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Review

Animal as the Solution: Searching for Environmentally Friendly Dairy Cows

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Abstract: There is increasing societal concern surrounding the environmental externalities generated from ruminant production systems. Traditional responses to address these externalities have often been system-based. While these approaches have had promising results, they have served to view the animal as a problem that needs solving, rather than as a potential solution. This review attempts to answer the question: can we breed animals that are more environmentally friendly to address environmental outcomes and satisfy consumer demand? This was done by exploring the literature of examples where animals have been specifically bred to reduce their environmental impact. The use of milk urea nitrogen breeding values has been demonstrated as a tool allowing for selective breeding of dairy cows to reduce nitrogen losses. Low milk urea nitrogen breeding values have been documented to result in reduced urinary nitrogen concentrations per urination event, which ultimately reduces the level of nitrogen that will be lost from the system. The ability to breed for low methane emissions has also shown positive results, with several studies demonstrating the heritability and subsequent reductions in methane emissions via selective breeding programs. Several avenues also exist where animals can be selectively bred to increase the nutrient density of their final product, and thus help to address the growing demand for nutrient-dense food for a growing human population. Animal-based solutions are permanent, cumulative, and often more cost-effective than system-based approaches. With continuing research and interest in breeding for more positive environmental outcomes, the animal can now start to be viewed as a potential solution to many of the issues faced by ruminant production systems, rather than simply being seen as a problem.

Keywords: milk urea nitrogen; methane; selective breeding; MUNBV

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1. Introduction

There is increasing global concern about the environmental costs of ruminant animal production. In temperate pastoral dairy production systems, two of the main environmental concerns are nitrogen (N) losses to the environment and greenhouse gas emissions (GHG) in the forms of methane (CH_4) and nitrous oxide (N_2O).

The low level of N utilization of dairy cows results in approximately 70% of ingested N not being used for animal production [1], with approximately 60% of this surplus N being excreted as urinary N [2,3]. In temperate pasture-based dairy systems, approximately 82% of this urinary N (UN) gets discharged onto pasture [4,5]. At the pasture level, high concentrations of N in the urine patch saturates the soil and the swards' ability to utilize the N, making it vulnerable to being lost from the system [6]. This excess of N results in N being leached from the system into groundwater, with typically 20–30% of UN lost in this manner and 2% lost as N_2O [6]. High levels of N in waterways have been associated with widespread environmental degradation. One such form of environmental degradation is eutrophication, which is the enrichment of aquatic or terrestrial ecosystems with anthropogenic sources of nutrients [7], such as N from dairy production systems. Nitrogen is considered to be a key macronutrient that limits primary productivity to estuarine and coastal waters [8] that, when present, results in hypoxic zones from uncontrolled growth of phytoplankton and macroalgae [9,10] which results in oxygen depletion in the lower layers of the water body [8]. These changes to the aquatic ecosystem can result in the loss of ecosystem services through the resulting death and decomposition of aquatic flora and fauna [7], thus altering the aquatic food webs [9,11].

Pollution from excess N on pastures not only contaminates waterways, but also produces the GHG N_2O during the denitrification process as a result of volatilization [12]. Nitrous oxide, alongside enteric CH_4 production, are considered the largest contributors to GHG emissions from ruminant production [13]. Animal agricultural production GHG emissions are estimated to account for 8–10.8% [14] of global GHG emissions. When considered as a lifecycle analysis, this figure increases to 18% [15]. Enteric CH_4 is produced primarily as a result of rumen microbial methanogenesis, which accounts for 73% of the livestock sector's GHG emissions [16–18]. Due to the high global warming potential (GWP) of one ton of both CH_4 (GWP = 28–36 tons of CO_2 equivalent) and N_2O (GWP = 265–298 tons of CO_2 equivalent), these emissions have been highlighted as major concerns with regard to causing climate change and global warming. Global warming and climate change have been linked to increasing frequencies of extreme weather events [19] and more acidic and rising ocean levels [20,21], all of which are suspected to result in several detrimental outcomes for humanity.

