lying spend less time chewing, resulting in reduced saliva buffering and lower ruminal pH, leading to reduced milk fat production.

Rumination time was also linked with milk protein. A study has already reported that milk protein yield was positively associated with rumination time (Johnston and DeVries 2018). In another study, increased milk protein was associated with enhanced chewing activity and greater rumen pH (Caccamo et al. 2014). The increased protein content can be attributed to the energy provided to the udder by the increased propionic acid supply to the rumen from the grass diet (Couvreur et al. 2006). Furthermore, it has been also inferred that pasture-based diets produce milk with more fat and protein (O'Callaghan et al. 2016). Rumination time showed a positive relationship with total milk solids (r = up to 0.57). The total average of milk solids content over lactation has been observed significantly higher in cows fed pasture than in those fed TMR (Couvreur et al. 2006). Increased rumination time might have produced a more favourable ruminal environment for fibre digestion, thereby enhancing the productive response of cows (O'Callaghan et al. 2016; Nannig et al. 2018). The increase in milk protein output was indeed due to better use of energy and Nitrogen by ruminal microbes leading to increased microbial protein synthesis (Pacheco and Waghorn 2008). However, this hypothesis must be proven.

Grazing time had a significant negative association with LW (r = up to -0.47) of animals accounting for an explanation of up to 0.2% variance in LW over the lactation period. Rumination time has a positive association with LW (r = up to 0.26) only in Year-1 and explained 0.44% of the variance in LW. Both grazing time (r = up to 0.24) and rumination time (r = up to -0.26) had a significant association with BCS and both explained 0.20% and 0.17% of the variance 'respectively' in BCS. Perojo et al. (2005) have already reported a significant effect of time spent grazing on the body weight of grazing dairy cows. Dry matter intake is a measure of body weight, on the other hand, DMI is controlled by the time spent grazing. This further explains the validity of the association between LW and grazing time. Moreover, (Johnston and DeVries 2018) observed that when LW and parity were controlled, DMI was positively associated with feeding time, and tended to be associated with rumination time and meal frequency. Also, LW changes over the lactation length reflect differential energy portioning across treatments. This further explains the 0.2% of variation accounted for by grazing time in this study. The association between rumination time and LW was slightly positive in this study where low ruminating cows had higher body weight and vice versa. Mikuła et al. (2021) observed similar results in their study. In contrast to the present study, (Watt et al., 2015) reported that high-ruminating cows were heavier than low-ruminating cows.

6.6.Conclusion

This multifactorial study identified the associations of grazing and ruminating behaviours with milk production, composition, liveweight and body condition score. Grazing and ruminating behaviours had weak to moderate correlations with milk yield, milk protein, milk fat, milk solids and body weight and body condition scores in different study years. The magnitude of variance in milk and milk components' production, liveweight and BCS explained by behaviour varied each experimental year. Overall, grazing, and ruminating behaviours together explained up to 0.66% variance in milk yield, 7.22% in milk fat, 4.67% in milk protein, 6.73% in milk solids, 0.44% in liveweight and 0.32% in BCS. Grazing and rumination behaviour together explained a small amount of variance in milk yield and its composition.

Chapter 7

General discussion

This thesis identified the need to bridge the research gap in understanding the individual variations in grazing and rumination behaviours in grazing dairy cows in New Zealand's pasture-based system. To do this, the following specific objectives were formulated:

i) Test the accuracy of AfiCollar, an accelerometer sensor-based automated device to monitor grazing and rumination behaviours of dairy cows in a pasture-based grazing system.
ii) Determine the general profile of grazing and ruminating behaviour patterns and time budgets over the lactation period and explore their variation among animals of different breeds and lactation years consuming different supplementary feeds in different seasons.
iii) Explore variations in daily grazing and rumination times considering the effects of breed, lactation year, season, feed, genetic merit, and days in milk.
iv) Evaluate the associations of grazing time and rumination time with milk production, milk composition, liveweight and body condition score.

