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Derradji Harek,
Algerian National Institute for Agronomic Research INRAA, Algeria

*CORRESPONDENCE
Julia Bello-Bravo,
mbellobr@purdue.edu

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Social sustainability and genetic biodiversity in Peruvian alpaca production: a review

Julia Bello-Bravo[1]*, Denis Pilares[2], Luiz F. Brito[3], Alejandra M. Toro Ospina[3], Luis P. B. Sousa Junior[3], Gerardo Cornelio Mamani Mamani[3], Jon Schoonmaker[3] and Jennifer Richardson[4]

[1]Department of Agricultural Science Education and Communication, Purdue University, West Lafayette, IN, United States, [2]Departamento de Ciencia Animal, Universidad Nacional de San Agustin de Arequipa UNSA, Arequipa, Peru, [3]Department of Animal Sciences, Purdue University, West Lafayette, IN, United States, [4]Department of Curriculum and Instruction, Purdue University, West Lafayette, IN, United States

This conceptual review addresses the social sustainability challenges facing traditional alpaca pastoralism in Peru, particularly in light of economic and environmental interventions such as selective breeding for international market demands. While efforts to prioritize economic and environmental sustainability are well-documented, the neglect of social sustainability threatens the survival of traditional Andean knowledge, practices, and cultural resilience. Utilizing a triple-bottom-line framework, this review explores the social impacts of genetic biodiversity conservation efforts within the Peruvian alpaca value chain. It highlights how selective breeding, driven by global market preferences, risks eroding not only the genetic diversity of alpacas but also the sustainability of traditional herding practices. The review underscores the need for increased attention to social dimensions when implementing technical solutions to economic and environmental challenges, emphasizing the preservation of indigenous knowledge systems and practices to sustain the livelihoods and cultural heritage of alpaqueros. Recommendations include prioritizing social sustainability by integrating traditional practices into development agendas, fostering greater participation from indigenous communities, and encouraging the transmission of intergenerational knowledge to ensure the long-term viability of Peruvian pastoralism. Future research directions are also discussed.

KEYWORDS

alpaca production, social sustainability, biodiversity, Andean culture, climate change adaptation, Peru

Introduction

The historical resilience of alpacas and pastoralist traditions of alpaqueros in Peru highlight the lasting significance of this relationship, which continues to provide economic livelihoods for approximately 1.5 million pastoralists and contributes, in principle, to the environmental biodiversity of the region and the social wellbeing of

traditional Andean peoples generally (Ens et al., 2016). Nonetheless, alpacas and their traditional herders now currently face such an extent of environmental and economic pressures and impacts to their sustainability that their future is at risk (Astacio, 2022).

This conceptual review applies a triple-bottom-line framework (discussed below) to explore how *impacts from economic and environmental factors on the social sustainability of traditional Peruvian alpaca herding*—especially selective breeding practices aimed at meeting international market demands for specific alpaca fiber traits (e.g., more readily dyeable white colors and low medullation)—can affect the genetic biodiversity of alpacas and, consequently, the sustainability of traditional pastoralism. Salas (2003), for example, could draw attention in 2003 to the then-increasing threat of biological extinction facing the Suri breed of alpaca in Peru; a situation subsequently turned around thanks to environmental (genetic) and economic conservation efforts (GEF, 2018; Salas, 2015). A more immediate impact involves hereditary deafness associated with genetic loci and selective breeding for white pigmentation in many species, including alpacas (Gauly et al., 2005; Strain, 2015). The core issue here is not selective breeding *per se*, given that the initial domestication of alpacas ~6,000 years ago (Browman, 2014) and 200 years of an "alpaca wool industry" (Astacio, 2022, p. 1) in Peru have required selective breeding; rather, the issue is whether the long-term effects of current selective breeding practices aimed at meeting international market demands will sustainably conserve genetic biodiversity in Peruvian alpacas (Salas, 2015). Numerous Peruvian studies and projects (not documented in English) address the technical (environmental/genetic) aspects of this question (e.g., Chupillón Vásquez and López Cotrina, 2019; Córdova Flores et al., 2023; Espinosa-Heywood, 2010; Inocente Valverde and Miranda Diaz, 2021; Jara Ortega et al., 2019; Makini et al., 2020; Mercado Herida, 2023; Rosas, 2013; Salas and Belén, 2019; Salas, 2003; Sandi Ochoa, 1998). Prospects for extending successes like those described by Salas (2015) and other efforts to national-level breeding programs have been discussed (Gutierrez et al., 2018; Wurzinger and Gutiérrez, 2022).