Moreover, N losses to the environment, whilst being determinantal to the environment, can also be detrimental to human health. Blue baby syndrome is a health problem that has been largely associated with high levels of nitrates in drinking water resulting in methemoglobinemia in infants [22]. Methemoglobinemia is the increase of methemoglobin in the blood and a decreased capability of red blood cells to oxygenate tissues, which can be fatal in severe cases [22]. Infants are more susceptible to methemoglobinemia as they drink more water per body weight compared to children and adults, have lower NADPH methemoglobin reductase activity, and have a higher percentage of fetal hemoglobin, which is easier to convert to methemoglobin [22]. There is also evidence of an increased risk of developing colorectal cancer [23], thyroid disease [24], and neural tube defects [25] from high levels of nitrates consumed in drinking water [24].

These negative environmental and human health externalities are compromising the ability for some of the United Nations' sustainable development goals (UN-SDGs) [26] to be achieved. Goal 6 of the UN-SDGs relates to the availability and sustainable management of water and sanitation, with water quality being highlighted as a key concern. Nitrogen losses from temperate pastoral dairy production systems are known to harm water quality. Thus, to achieve this goal, changes must be made to limit the amount of N lost from the system into waterways. Goal 12 of the UN-SDGs pertains to responsible consumption and production. The externalities arising from GHG emissions and degraded water quality from temperate pastoral dairy production do not align with this goal. Pastoral dairy production must become more environmentally friendly and avoid any environmental degradation to meet this goal.

Previous approaches to remedying the environmental effects of livestock production have focused on protection and restoration, rather than on the more cost-effective approaches of prevention and mitigation [15]. When these prevention and mitigation approaches have been implemented, they have often been incorporated at the system level. For example, dietary manipulations to dilute UN excretions and reduce CH_4 emissions have been extensively researched [3,27–29]. Although this approach to reducing the environmental impact from ruminants has shown promising results, they have served to paint the animal as a problem that needs solving, rather than viewing the system as ill-designed for the animal. The continual view that animals are the problem has created negative connotations around animal-based production systems [30,31], which has potentially resulted in a lower rating of animal perspectives relative to other perspectives used in system design [32]. Increasingly, environmentally conscious consumers are now in a 'moral conundrum' [33] about consuming animal-based products, which has generated an increased interest in alternates to animal products as a way to address environmental issues [34,35]. Questions remain about the efficiency [36] and nutritional quality [37,38] of some of these alternate products compared to the products produced by highly efficient pasture-based ruminant production systems. Inefficient production of products with lower nutritional quality may clash with the UN-SDGs [26], such as goal 2 (zero hunger) by not adequately meeting nutritional requirements, and goal 12 (responsible consumption and production) by inefficiently producing and consuming products where more environmentally friendly alternatives exist. By seeing the animal as a problem that needs solving, we are ignoring the potential for animal-based solutions. Humans have been selectively breeding for beneficial traits such as improved temperament and production for thousands of years, yet remarkably, breeding for improved environmental outcomes has not been a mainstream avenue considered for reducing the environmental impact of livestock-based systems.

Thus, this question arises: if we can breed for animals to enhance production, then why do we not also breed for animals to be more environmentally friendly, to not only address environmental outcomes, but also to satisfy consumer demand? The objective of this review is to answer this question, and will cover two topics that directly pertain to reducing the environmental impact of ruminant production, with a particular focus on temperate pastoral dairy production: N loss and CH_4 production. The ability to breed for lower N excretion in cattle is a developing area with only a small amount of research available (illustrated in Figure 1). For example, at the time of writing this article, a search for 'breeding for reduced nitrogen excretion in cattle' on the Web of Science yielded 31 results. Comparatively, a search for 'breeding for reduced methane production in cattle' yielded 136 results.