Wearable devices such as accelerometer sensor-based collars (Williams et al. 2018) or ear tags (Reiter et al. 2018) are precision tools used to monitor livestock behaviour. This research found that the AfiCollar was able to accurately monitor and record grazing and rumination times in grazing dairy cows (Chapter 3). AfiCollar was further used to record grazing and ruminating behaviour patterns and time budgets in lactating cows over three consecutive lactation periods. The analysis indicated the AfiCollar can accurately monitor behaviour in grazing dairy cows. Grazing dairy cows spent most of their daylight hours grazing and most of their night hours ruminating with a smaller grazing peak around midnight (Chapter 4). Grazing intensity was higher at dawn after milking and around dusk. The onset and cessation of grazing activity and its intensity were adjusted by the cows with the varying daylengths in different seasons, and when cows received supplementary feeds. This thesis further found that variations in daily grazing time and rumination time are highly dependent on the animal itself, followed by season, supplementary feed, and breed (Chapter 5). However, the lactation year of the cow was the only significant influencer when multiparous and primiparous cows were included in the experiment. The results also indicated that the patterns of variation in grazing and rumination behaviours and milk production were aligned with each other over the lactation period (Chapter 6). Compared with grazing time, rumination time had a stronger effect on the production of milk volume, milk fat, milk protein, and total milk solids. Moreover, grazing time affected liveweight and body condition scores while there were no effects of rumination time on liveweight and body condition scores.

The accuracy of the AfiCollar device to monitor and record grazing and ruminating behaviours in grazing dairy cows was tested. The data recorded with AfiCollar were validated against the data obtained through visual observations. The sensor's performance was evaluated for different parameters affecting behaviour in dairy cows such as animal's breed (Prendiville et al. 2010), lactation year, and milk production level (Wright et al. 2016; Johnston and DeVries 2018), and different seasons (Leso et al. 2018) across the lactation period. Behaviour data recorded with AfiCollar had a strong association with the data obtained through visual observation for grazing (r = 0.91, CCC = 0.71) and rumination (r = 0.89, CCC = 0.80). Consistency of the current findings with other reports (Molfino et al. 2017; Pereira et al. 2018) indicates the reliability of the AfiCollar device to accurately monitor the grazing and rumination activities of individual dairy cows in grazing-based settings. Further, the AfiCollar system was able to adequately measure grazing and ruminating times at the animal level.

Cows utilized most of their 24-hour period grazing pasture followed by ruminating the ingested feed and idling or resting (Chapter 4). Cows grazed consistently for hours around sunrise and sunset (with slight modulation in start and finish timings depending on the season) and appeared to maximize their energy intake when the herbage was of higher quality (Gregorini et al. 2006). Studies have reported within the day variation in the chemical composition and nutritive value of herbage across daylight hours; non-structural carbohydrates increased by 35% and neutral detergent fibre decreased by 11% from morning to evening (Delagarde et al. 2000; Gregorini et al. 2006). Another report suggests a potential increase in non-structural carbohydrate concentrations at dusk (Griggs et al. 2005). Functional heterogeneity suggests that foraging behaviour is not a constant process, rather it may change over time because the daily pattern of grazing behaviour in cattle is the result of complicated decisions made in response to several factors. The analysis of daily behaviour patterns can help predict and address the behavioural needs of different animals in different climatic conditions (seasons). The analysis of behaviour patterns and time budgets through integrating Spatiotemporal scales helps to better understand the grazing process. Integrating the temporal distribution information of grazing behaviour into management strategies to drive the 24-hour supply of nutrients (Gregorini et al. 2006) can be a potential tool in grazing management. For example, daily herbage allowance which is considered as the main grazing management factor to improve milk production through pasture utilization can be optimized for the individual cow with the knowledge of their time spent on grazing. Time spent grazing, along with bite mass, pasture allowance and pasture nutritive value can serve as a combination of potential factors to optimize grazing management and can be a focus for future research.

This is the first study to my knowledge that investigated the combined effects of the individual animal, breed, lactation year, genetic merit, days in milk of the cow, and season and feed within season on the grazing and ruminating times of New Zealand dairy cows (Chapter 5). These factors inclusively could explain only 40% of the variance in grazing and rumination times, while 60% of the variance remained unexplained. Analysis showed that among the study factors, the individual animal was the largest source of variation in grazing and rumination behaviours.

