Dairy Cattle Genetics by Environment Interaction Mismatch Contributes to Poor Mitigation and Adaptation of Grazing Systems to Climate Change Actions in the Peruvian High Andes: A Review

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Abstract
The high Andes of Peru includes fragile ecosystems. Nevertheless, it plays important ecosystem functions (e.g., biodiversity, water supply for the lowlands, CO_2 sinks in soil, etc). More than 80% of the livestock population of Peru is farmed in this area, supporting the livelihood of approximately 1'400,000 poor families, who are vulnerable to climate change (CC). Climate change in the high Andes is occurring at accelerated rates, compared to lowlands regions. Prevalent factors in the high Andes, such as hypoxia, high UV radiation, climatic extremes, large variation between maximum and minimum temperatures, seasonality in rainfall (determining highly seasonal forage growth) and CC, not only increase the feed and water needs of animals, but also affect animal production, reproduction, rumen function and welfare, making them more vulnerable to CC. During the last three decades, livestock farming in the high Andes has undergone transformation. The farming of camelids and creole species has been almost replaced by smallholder dairying, which have a higher environmental footprint. Institutions promoting dairying neglect the fitness requirement for the animal genetics to perform in such environments. Recent work of the New Zealand Peru Dairy Support Project (NZPDSP; 2016–2020) demonstrated that rapid and significant improvements in animal productivity and profitability of dairying can be achieved by promoting adoption of simple and low-cost husbandry practices. Nevertheless, further improvements are constrained by the unfitness of the current animal genetics. Here, based on a literature review and experience from the NZPDSP, we propose a search for dairy cattle genetics that contributes to mitigation and adaptation to CC, while enhancing the livelihoods of the poor.

Introduction
The Andes are home to varied biotic communities and diversity of species; reasons by which it is recognized as the most important global biodiversity hotspot (Tovar et al., 2020). This great biodiversity, the ecosystem services and sustainability of Andean agriculture are threatened by CC (Tito et al., 2017). Indeed, CC at high-altitude ecosystems is occurring at an unprecedented rate (You et al., 2019). According to INEI (2013), 73% of cattle, 94% of sheep and 100% of camelids are found in the Andes, providing the livelihoods to 1'400,000 smallholder families. INEI (2013) reported that in 2012 there were 5'156,000 cattle, 9'532,200 sheep and 3'685,500 alpacas, representing increases of 15, -21 and 50%, respectively, in relation to those reported for 1994. During the last decade, specialization towards dairying has occurred and likely the cattle population has increased even further. Now, Brown Swiss dairy cattle are a predominant feature of the Andean landscapes, whereas the farming of creole cattle and sheep, and camelids is only marginal.

Dairy farming at the Peruvian Andes has been aggressively promoted by state and mining institutions. It is attractive to smallholders because it provides them with a continuous income. However, the sustainability of the current system is questionable given that it requires high inputs and is reliant on subsides (NZPDSP 2020). Efficient production of milk by specialized genotypes is highly dependent on consistent supply of high-quality feed, water, and other inputs, which are scarce in the Andes. Furthermore, the evident mismatch between the characteristics of the predominant animal genotype and the prevalent conditions in the Andes is a determining factor for the poor production performance and profitability (NZPDSP, 2020). Andean dairy farming possibly has the highest environmental footprints of global livestock production systems. Addressing sustainability and CC issues in the livestock sector requires harmonizing synergies and reducing trade-offs between mitigation, adaptation, productivity, food security, animal welfare and general health (Orchard et al., 2020). In pastoral farming, the animal defines the efficiencies in the cycle of nutrients and energy flow, and consequently the environmental impact. The prevailing dairy genetics in the Andes is unfit to perform at the severe biotic and abiotic conditions of the Andes. Here, based on a literature review and experience from the NZPDSP, we

propose a rethink of the traits that dairy cattle should have to contribute to mitigation and adaptation to CC in the Andes, while improving the livelihoods and food security of the population involved.

Prevailing abiotic and biotic factors at the Andes limiting animal production.

The Andes climate is turning warmer and drier (Michelutti et al., 2015), with likely negative effects on pasture physiology, botanical composition, productivity, and forage quality (Ghahramani et al., 2019). Warming also increases the risk of pests and diseases, as well as heat and water stress in animals. Hypoxic stress is perhaps the most important single factor determining animal health, production, and reproduction performances of non-adapted genotypes. High mountain disease can be an acute or chronic response to hypoxia. At high altitude, basal metabolism of non-adapted animals can be up to 30% higher than at lowlands (Qiao et al., 2013), and up to 50% higher compared to that of adapted species (Han et al., 2003). High altitude also affects rumen microbiome diversity and function (Zhang et al., 2016; Wu et al., 2020), with consequent decreases in feed digestibility and concentration of volatile fatty acids but increases in CH_4 production.