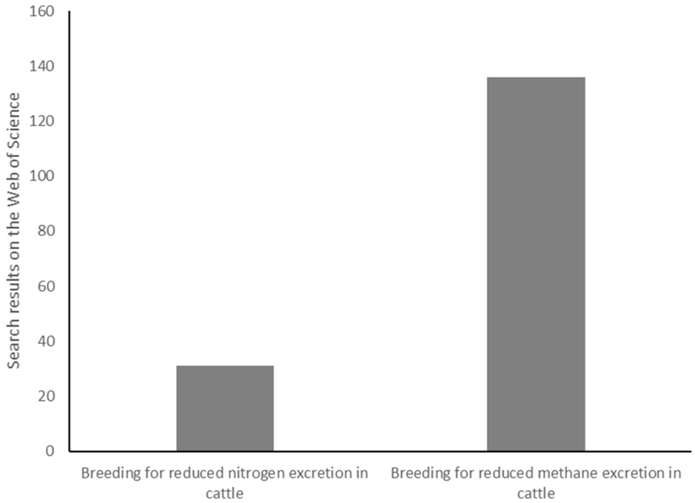

Figure 1. Search results on the Web of Science for breeding for reduced nitrogen excretion in cattle, compared to breeding for reduced methane excretion in cattle.

2. Methodology

Literature was explored that related directly to the ability to breed for environmentally beneficial outcomes. A particular focus was placed on peer-reviewed articles that were published in the last two decades.

Methane and UN excretions were considered the main areas of interest, as they have been widely associated with detrimental environmental outcomes from pastoral dairy production practices. Milk urea nitrogen was focused on as a breeding solution for reducing UN excretions due to the recent popularity this concept has held with scientific research and development organizations within the New Zealand dairy industry. The authors are aware that other breeding programs exist, where 'animal-based solutions' can be implemented to solve specific problems.

Google, Google Scholar, and the Web of Science search engines were utilized to find and explore literature. The following keywords were used for finding literature related to MUN: "breeding"; "milk urea nitrogen"; "environmental impact"; "nitrogen losses"; and "cattle". The following keywords were used to discover literature relating to methane: "breeding"; "methane"; "production"; and "ruminant". The keywords of "breeding", "nutrient", "density", "value", and "animal" were used to discover literature relating to breeding for increased nutritional value of animal products.

3. Discussion

3.1. Breeding for Reduced Milk Urea Nitrogen Content

Dietary protein represents the main source of ammonia production for ruminants, which is used to meet the requirements of cellulolytic bacteria within the rumen [39]. Excess ammonia is absorbed or diffused across the digestive tract into the portal vein. Because high levels of ammonia can be toxic to the animal, it is synthesized by the liver into urea [39,40]. Urea is a small, non-toxic, and highly soluble molecule known to equilibrate throughout the body fluids of an animal [41,42]. The amount of urea excreted by cows in urine is known to be directly proportional to the concentration of urea in the blood [43,44], which in turn is proportional to the concentration of urea in milk [45,46]. This relationship makes it possible to infer the concentration of urea in urine relative to either the blood or the milk. Milk urea nitrogen (MUN) measurements are preferable over blood urea nitrogen (BUN), as BUN is highly variable as a result of digestive processes, and peaks 4–6 h after feeding [47]. Milk urea N is comparatively less variable, as it is produced and then stored within the mammary gland between milkings [40]. Milk urea N measurements are also able to be made at an individual or herd level twice daily on most commercial dairy farms.

By knowing the concentration of urea in urine, inferences can be made relating to the level of nitrate leaching and, therefore, the environmental impact. Increasing levels of N application at the urine patch are associated with higher potential nitrate leaching losses [48], as any additional N above what the soil and the sward can utilize is in a readily available form for leaching. However, the measurement of UN output in a field setting is difficult and expensive [49]. Due to the fact there is a linear relationship between MUN and UN, where MUN can be used as a proxy for UN excretions, several models have been developed to estimate this relationship [45,50,51]. This has allowed for reliable calculations to be estimated for individual or herd UN excretion levels, and, therefore, the environmental impact.