However, the specific focus of this conceptual review is the *social* sustainability of traditional pastoralism in Peru facing these impacts. Notably, Astacio (2022) has expressed concern that the traditional knowledge and practices of pastoralist cultures in Peru have become *unsustainable*, primarily due to the "the ways in which extreme poverty, state abandonment, and climate change make alpaca herding itself an unsustainable practice" (Astacio, 2022, p. 1). Like other research (Bello-Bravo, 2023a; Bendix, 2000; Corntassel, 2008; Nadasdy, 2005; Watson, 2001), Astacio (2022) rightly notes that essentializing, or romanticizing, indigenous cultural knowledge and practices can contribute to its unsustainability, if not its demise, when it is imagined as fixed in time and not liable to (or permitted to) evolve and change (Bello-Bravo, 2023a). By "traditional" knowledge and practice we mean precisely any long-standing indigenous knowledges and practices that continue to evolve, adapt, and respond (like any other cultural form) to contemporary influences (Kimmerer, 2013; Waller and Reo, 2018).

Spanning at least six millennia, these contemporary influences have included indigenous, colonial, and post-colonial eras—from the initial adaptation of pastoralism and the domestication of wild alpacas as a response to the Andean environment's unsuitability for large-scale agriculture and their increasingly complex role over the rise of the Inca Empire, through colonialism's accelerating social displacements due to the introduction of new livestock, European diseases, and the suppression of indigenous culture, then post-colonial political instability, civil war, neoliberal globalization, zootechnical changes to alpaca production and breeding, and the degradation of grazing habitats from outsized climate variation, mismatches between larger herd sizes and available forage driven by increasing international demand for alpaca fiber, and the resulting deterioration of alpaca dentition and increased mortality rates, especially among newborns (Browman, 2014; Campos et al., 2021; Gill, 2019; Mengoni Goñalons, 2008; Klarén, 2022; Radolf et al., 2022; Soto and Ruelas, 2022; Wheeler et al., 1995).

In general, these are the well-known problems raised by unsustainable industrialized livestock production, especially when transitioning or attempting to modify indigenous or previously non-industrialized pastoralism (Tejon Tejon, 1982; Thompson and Nardone, 1999). However, it must also be stressed that despite two centuries of selective breeding for markets (Astacio, 2022), an alarming decline of non-white alpacas was first noted in the 1970s (Bustinza Choque et al., 2021). It is especially these problems posed by present-day environmental and economic impacts that Astacio (2022) cites as making traditional pastoralism in Peru now unsustainable. That the disappearance or destruction of languages and the cultures its speakers embody can be likened to an extinction (Ogwudile, 2023; Ortiz et al., 2020), it may be, as for the Suri alpaca in 2003, Peruvian pastoralism may now require concerted efforts to socially move it away from the brink of extinction.

Conceptual framework: triple-bottom line sustainability

Because no mechanism exists to enforce any standardization or consensus around what sustainability is, means, or does (Apetrei et al., 2021), we provide an abbreviated declaration of our framing of it for this paper, primarily for brevity, relying on previous work to elaborate any details not brought in here (Bello-Bravo and Lutomia, 2022; Giovannoni and Fabietti, 2013; Glavič and Lukman, 2007).

Since the time of its most-cited formulation by Brundtland et al. (1987), sustainability has been linked to *triple-bottom-line decision-making*, which evaluates the anticipated benefits or

drawbacks of a proposal, solution, intervention, or approach across three key domains: economic, social, and environmental (Schweikert et al., 2018). Rather than focusing on one domain in isolation, this framework prioritizes one or more while treating the others as collateral or supporting benefits. For example, prioritizing environmentally sustainable practices at a factory can reframe expenditures for training and equipment, as well as the enterprise's improved social perception, as benefits rather than costs (Ketelsen et al., 2020). Similarly, prioritizing industrialization for national economies and unlimited growth can reframe the use of seemingly unused or indigenously occupied environments, along with the transformation of long-standing socio-cultural knowledge and practices, as goods rather than losses (Desai, 2017; Fressoz and Bonneuil, 2017). These examples draw attention to two points: first, that decisions can allocate benefits across different domains without treating them as trade-offs; and second, that a further evaluation is needed to assess whether a given configuration of benefits is more or less sustainable than others (discussed below).