These findings suggest that variation in behaviour describes variation among the personality traits of individuals (Müller and von Keyserlingk 2006; Gibbons et al. 2009; MacKay et al. 2014). For example, animals that are under highly competitive pressure may exhibit different ingestion behaviours to those with less competition. The mechanism of harvesting food by the individual also influences diet selection, bite mass and bite rate (Boval and Sauvant 2019); for example, cows mainly use their tongue to harvest forage and they have a large mouth for a large bite. In addition, previous experience (e.g., previous feeding regime), the physiological status of the animals, and the digestive processes also influence their choice of pasture and drive for grazing (Hill et al. 2009). Thus, individual differences (e.g., breed, lactation year) must be considered while making management decisions. Moreover, pasture grasslands naturally offer a wide variety of forages to grazing ruminants, allowing individuals within herds to have differences in grazing patterns (Machado et al. 2022). Exploring diverse habitats and swards provides individual animals with the opportunity to express their grazing pattern and feed preferences, depending on the individual personalities, with the latter being regulated by social and biophysical environments, as well as the emotional state of the animal (Moreno et al. 2020).

Grazing management practices, the state of the grazed pasture, pasture availability and the quality or composition of pasture have significant effects on the selection of herbage (Lambert et al. 1986; Poppi et al. 1987). Selection within a grazing sward is varied based on topography, shade, and spatial distribution of pasture. Animals tend to choose a diet of higher quality and for example, they select clover over grass and leaves over the stem and dead material (Litherland and Lambert 2007). Those variations in animal behaviour are linked with the individual traits relevant to production, such as growth (Müller and von Keyserlingk 2006) and susceptibility to diseases (Hulbert et al. 2011). Responses towards stressful situations vary among different cows (Boissy 1995), and the information about how individual animals react to various stressors can be used to mitigate the intensity of stress. Due to their links with production traits, the investigation of behavioural values, therefore, has the potential to bring improvements in the health and productivity of individual animals in the herd (Boissy et al. 2005; Adamczyk et al. 2013).

Results further indicated that the onset and cessation of grazing activity by cows is adjusted according to lengths of days and nights in different seasons and when fed with different supplementary feeds. These findings are consistent with other reports (Benvenutti et al. 2016; Schoenbaum et al. 2017). Cows started grazing earlier in the morning during autumn when days were short, to fulfil their feed requirements before sunset; they also had slightly longer midnight grazing peaks during the autumn. In addition, cows finished grazing activity earlier when they consumed additional supplements and silage along with pasture. Season and feed consumed by animals within the season also influenced the daily grazing time and rumination time. Grazing time was highest in spring, which indicates cows need more grass due to increased production requirements (start of lactation) and the high palatability, availability, and nutritional value of pasture (Gregorini et al. 2006). Thus, longer grazing time in spring was due to the abundance of green grass and higher production requirements by the dairy cows (Dillon 2007). Moreover, when animals grazed for a longer time and had high intake it resulted in longer time spent on rumination in spring. Grazing and rumination times were reduced in summer potentially because of high temperature and humidity index (Reis et al. 2021; Hut et al. 2022). Cows are sensitive to higher ambient temperatures (Hahn 1999; Kadzere et al. 2002), and in outdoor grazing settings cows are challenged when exposed to severe thermal conditions (Ammer et al. 2016; Heinicke et al. 2018). These findings indicate that pasture-grazed cows reduced their grazing time in summer and might have suffered from reduced intake because a reduction in eating time has been linked to a reduction in intake (Galan et al. 2018). The grazing time and rumination time were minimal in autumn because animals were gradually reducing their milk production due to getting closer to the end of the lactation period. Also, pasture production and quality were affected due to hot weather in autumn which was also a reason for low grazing time (Rennie et al. 2014). Due to the shortage of quality pasture, animals spent less time on grazing grass. Cows were fed with additional supplementary diets (e.g., tapioca, corn gluten, maize silage, distiller's grains) to address their feed demand which resulted in a reduction in grazing and rumination times during autumn (Bargo et al. 2003; Scaglia et al. 2009; Sheahan et al. 2011). These findings provide a general curve of pasture demand by the dairy herd over the lactation period. The pasture supply can be aligned with the individual animal's pasture demand and reduce the requirement for additional feeds.