The heritability of MUN has been previously investigated as a way to predict the efficiency of dietary N use and milk production parameters [52], with its heritability estimated to range between 0.14 to 0.23 [52–56]. Whilst the ability to breed for MUN is not disputed, the effectiveness of breeding for MUN as a proxy for reducing UN has been questioned. Huhtanen et al. (2015) [57] investigated the differences between cow variation for milk urea, rumen ammonia N concentrations, and the association with N utilization and diet digestibility in lactating cows across 21 milk production trials. Huhtanen et al. (2015) [57] suggests that breeding for animals with low MUN concentrations is unlikely to have any great effect on UN excretion. Huhtanen et al. (2015) [57] also suggests that MUN concentration is not a useful phenotyping tool for improving milk N efficiency. A decreasing milk N efficiency is associated with an increasing UN excretion [58]. Therefore, based on the lack of effectiveness for affecting milk N efficiency, Huhtanen et al. (2015) [57] assumes that breeding for low MUN levels will only have a small influence on UN excretion. Huhtanen et al. (2015) [57] goes on to suggest that dietary manipulation is a more efficient tool for reducing N losses. Several works detail dietary management solutions for reducing N losses [3,59,60], so, in this manner, Huhtanen et al. (2015) [57] was not wrong in that greater gains in reducing N losses can often be made via dietary manipulation. However, these are 'silver bullet' approaches, and often do not have any lasting effects. This is where genetic selection differs. Genetic selection offers a tool that is permanent and cumulative over generations [61]. Whilst the genetic gains may seem to be small, they are still important due to their persistent cumulative nature and potential likelihood of additive and synergistic effects between breeding for the right animal and other management practices.

The heritability of MUN for New Zealand was calculated as 0.22 for dairy cattle by Beatson et al. (2019) [49], who then suggested that breeding for lower MUN values could be a mitigation tool to produce cattle with lower UN excretions. Building off of this hypothesis, Marshall et al. (2020) [62] tested the hypothesis that grazing dairy cows that were classified as low for MUN breeding values (MUNBV) would have reduced urinary urea nitrogen (UUN) excretions. Marshall et al. (2020) [62] conducted a study using 48 multiparous lactating Holstein-Friesian × Jersey dairy cows in both early and late lactation grazing, either using a ryegrass (*Lolium perenne* L.) and white clover (*Trifolium pratense*) sward, or a ryegrass, white clover, and plantain (*Plantago lanceolate* L.) sward in New Zealand. It was found that when MUNBV was expressed as a continuousness variable ranging from −2 to +4, a one-unit decrease in the BV resulted in a 0.67 g/L reduction in the concentration of UUN [62]. These results were then extrapolated to calculate a difference of 40.72 kg NO_3N leached per ha^{-1} indicating the potential for genetic selection to reduce nitrate leaching from dairy cows. A similar relationship was also detected using 16 multiparous lactating Holstein-Friesian × Jersey dairy cows housed within metabolism crates for 72 h [63]. This study measured total daily N excretions as well as total N excretion per event, thus allowing for inferences to be made directly about the urine patch, which is considered the engine room of nitrate leaching [6]. It was found that, on a total daily level, there was no difference in the amount of N that would be deposited onto pasture, albeit a numerical difference was observed for animals with low MUNBV cows having less N excreted per day. On an individual urination event-level, Marshall et al. (2021) [63] found similar results to Marshall et al. (2020) [62] in that there were lower UUN concentrations per urination event based on MUNBV when animals were consuming ryegrass diets. This reiterated the ability of animal genetics to reduce the level of N excreted onto pasture during a urination event, and ultimately N leached. The results of Marshall et al. (2021) [63] also indicate that different excretion patterns may exist based on MUNBV, which may have implications for animal management decisions that could facilitate better environmental outcomes for animals divergent in MUNBV. The genetic potential of animals used in both Marshall et al. 2020 [62] and Marshal et al. (2021) [63] represent natural variation within a herd setting. Based on the known moderate heritability of MUNBV [49], it would be expected that further gains in regard to lower UN concentrations per animal would be possible via selective breeding programs. A study by Ariyarathne et al. (2021) [64] investigated whether N excretion of dairy cows could be reduced by selecting for low MUN concentrations. Ariyarathne et al. (2021) [64] utilized data from the New Zealand Dairy Statistics in the years of 2018 to 2019 and herd test data from two research dairy farms in New Zealand to create multiple scenarios and model results over several years. Ariyarathne et al. (2021) [64] concluded that breeding for low MUNBV was able to reduce UN concentration per animal; however, Ariyarathne et al. (2021) [64] also concluded that there was no substantial benefit to reducing UN excretion for New Zealand. The conclusion of Ariyarathne et al. (2021) [64] about the lack of benefit for breeding for low MUNBV may potentially be a result of an increased stocking rate relative to other scenarios in this study. Despite questioning the benefits of breeding for less MUN, the results found by Ariyarathne et al. (2021) [64] concur with Marshall et al. (2020, 2021) [62,63], and indicate the potential of breeding for lower UN excretions. This lends credence to the suggestion of Gregorini et al. (2010) [65] and then Beatson et al. (2019) [49]; that it may be possible to breed cows with lower UN excretions. By breeding for lower UN concentrations and therefore less N leaching, pastoral dairy production systems will be moving towards achieving goal 6 of the UN-SDGs by reducing the impact of these production systems on water quality.