While the sufficiency and coherence of various framings of triple-bottom-line decision-making have been questioned (e.g., Bello-Bravo and Lutomia, 2022; Longoni and Cagliano, 2018; O'Neil, 2018; Schweikert et al., 2018; Sridhar and Jones, 2013; Svensson et al., 2018), a core emphasis is not to *equalize* sustainability's three pillars but to configure them such that *the ability of future generations to meet their needs are not compromised by meeting our needs in the present* (Brundtland et al., 1987); importantly, Brundtland et al. (1987) specifically mandates a first task of sustainability is to give overwhelming priority to meeting of the needs of the world's human poor (p. 41). This provides one evaluative criterion for determining whether a given decision is more or less sustainable.

To be clear, we say "the world's human poor" in part because that is the tacit assumption in Brundtland et al. (1987)—the "our" in the subtitle's *Our Common Future* embraces no species other than humans—but also because the sustainability of all other life on the planet is generally assimilated to the environmental. At the same time, numberless indigenous traditions—which sustainably maintained the persistence of the human species for hundreds of thousands of years—recognize the world's other species of life as sovereign beings, as our brothers and sisters, to whom we owe a moral regard at least analogous to (if not identical with) our regard for our fellow human beings (Baynes-Rock, 2012; Kimmerer, 2013; Mangena, 2013; Waller and Reo, 2018). In that light, we must reckon them, like ourselves, among the world's poorer or more well-to-do, not simply of world generically (the environment) (Kimmerer, 2013). Nor do we raise this point to additionally complicate the already intractable stakes of this paper. Nonetheless, we can (if not must) still acknowledge how sustainability can (if not must) include other life-forms in our decision-making, especially in a context of social sustainability for a form of indigenous pastoralism that recognizes alpacas are not simply livestock or a "natural resource" to be used at will (Parsons et al., 2021; Semplici, 2023; Trosper, 2002).

However we widen or narrow this scope of sustainability, another criterion for its *decision-making metric* echoes the medical decision-making principle (traditionally associated with Hippocrates) "to help, or at least to do no harm" (Smith, 2005, p. 371). Both in the practice of medicine and international development, this means making *the most effective, least invasive short-term intervention with the smallest, and least detrimental long-term impacts* (Bello-Bravo and Lutomia, 2022). Accordingly, interventions with smaller, less detrimental long-term impacts are by definition more sustainable than alternatives for any given effective, least invasive short-term intervention, ceteris paribus (Bello-Bravo, 2023b). Moreover, adherence to sustainability principles means selecting those more sustainable interventions.

If this provides insight into how to assess the sustainability of decisions, what is social sustainability itself? Here again, no consensus exists about it or its operationalization, and it is well-beyond the scope of this paper to elaborate its details or metrics sufficiently (see Baffoe and Mutisya, 2015; Colantonio, 2009; Desiderio et al., 2022). By social sustainability, we mean those continuities and supports for cultural knowledge and practices that contribute to communities' futures. While material wellbeing can be implicated in this, immaterial wellbeing is of no less (but probably greater) importance, i.e., qualities of community relationships between people and the world, mental and spiritual health, intergenerational continuity of knowledge and traditions, and the sheer prospects and hopes for a future itself (Williams, 1989).

Prioritizing the world's human poor in this paper—as the most basic criterion for sustainability (Brundtland et al., 1987)—means centering the social sustainability of the traditional relationship between alpacas and *alpaqueros* and the continuity of its culture, knowledge, and practices. If—as Salas (2003) warned—a short-term intervention was necessary to prevent a potential long-term extinction of the Suri alpaca—clearly an unsustainable outcome for the species—then the same logic applies to safeguarding the cultural knowledge and practices of Peru's traditional pastoralism to avoid its long-term erasure, which would be equally unsustainable. This does not mean that Peruvian pastoralism must remain unchanged, but rather that any changes should not be so drastic that it is no longer exists for future generations.