These grazing behaviour patterns and times and their variations due to seasons and feed revealed how cows exploit forage plants and survive in outdoor grazing environments. For example, they start grazing early in autumn when days are short to address their feed requirements and finish grazing before night, mainly in daylight hours. Also, their morning grazing peaks were comparatively more intense in the winter and spring seasons when the temperature was low Gregorini et al. 2006). If bite mass and bite frequency are known, this information can be applied to manage pasture allowance and feed resources for day-to-day and even within a day throughout the lactation period (Gregorini et al. 2006; Gregorini et al. 2013). These findings also demonstrated that night grazing duration is comparatively high in summer, this is a very important point to be considered for pasture management and allocation for night grazing in summer. In summer, additional night grazing is crucial as it leads to increased forage intake and consequently provides an opportunity for better animal performance, especially when animals feel heat stress (Ayantunde et al. 2001; Corazzin et al. 2021). Although, increased grazing activity at night might be a challenge for other biological and welfare needs such as the time spent resting, sleeping, and ruminating; the less time available for sleeping and resting may lead to compromised animal welfare and performance (Tucker et al. 2021). Animals of different breeds have different tolerance levels for temperature and humidity index (Bryant et al. 2007) and any severe effects can be identified through individual monitoring. For example, a higher-than-normal dip in the grazing time or consistently low grazing time of an individual dairy cow during the daytime in summer may be an indicator of heat stress; and that specific animal needs a change in access time to pasture with the supply of extra feed and shade. Furthermore, in autumn, grazing time is usually even lower than that in summer and resting time is higher. However, prolonged resting time in an individual could be an indicator of sickness.

Results of this research indicated that Jersey cows grazed longer and finished their grazing activity later in the evening than Holstein-Friesian and KiwiCross cows. Due to these breed-specific differences in the behaviour or intake, management of each breed separately can lead to improved pasture management for each breed in a mixed breed herd. The choice of the breed has important implications for farm management, but its impact on pasture vegetation is underestimated (Pauler et al. 2020). Thus, based on the year-round pasture production and availability at a farm, breed choices for the farm can be made considering not only the production levels of the breed but also their pasture-utilising behaviour. In this regard, the findings regarding breed-specific behaviour presented in this thesis can play a potential role in supporting decision-making.

Longer grazing time in first-lactation cows was presumably caused by smaller bites due to smaller mouth size, additional nutritional demand, and being socially influenced by mature animals in the herd (Konggaard and Krohn 1978; Ungerfeld et al. 2014 Amaral-Phillips 2020). These inherent differences in feeding behaviour suggest that primiparous cows may need special consideration to meet their behavioural needs within commingled groups. These findings further suggest that first lactation heifers can be well fed if managed in a separate paddock which might bring positive outcomes in terms of their growth, performance, and welfare. The analysis further indicated that first-lactation cows did not differ from mature cows regarding time spent on rumination. The similar rumination time but different grazing time of first-lactation cows from mature cows needs further exploration.

Grazing and rumination behaviours trends and milk production curves over the lactation period were aligned in dairy cows (Chapter 6). Grazing and rumination behaviours explained a small amount of the variance in milk yield and milk quality. Rumination time and grazing time explained up to 1% of the variance in milk yield. Similarly, rumination explained up to 7%, 5%, and 7% of the variance in milk fat, milk protein, and milk solids, respectively. These findings indicate rumination behaviour as a better predictor of milk production and quality. Previous studies have also highlighted that animal behaviour plays a key role in its performance and welfare (Noelle et al. 2020; Pauler et al. 2020). In New Zealand, the national breeding worth index (BW), or genetic merit of dairy animals is made up of nine main traits. Those are categorized as production traits (protein, fat, volume and liveweight) and robustness traits (fertility, somatic cells, body condition and survival) by New Zealand Animal Evaluation Limited. These traits are believed to be responsible for producing economically efficient animals. However, my findings highlight how rumination behaviour has contributed to the production efficiency of dairy cows. The findings further suggest consideration of behavioural traits in the BW index as they are also related to the profitability of dairy animals due to their impacts on production parameters. Selection of animals based on better grazing and rumination behaviour traits can produce animals with improved grazing (e.g., animals that eat faster and spend less time on eating) and digestive (e.g., animals that more efficiently convert grass into milk) efficiencies (Golden et al. 2008 Bingham et al. 2009). Thus, selective breeding based on behavioural traits can lead to future generations of dairy cows with improved grazing and production efficiencies producing increased quality milk (Kiplagat et al. 2012) and reduced environmental footprints (De Haas et al. 2021).