Not only does breeding for lower MUNBV reduce UN, but it may also result in less GHG emissions from urinary excretions. A 1 mg dL reduction in MUN within the ranges of 16 to 10 mg dL was found to reduce UUN by 16.6 g/cow per day, which in turn resulted in a 7% reduction in NH_3 and a 12% reduction in N_2O emissions [42]. It would, therefore, be expected that any reductions in UN concentration as a result of MUNBV would also be resulting in a reduction in NH_3 and N_2O emissions.

There is also the possibility that breeding for low MUN may increase the overall profitability and reduce the intensity of greenhouse gas emissions of the animal. A study by Grandl et al. (2019) [66] investigated the greenhouse gas emissions and profitability of dairy cows. Grandl et al. (2019) [66] reported that animals with a low length of production lives had the greatest GHG emission intensity for milk production. Therefore, it could be expected that cows with longer production lives would be considered to have a lower GHG emission intensity than cows with shorter production lives. Multiple studies have documented the relationship between high MUN levels and poor fertility performance in dairy cattle [54,67,68]. It is speculated that the correspondingly high BUN levels from animals with high MUN are reducing uterine pH, and therefore increasing embryo mortality [69]. A modeling exercise by Garnsworthy (2004) [70] modeled the GHG emissions of herd replacements and found that increases in fertility would reduce GHG emissions at the herd level as fewer replacement animals would be needed. It could, therefore, be hypothesized that while breeding for lower MUN values, you would also be breeding for increased fertility and therefore longevity of the herd, thus reducing the emission intensity at a herd level. This concept requires further investigation.

Breeding for low MUN is not necessarily the only mechanism available for reducing UN losses. Theoretically, any trait that can be bred for that results in differences in N partitioning, could result in less UN excretion. Multiple studies have indicated the ability of diets to alter N partitioning, resulting in greater milk protein yields and reduced UN excretions [71,72]. These relationships are in part due to the primary and secondary compounds of the plants such as aucubin, acteoside, and catapol found in plantain [73]. It is conceivable that breeding for a trait such as protein yield with a heritability of 0.13 [74] could theoretically result in more N being partitioned into milk protein, and therefore away from urine.

The daily effects of urine patches can be greatly reduced by strategic animal management practices. A study by Christensen et al. (2012) [75] found that the amount of total N lost could be reduced by 36% by strategically removing animals from pasture. A study by Aland et al. (2002) [76] indicated that individuality exists in elimination events for both urine and feces, thus indicating the potential for different diurnal excretion behavior controlled by genetics. Studies by both Gregorini et al. (2015) [77] and Marshall et al. (2021) [78] have demonstrated that animals that are considered genetically divergent express different grazing behaviors and therefore different strategies for the acquisition of nutrients. The use of new technologies such as virtual fencing [79] and animal monitoring [80] may provide an opportunity to capitalize on these behavior differences of genetically divergent animals. For example, hypothetically, if the known differences in grazing behavior in cows divergent for MUNBV are also observed in elimination events, animals could be strategically removed from areas of pasture that may be more ecologically sensitive during times of the day when high levels of N are being excreted. This management could be facilitated through the use of virtual fencing [79] and GPS collars, which could ensure animals are still kept within the paddock but could potentially be removed from sensitive areas such as waterways to achieve ecological goals [81]. Virtual fencing may also allow for pasture allocations autonomously [82] in a manner that is more conducive to differences in grazing behavior, which may result in potential synergistic effects in regard to environmental and production outcomes. Further research is required to investigate these potential synergies.