Method and discussion

In February of 2024, Google Scholar (GS) was selected to conduct a review of the literature on *impacts from economic and environmental factors on the social sustainability of traditional*

Peruvian alpaca herding, because although GS can be more time-intensive than Web of Science to work with (Cantrell et al., 2024), studies have found that its search results equal or exceed the Internet and other repositories as bibliographic sources (Cantrell et al., 2024; Gerasimov et al., 2024; Singh et al., 2023).

Generally, intitle-delimited searches (IDS) were conducted to ensure that key search topics were robustly represented, but this was supplemented at times by non-IDS searches (and searches in Spanish) due to limited relevant search results. Two factors complicated the initial non-IDS searches for relevant studies on alpacas in Peru: 1) the prevalence of zoological research that broadly addresses camelids as a group, and 2) the socio-cultural significance of herding various livestock species—including alpacas, llamas, vicuñas, and sheep—as part of Peru's pastoralist traditions. As a result, isolating studies focused solely on alpacas was not only challenging but also, in some cases, not desirable given the cultural interconnected of species. Moreover (as the Findings indicate), themes associated with social sustainability are often buried quite incidentally inside of otherwise explicitly zoological (genetic or alpaca breeding) studies; for example, Quispe et al. (2011) notes that farmers' traditional practice of a "willingness to exchange males across herds by different farmers" (p. 116) complicates scientific tab-keeping for breeding inputs and outcomes.

After trial and error experimentation with searches, a baseline intitle: "alpaca OR alpacas OR camelids" -"llama OR llamas" Peru search (yielding 2,290 results) was then further IDS and non-IDS for specific topics (e.g., sustainability, genetics, breeding, etc.). Duplicates were eliminated, and articles were reviewed for relevance to the review. The sections that follow present specific search terms used and findings for relevant studies, as well as discussion organized thematically for 1) economic and environmental sustainability, 2) genetic and breeding issues, and 3) social sustainability. Throughout, our metric for social sustainability configures traditional knowledge and practices as priorities such that environmental and economic aspects provide collateral or supporting benefits.

Environmental and economic sustainability

Narrowing the baseline with a non-IDS for "sustainability OR sustainable" (and later "sostenible OR sostenibilidad") yielded 702 results (7% of the 9,220 overall); further refining this as an IDS for the terms in English and Spanish yielded 17 items (0.18% of the 9,220 overall), with only 6 in English (e.g., Al Faruque et al., 2018; Andrade et al., 2024; Astacio, 2022; Gillespie and Terrill, 2009; Gutiérrez et al., 2024; Van Dyke, 2002).

Only 1 of these studies significantly addresses the central theme of this review (Astacio, 2022, discussed in the section on social sustainability below). Of the remaining five, 2 generically invoke the sustainability of alpaca herding in the United States (Gillespie and Terrill, 2009; Van Dyke, 2002); 1 addresses sustainable energy within the alpaca fiber value-chain (Gutiérrez et al., 2024), and 2 address issues around sustainable alpaca fiber dyeing (Al Faruque et al., 2018; Andrade et al., 2024). Specifically, Andrade et al. (2024) addresses "environmental sustainability of the removal of alpaca fiber dye using a thermally modified sludge from a drinking water treatment facility," while Al Faruque et al. (2018) describes a "chemical-free biocompatible and natural pigment based dyeing technique to colour acrylic fibres" (p. 1).

What is critically important to emphasize here is how the benefit to social sustainability is framed in terms of, or consequent to, environmental (and possibly economic) benefits for fiber processers. That is, one can readily imagine how more environmentally sustainable energy and chemical processes for producing whitened alpaca fibers could have collateral social benefits for traditional pastoralists in Peru. But as the first task of sustainability is prioritizing the needs of the world's human poor (not its manufacturing sector), these undeniably positive and helpful proposals for greater environmental sustainability are by definition less sustainable than similar efforts that forefront social sustainability itself.