7.1.Implications

Farmers want their farms to perform at the optimum level. However, cows are not consistent in their behaviour around the clock, and nor do they produce the same quality or quantity of milk. Within commercial herd environments, grazing groups often consist of a collection of animals with varying milk yields and stages of lactation, impacting nutrient demand for both animal maintenance and milk production. This variance in the individual cows could be an indicator of sickness, oestrus, changes in feed quality, changing weather, or other stress (Walker et al. 2008; Polsky and von Keyserlingk 2017). The findings of this study have suggested that most of the variation in behaviour is due to individual animals in the herd. Individual animals within the herd differ in traits such as age, body size, physiological and emotional states, social dominance, past experiences, and personality, and exhibit different behaviours (Grant and Albright 2001; Braun et al. 2015; Grandl et al. 2016).

Behaviour patterns different to the base line of behaviour for the herd are true indications of health status, physiological state and traits related to productivity or welfare associated with the individual animal. Cattle behaviour is usually represented as an average of the herd to make management decisions. However, management decisions based on herd averages are not equally applicable to each individual and may negatively affect some individuals (Richter and Hintze 2019). To improve the productivity and welfare of the individual animals in the herd, management decisions based on individual behavioural trends are crucial (Anzai and Hirata 2021). Individual behaviour can be analysed and understood in more detail when compared with those of herd mates using precision tools such as AfiCollar. In addition, management practices to enhance productivity and welfare based on the individual animal will be possible by focusing on inter-individual behavioural differences. More sensitive monitoring of the behavioural responses of individual animals due to changes in nutritional, physical and social environments will lead to tailored management that better meets the needs of individuals (Anzai and Hirata 2021).

Grazing and rumination activity patterns offer the opportunity to explore what is happening with the individual cow and its underlying reasons. Similarly, the time budgets of an animal represent its active response to the surrounding environment, and disruption of this response may negatively affect its performance. The differences in the time spent grazing and ruminating depending on the weather conditions in different seasons (Högberg et al. 2021) can assist management in making changes to address the varying feed demands. This can help manage the availability of additional feeds required by animals to address the production requirements when pasture quality is not optimum (Robaina et al. 1998; Smith 2012). Herbage intake will decline if the quality and yield of pasture decreases, and cows maintain their intake by increasing grazing time. However, with increased grazing time, energy utilization for activity increases leaving less energy for production. Therefore, minimum grazing time with sufficient intake can be achieved by offering cows the sward with an adequate yield of herbage to ensure adequate intake and better performance with minimum distances travelled. Thus, when forage is too mature and low in nutritional value, cattle need to spend more time to get the required amount of nutrients. This is when they should be fed with supplements and conserved feed. Providing supplementary feeds according to individual animals' production and behavioural demands instead of random supply to the whole herd during summer should bring better outcomes in animal productivity. Moreover, behaviour monitoring during summer can support the implementation of effective strategies by the producer for heat abatement in grazing cows (Vizzotto et al. 2015).

This information can give farmers valuable insight into why changes in behaviour are happening and how these changes can affect animal productivity and welfare. For example, both grazing and rumination times differ between first lactation and mature cows, healthy and sick cows, and for different seasons and feeds offered within the season. Thus, monitoring these metrics in individual cows allows farmers to manage the feed resource to take notice of these fluctuations in behaviour patterns and investigate whether the animal has health problems (Schirmann et al. 2016). In this way, farmers can predict, detect, and detect and treat disease on time. Understanding the daily activities and the normal behaviour of grazing dairy cows can be helpful in two ways: it can be a tool to improve the herd routine based on normal behaviour patterns; a change in the normal behaviour indicates animal health status or impaired management. The findings also indicated the normal time required for grazing and ruminating activities by animals of different genotypes, and parities during different seasons and when fed with supplements. These findings can support the pasture allocation for a mixed herd comprising Jersey, Holstein-Friesian and KiwiCross breeds in different years of lactation during different seasons over the lactation period. Ideal grazing management means obtaining a balance between the varying levels of animal demand over the lactation period depending on their age, physiological state, and rate of pasture growth.