Breeding for lower MUNBV appears to be a valid mechanism for incremental sustained environmental impact reductions from temperate pastoral dairy production systems. Based on the physiological principle that determines the concentration gradients between BUN, MUN, and UUN, we argue that this concept could be applied to multiple species. This would allow for breeding programs targeting lower MUN levels to be applied to systems other than just cattle, such as deer and sheep production systems. It could also be hypothesized that, because this is a physiological mechanism, additive and therefore synergistic effects are likely to occur when pairing animals with low MUN with diets that are known to reduce MUN and, therefore, UUN levels.

The addition of MUN into breeding indexes, along with the potential synergistic effects of pairing selective breeding for lower MUN and dietary manipulations with new technologies, offer viable mechanisms for producers to reduce N losses. The potential for these reductions in N losses to waterways will help to improve the relative health and quality of local waterways and, therefore, help countries achieve goal 6 of the UN-SDGs. This will also likely help to address consumer concerns surrounding environmental impacts from pastoral dairy production.

3.2. Breeding for Lower Methane Production

The primary energy source for ruminants is volatile fatty acids (VFA's) [83]—with the three main VFA's being acetate, butyrate, and propionate—which are produced during the fermentation of feed inside the rumen. This process is facilitated by a plethora of micro-organisms that encompass bacteria, archaea, protozoa, viruses, and fungi. Based on stoichiometric principles, the production of both acetate and butyrate will produce H_2 as a byproduct [59], and excessive concentrations of H_2 can inhibit the function of certain micro-organisms [84] that are involved in electron transfer reactions [85]. Methanogens are a micro-organism in the rumen which belong to the domain of archaea [85], and use a hydrogenotrophic pathway using CO_2 as a carbon source and H_2 as an electron donor to create CH_4 and H_2O ($CO_2 + 4\ H_2 \rightarrow CH_4 + 2\ H_2O$). In this way, methanogens provide an important role within the rumen by mediating H_2 concentrations.

Numerous in-depth reviews have been conducted on management strategies in the existing literature to reduce enteric CH_4 production with a focus on animal genetic merit [86–89]. Multiple genetic pathways exist for reducing CH_4 production, from directly breeding for animals that produce less CH_4, to diluting the CH_4 emissions by breeding for animals that are more efficient, thus emitting less CH_4 per product produced.

A modeling exercise by Lahart et al. (2021) [90] investigated the effect of genetic selection by comparing the effect of breeding using genetics from the top 5% of all animals based on the Irish economic breeding index, compared to the national 'average' genetics for GHG emissions of lactating dairy cows across six different scenarios for four years. Lahart et al. (2021) [90] detailed a dilution effect from breeding for 'elite' genetics of animals ranked highly based on the economic breeding index. The result of increased genetic potential was an increase in productivity, primarily driven by improved reproductive performance, resulting in better herd age structure and productivity potential [91]. An increase in production resulted in an increase in feed intake, which increased enteric CH_4. However, these emissions were offset by reproductive performance. Fewer replacement animals needed to be reared, with elite animals staying in the herd for longer compared to the national average, thus resulting in a 10% reduction in GHG emissions compared to the national average. Lahart et al. (2021) [90] found that, based on the current rate of genetic gain in Ireland, a 1% reduction in emissions intensity per year is being achieved. The findings of Lahart et al. (2021) [90] indicate the potential for achieving environmental parameters through breeding for more productive herd members with increasing longevity and reproductive performance, and thus diluting GHG emissions/kg of product. A similar modeling study by Beukes et al. (2011) [92] detailed a synergistic effect that occurred when breeding and replacement strategies were incorporated with other dietary and animal management strategies to reduce GHG emissions.

Several studies have investigated the use of breeding for lower residual feed intake (RFI) as a way to reduce CH_4 production [93–95]. A scenario was conducted modeling feed intake and CH_4 production rates in an Australian beef herd selected for low RFI compared to a national Australian herd for 25 years [96]. It was found that, over 25 years, there was a 7.4% cumulative decrease in enteric CH_4 production from the low RFI herd compared to the national average/unimproved herd [96]. By year 25, the low RFI herd produced 15.9%

less CH_4 than the unimproved herd annually, thus indicating a promising animal-based solution for reducing CH_4 emissions.