The Andes due to its latitude, altitude, glacier retreat and lack of cloudiness has high solar radiation, having the highest UV index in the world. The maximum temperatures have little variation throughout the year, whereas the minimum temperatures drop during the dry season (winter). Heat stress may be a serious issue during the dry season, aggravated by the lack of shade and drinking water. Han et al (2003) have reported that exposure to solar radiation at high altitude may increase basal metabolism of cattle by up to 50%, compared to that on shade. The UV radiation negatively affects animal health as well as forage production and quality and feeding value (Comont et al., 2013). The low seasonal rainfall and shortening, high evapotranspiration (ET), a short frost-free period, and poor soil fertility in the Andes limit pasture growth. ET is not only high compared to that in the lowlands, but it is increasing due to CC (Torres-Batlló et al. 2020).

Characteristics of the current Andean dairy farming

Dairying in the high Andes is a relatively recent development (~3 decades). It is generally based on feedlot principles (NZPDSP, 2020). Supply of cut forage and concentrates feeding are favoured, whereas pasture management is neglected. Animals are already of high genetic merit and the trend is the use of purebred Brown Swiss of large body size imported via AI and embryo transfer from breeding programs suited to intensive feedlots. Feed requirements of the herd are almost constant across the year because calving is not seasonal, whereas the home-grown feed supply is highly seasonal. Excess pasture from summer is not conserved, but oats are grown specifically for hay that is harvested at full maturity, and hence of very poor quality.

Feed management does not respond to the requirements of animal classes. Drinking water is provided 2 or 3 times a day. Cows are in a body condition far below the recommended scores, which is also an animal welfare issue. Age at first calving is around 3 years and calving intervals are generally more than 18 months. Calf mortality is high. Cold stress, especially during the dry season is exacerbated by poor body condition, poor feed supply and milking. Cows are housed overnight for ~18 hours. Cow sheds are rarely cleaned, implying a huge environmental impact and loss of potential soil fertility (export of nutrients in excreta). Cow sheds also have implications on animal health, mortality, and milk quality. The dairying boom is likely aggravating the condition of the native grasslands, which are already in a severe process of erosion and loss of carrying capacity. The government runs a subsidised pasture sowing program, which in some degree turns native grasslands into pastures, with subsequent release of soil organic carbon. If new pastures are poorly sown and subsequent support for pasture management is not provided, the state of the grasslands can be jeopardised.

Improving the productivity, profitability, resilience, and adaptation to CC of Andean dairying

In principle, mitigation and adaptation to CC in the Andes should be based on exploiting the fitness of the local genetic resources (i.e., camelids and creole species). However, these resources are in the process of erosion due to the neglect by the academia, policy makers and influential institutions. Instead, Andean dairying has been greatly favoured despite its likely high production and environmental costs. Nevertheless, due to the large number of smallholders involved in this activity, improvement of the current levels of productivity, profitability and sustainability needs to be sought. In this direction, the recent work of the New Zealand Peru Dairy Support Project (NZPDSP, 2020) had demonstrated that rapid and significant improvements in productivity and profitability are feasible by applying improved animal husbandry practices that are simple, of little or nil cost, but of significant and rapid impact; hence, reducing its current environmental footprint (NZPDSP, 2020). In fact, permanent provision of drinking water, pasture and grazing management, management of body condition score, among other practices, are simple to be applied. Andean dairying is a complex system and interventions should be evaluated for system-wide effects. One single major decision that

may enhance productivity and decrease vulnerability to CC is establishing seasonal calving to match forage demand and offer, but this is a process that requires slow change. The current animal genetics are, however, a major cause of concern. The system involving highly specialised and large body size animals results in poor overall feed conversion efficiency, high cost of milk production and high environmental footprint. Andean dairying should be based on grazed pastures (cheapest source of metabolisable energy) to reduce costs. The grazing animal should be of medium or smaller size to counteract variability in feed supply and reduce maintenance/production ratio of feed requirements. Another positive effect of reducing body size would be the reduction of pasture trampling and soil compaction.

No company in the world breeds dairy cattle for high altitude conditions. The objective of production should not be milk yield per cow *per se*, but production with the lowest cost and environmental impact. The best bet genetic approach for the Andes should use creole cattle in crossbreeding with medium or smaller size dairy cattle bred on grazing situations, to gain fitness and competitive grazing ability and efficiency of digestion of grazed forage (Waghorn 2002). Meat must be a by-product. Specialized double purpose cattle are not an option due to their large body size, lack of fitness, and lower energy efficiency but high environmental footprint compared to dairy breeds (Reynolds et al. 2011).

Concluding remarks

Andean dairying provides a critical livelihood to many impoverished villagers. However, currently it is of low productivity, profitability, high environmental footprint and of high vulnerability to CC. Animal genetics is a key constraint for system improvement. Animal fitness traits need to be incorporated into genetic management aimed at lowering production costs, environmental impact, and vulnerability to CC.

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