7.2.Limitations

Considering the variations in weather patterns, animal's physiological state and nutritional demands, and pasture quality and their effects on animal behaviour, visual observation experiments to validate AfiCollar were performed during different times over the lactation period. AfiCollar accurately measured grazing and ruminating behaviours in dairy cows however, the device was not able to perform well in some situations (e.g., when environmental temperature and humidity were high during summer). Weather patterns, where the ambient temperature and relative humidity are high, can lead to heat stress in dairy cows. During heat stress, cows change their behaviour to reduce heat loads; they respond by spending more time standing, walking, and seeking shade, spending more time near the water trough, increasing respiration rate, and reducing feed intake (Overton et al. 2002; Etches et al. 2008; Schütz et al. 2009). In several instances during summer, grazing time recorded by the AfiCollar was higher than that obtained through visual observation. This was probably because the time spent by animals walking to seek shade was falsely positively recorded by the collar as time spent grazing. Walking when looking for shade often mimics the walk typically observed during grazing pasture (i.e., head held down and moving slowly). Moreover, animals were also observed to stand and move their heads up and down and forward and backward (behaviour patterns that are interpreted by the collars as grazing behaviour) during times of heat stress and high insect loads. Ectoparasites (blowflies, lice, ticks, and mites) are abundant in New Zealand pasture during summer (Heath 1994). Cows are irritated by flies and can become distressed under excessive fly loads. Cows' response to heavy fly pressure by becoming restless (i.e. head, neck, body and tail movements) and decreasing the time spent lying down (Heins 2017). The head and body movements imitated grazing activity and were recorded by the collar as time spent grazing during times of heavy fly loads in summer. In addition, the correlation value between recorded and observed data was comparatively lower in summer than in other times. This further had a negative effect on the overall correlation value between recorded and observed data. Although, weather and flies are likely to affect the results, these were not measured or quantified. Thus, the recalibration of algorithms is required which can further improve the accuracy of the AfiCollar device for grazing-based conditions. A previous study (Molfino et al. 2017) found a correlation value of CCC = 0.99 and 0.80 for grazing and rumination times, respectively, by a neck-mounted electronic tag (SCR HR-LDn; SCR

Engineers). The higher correlation values for SCR's tag are potentially due to its suitability and special design for grazing-based systems. Whereas AfiCollar was originally designed for an indoor system. The overall correlation values between observed and recorded data were in the range of values reported by previous studies. Consistency of the current findings with the other reports indicates that AfiCollar is a reliable device to accurately monitor grazing and rumination activities in grazing dairy cows. Nevertheless, there is a need to make minor improvements in AfiCollar algorithms calibrations under outdoor grazing-based conditions (Riaboff et al. 2020) that will further improve its accuracy.

Moreover, this study measured only grazing and rumination times in dairy cows but did not focus on herbage intake, bite mass, bite count, bite rate or frequency, and rumination chews. The daily intake is a product of grazing duration (duration and frequency of meals) and intake rate (biting rate and mass per bite) in grazing animals (Cosgrove and Edwards 2007). Measuring herbage intake, bite mass, bite count, and bite rate could further improve the inferences made in this thesis regarding effective time spent by dairy cows on grazing. This could also have improved the understanding of the relationship between time spent grazing and ruminating and herbage intake, and the relation between herbage intake and production parameters. Bite frequency, a potential indicator of feed intake (Pahl et al. 2016), along with bite mass, grazing time, rumination chews per bolus or mean rumination bout length can be used to estimate sufficient grass allocation. These variables if integrated within a decision support tool for farmers can potentially optimize the grazing management for dairy cows (Werner et al. 2019).