How RFI reduces CH_4 emissions remains unclear; however, there have been several hypotheses put forward to explain the relationship. Methane production can be calculated based on an animal's gross energy intake. Approximately 4–6.5% of the gross energy of an animal will be lost as CH_4 [93]. Therefore, more efficient animals that have a lower feed intake but maintain high production levels will be producing proportionally less CH_4 as a result of a lower energy intake. Another hypothesis links intake and rumen retention time for RFI cows [93,97], which is likely related to the grazing differences observed in cattle divergent for RFI [77]. Longer retention times can facilitate non-glucogenic fermentation, which has associated environmental effects such as CH_4 production [98,99]. It would, therefore, be expected that if low RFI cows had a shorter rumen retention time, it would lead to a proportional decrease in CH_4 production. The final hypothesis is a host-microbiome relationship that facilitates greater ruminal fermentation [97], thus favoring propionate production. This leads to less H_2 production and subsequently less CH_4 produced by methanogens [93]. There is also the possibility that these animals have morphological differences internally that are affecting CH_4 production. A study by Goopy et al. (2013) [100] investigated if there were morphological differences between sheep classified as having a high CH_4 yield and a low CH_4 yield. Goopy et al. (2013) found that low methane-yielding sheep had smaller rumens and shorter rumen retention times, with the inference that these morphological differences were affecting fermentation patterns and digesta outflow rates and, ultimately, CH_4 production.

Although several studies have indicated the potential of animals selected for RFI to have reductions in CH_4 emissions, there have also been studies that have found no relationship between RFI and CH_4 emissions [101,102], thus indicating further research is still required to understand the viability of breeding for low RFI to reduce CH_4 emissions.

A study by Pinares-Patiño et al. (2013) [103] investigated the genetic parameters of CH_4 emissions by placing 1225 lambs between the ages of 5–10 months old, selected based on their progeny records within respiration chambers and assessing the heritability and repeatability of measurements. Pinares-Patiño et al. (2013) [103] found that CH_4 production per day and per kg DMI were moderately heritable (0.13) and repeatable, and thus offer the potential for using breeding to reduce CH_4 emissions. Similar findings were found by Donoghue et al. (2013) [104] in beef cattle, using 530 animals and the use of respiration chambers. A low to moderate heritability was detected [104] for CH_4 yield (0.21), CH_4 production per unit feed intake (0.19), and CH_4 production per unit body weight (0.23). Donoghue et al. (2013) [104] had a similar conclusion to Pinares-Patiño et al. (2013) [103] in that the possibility for using genetic improvement to reduce CH_4 emissions exists, but more research is required.

Several avenues appear feasible for implementing animal-based solutions to address CH_4 emissions from ruminant animals. Methane emissions are problematic for all ruminant production systems and are not unique to temperate pastoral dairy production. By either breeding for greater efficiency or breeding directly for less CH_4 emissions, ruminant production systems will be progressing towards achieving the UN-SDG of responsible production by reducing the externalities associated with CH_4 emissions from ruminant animals.

Future research should investigate potential interactions between animals that are considered low for MUN and low for RFI or other methane-reducing traits, with the hypothesis that it is possible to breed for an animal with reduced environmental impacts on multiple fronts. It would also be important to investigate this hypothesis because it is known that, for certain feeding management practices in ruminants, pollution swapping between UN excretions and methane occurs [60]. However, it is not known if pollution swapping would occur in animals selected for low MUN and methane reducing traits.