Another limitation of this study was not considering the pasture quantity and pasture quality for the individual animal. Seasonality in pasture production and /or its quality imposes periods of unfulfilled nutrient demands and even sometimes hunger. This is very important to consider as pasture quality varies during different times over the lactation period (Machado et al. 2005) and it affects bite mass (Pulido and Leaver 2001) and intake (Hodgson et al. 1994). Moreover, pasture quality measurements in different seasons over the lactation period could support inferences on the amount and quality of feed consumed or required by individual animals in the herd. Including pasture quality in the analysis focusing on grazing and ruminating times could also provide the actual amount of nutrients being consumed by the animals and would be a potential tool to measure the additional feed demands by each animal in the herd. Real-time measurement of pasture nutritive value and grazing time could lead to more efficient grazing management long-term efficiency and productivity gains at the farm level (Duranovich et al. 2020).

Moreover, to compensate for the pasture shortages, silage or hay and other supplements were offered to animals (Wendling and Machado 2018). The additional feeds provided to the animals were given on a herd basis without considering the actual demands of each animal based on its production level. Supplements are fed to animals based on their stage of lactation, daily herbage mass allowance, herbage nutritional composition, and type and amount of supplement offered (Tozer et al. 2004; De Klerk 2012). In cattle and other social ruminant species, because of group hierarchy, dominant animals have priority over subordinates in accessing resources, especially when resources are limited (Lazo 1994; Broom 2021). This leads to competition among animals where low ranked cows must develop tactics to access the resources. In the current rotational grazing management, when supplementary feeds were offered at the paddock level, the subordinate heifers might have to compete for access to the supplement feed and might have continued grazing pasture due to having no access. Therefore, offering supplements individually before entering the paddock or separately to heifers at the paddock level can offer heifers the opportunity to consume supplements and, improve their welfare. I found that feeding supplements reduced the amount of time spent grazing and ruminating; this might have reduced the amount of herbage intake (Krysl and Hess 1993). However, the intake of additional feed was not measured and remained unknown. The actual amount of supplement fed to the individual animals could support the investigation of the effect of the amount of additional feed consumed by individual cows on their grazing and ruminating times and performance.

This study did not consider grouping similar cows (e.g., age, breed, milk production level), thus inter-breed and inter-lactation interactions might have affected the results. For example, there were significant differences in grazing time (but not in rumination time) between first-lactation heifers and mature cows. To reduce stressful consequences the familiar animals should have been grouped. The grouping of familiar cows with each other could bring more stability and reduce aggression among animals and might have reduced the potentially negative effects on their behaviour (Sosa et al. 2019). Likewise, although this study collected a large data set over three years, the study years varied in lactation years of animals and additional feeds offered to animals, so it was not possible to investigate the effect of year on the data and the overall behavioural trends based on the three years dataset. These limitations of this thesis can be considered as potential research ideas for future studies focusing on cattle behaviour.

Further research is required to develop methods to effectively combine multiple behavioural indicators with physiological and performance indicators integrated with a behaviour monitoring tool to make management decisions in a grazing-based dairy farm.

7.3.Conclusions

AfiCollar device was shown to accurately monitor grazing and rumination behaviours of grazing dairy cows over the lactation period. The factors that drive the behavioural patterns in grazing dairy cows include the individual cow, seasonal variations, and feed type with the individual animals being the most dominant factor. Variations in the 24-hour temporal patterns of grazing and rumination behaviours are affected by the varying daylengths during different seasons. Consumption of supplementary feeds (e.g., Tapioca, corn gluten, turnips) substantially affects grazing and rumination behaviours. Grazing and rumination also varied due to the season and feed type consumed by the animals. Grazing and rumination behaviours had moderate correlations with both milk yield and milk composition; however, the effect of rumination was greater than that of grazing. Thus, relating the temporal distribution and duration of grazing events to management strategies becomes a possible option to control or drive the supply of nutrients and performance of animals. However, these findings should be further explored to improve the understanding and relationship between behavioural responses.

8. References

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Appendix

The ‘Statements of Contribution’ to Doctoral thesis containing publications or prepared for publication are appended below for Chapters 3, 4, 5, and 6.

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In which chapter is the manuscript/published work?	Chapter 3
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