3.3. Breeding for Increased Nutritional Value

With advances in technology and genetics, the ability to breed and create animals to be solutions to problems in synergistic ways is endless, and provides many avenues for reducing the environmental impact. Another problem facing the world currently is the need to feed a growing population that is expected to reach over nine billion by 2050 [105]. The United Nations has an SDG of zero hunger (goal 2). As a result, animal-based proteins are likely to play a key role in achieving this goal. The question therefore arises, could animal-based solutions be implemented to further increase the nutritional quality of an animal product, and can we breed for more nutritious meat and milk? Examples already exist where plant breeders have bred for higher nutrient density in the end product [106]. However, certain amino acids cannot be gained from plant-based diets, such as taurine, thus highlighting the need for an animal-based solution to provide these nutrients. The Omega Lamb Project is a breeding program targeting higher levels of polyunsaturated fats and omega-3 fatty acids in lambs in the New Zealand high country [107]. Whilst the scientific literature is limited about the program, it encompasses the idea of an animal-based solution for improving the nutritional quality of the product for the end consumer. The Omega Lamb Project also alludes to the synergistic effects that could be gained by pairing better genetics with current management practices to improve the nutritional quality of the end product. A similar synergistic result was proposed by Marshall et al. (2021) [63], where animals with low MUN (mg/dL) phenotypes had further reduced UN excretions when on a plantain diet compared to cows with relatively higher MUN phenotypes. Several examples exist where studies have been conducted investigating if breeding can increase the nutritional quality of the end product, such as increasing iron content [108], increasing amino acid content [109], and improving fatty acid composition [110]. All of these results indicate the potential for breeding for more nutritious products, which will help to facilitate animal-based solutions for global problems, such as addressing the UN-SDG goal 2 of zero hunger. Breeding for more nutritious animal products will likely become just as important as breeding for more environmentally friendly products as the world struggles to feed its growing population.

Whilst larger reductions in N losses and CH_4 production and greater nutrient density/value can be made via diet management strategies, these are short-term, near-sighted approaches. The reliance on 'silver bullet' solutions has removed the creative ability to look forward to planning and designing future productive landscapes. Genetic gain and breeding for more environmentally friendly animals will be a long slow journey that may never achieve a fully 'environmentally friendly' animal, but it will result in better environmental outcomes than if we do nothing and continue to rely on 'silver bullet' approaches that are yet to fix the problem. Humans have been selectively breeding animals for thousands of years. This is not a new concept to us as a species, yet for some reason, the idea of selectively breeding for environmental outcomes has never been considered as a key outcome or breeding goal. Every tool in the tool belt will need to be called upon to face the coming challenges and crises humans will face in the next 10–1000 years. Animal-based solutions and the potential synergies they may have with existing strategies must be considered.

In the case of animals that have been selected for reduced methane production, they have been reported to have faster rumen digesta outflow [99,100,111]. If when selecting for low methane animals, producers are consequently also selecting for animals with different rumen function leading to a faster digesta outflow rate, there would be less biohydrogenation of fatty acids, resulting in an increase in polyunsaturated fatty acid flow to the duodenum and consequently to the mammary glands. This could, therefore, hypothetically result in the selection of an animal with a reduced environmental impact, as well as increased product nutritional value. Based on the preliminary results that low MUNBV cows have greater digesta outflow rates and flow of microbial crude protein [63] to the duodenum, this question arises: would this affect the amino acid profile in the milk? If the amino acid profile in the milk was affected by breeding for low MUNBV animals, would this affect the biological value of milk for human consumption? In this manner, could breeding for both improved environmental outcomes from low MUN and low methane producing animals increase the nutritional value of the final product? Further research is required to investigate this potential.

4. Conclusions

There will be forever changing problems facing animal-based production systems, from environmental to nutritional concerns, surrounding the end product. However, advancements in technology and understanding of genetics present animal-based solutions that can be used to face these problems. The benefit of using animal-based solutions is that they are permeant, cumulative, and often more cost-effective than system-based approaches. The existing literature regarding reducing UN excretions from breeding for lower MUN levels suggests a promising avenue; however, this research is still very recent, and should be conducted at a whole farm level to further assess its benefits. Whilst reductions in CH_4 from breeding programs have been established in small trials as well as large modeling exercises, doubt remains about its effectiveness, with studies using the same metrics (e.g., RFI) finding conflicting outcomes. As a result, further research is needed. The use of new technologies and existing dietary manipulations are likely to produce synergistic effects with breeding programs. As a better understanding of animal behavior is developed from animals that have been bred for a reduced environmental impact, there is likely to be synergistic effects allowing for optimization of these beneficial traits through the use of new and emerging technology. This presents an area where further research and development are required. Although more research is required, the incorporation of environmentally beneficial or more nutritious genetic traits into breeding indexes is likely to allow producers to start incorporating these solutions into their systems. In this manner, producers will have the opportunity to breed more environmentally friendly animals, which are likely to have synergistic interactions with existing system approaches to solve problems faced by producers. This will allow for both the producers and the consumers to stop viewing animals as a problem, but rather as a potential solution.

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