Alternatively, how might prioritizing the social sustainability of alpacas and traditional alpaca herding yield more sustainable energy and more environmentally sustainable, less environmentally harmful, fiber processing approaches? Removing industrialized mass-production from the value-chain is the most obvious answer, even as that must surely result in a decreased fiber supply; nonetheless, the resultant exclusivity and rareness of the product might then generate a higher-end, not necessarily less profitable market for downstream stakeholders (McGrath et al., 2004). Alternatively, let an environmentally less toxic or non-toxic method of fiber processing be developed and placed under traditional herders' control as a value-added step to increase the downstream sale of the fiber (see the analogous example of neem use in Bello-Bravo et al., 2023a, p. 178). Not ignoring the difficulty, entrenched interests, or even the "Andean inhabitants aversion to risk" (Reyna, 2005, p. 3) toward implementing such changes, we can also at least not ignore that these alternatives are clearly (if not vastly) more sustainable than either current practices or the studies' proposals.

Further refining the 9,220 results IDS terms "indigenous," "traditional," and "alpaquero OR alpaqueros" yielded 4, 2, and 19 results, respectively; 19 in Spanish, 1 in Japanese, an English discussion of novel methods for sustainable control of gastrointestinal nematodes in llamas and alpacas in the southeastern United States (Gillespie and Terrill, 2009), and 2 addressing international importation of alpacas.

In one of these, Espinosa-Heywood (2010) frames economic and environmental issues around the impacts of the United States' "booming alpaca industry" on Peruvian alpacas

within its socio-historical context of illegal smuggling that afforded international alpaca markets (in the United States, Australia, and New Zealand) in the first place. Partly in response to this, national legislation in 1991 made the export of alpacas by Peruvian farmers legal for the first time in a century (Reyna, 2005), although a 1996 law then "declared alpacas and llamas . . . a genetic reserve of the country and put a ban on export on animals which won prises in fair" (Wurzinger and Gutiérrez, 2022, p. 1). Espinosa-Heywood (2010) specifically refers to this development by highlighting how international conventions continue to fail to recognize violations of such national "collective property rights" (Espinosa-Heywood, 2010, p. 29). In light of this social history, it is especially ironic that Sen (1995), in English, sounds an alarm that the importation of *Chilean* alpacas "may threaten indigenous species" *in Canada* (p. 1).

Genetics and breeding

Refining the initial 9,220 results with IDS terms "genetics OR genetic OR gene OR breeding" yielded 222 results (with 124 focused on Peru specifically). Understandably, the majority (120) in English addressed economic and technical aspects of alpaca (or camelid) genomics and diversity, reproductive and cria health traits, nutrition, and alpaca products (including meat and 65 studies on high-quality fiber, its improvement, low medullation, and avoidance of micron blowout) without any significant reference to social aspects.

Among the 4 studies that emphasized socio-cultural elements significantly, the excellent overview by Wurzinger and Gutiérrez (2022) highlights two important facts: 1) that genomic studies, although indisputable in value for livestock improvement (c.f., Meuwissen et al., 2016), also drive up production costs and will price out less well-to-do producers; and 2) that farmers are generally paid by weight for ideally finer alpaca fiber, which inherently weighs less; thus, there is an "antagonistic relationship between these two characteristics" (p. 2). Nevertheless, the authors also note some changes in the industry to pay farmers for the fineness of the fiber rather than its weight, and that it is "possible to consider both traits simultaneously . . . to achieve genetic progress in both" (p. 2). Related literature about community-based breeding programs (CBBPs) not limited to Peru raise similar themes (c.f., Haile et al., 2019; Wurzinger and Gutierrez, 2017; Wurzinger et al., 2021).

The authors also note farmer support and a measure of political will to establish a national breeding program in Peru, although the details and coordination for doing so are by no means at a consensus. They also cite two interviewed farmers, who expressed concerns about who would (or could) participate in such a program. The response of the authors also shows how it is possible to consider two traits at once (in this case social and genetic/environmental sustainability) for sustainable decision-making:

> Social inequalities must certainly also be taken into account in any implementation. But also from a technical perspective, the possible GxE [genetic by environmental] interaction has to be considered, as the management of the animals can vary greatly between farms with more or less technical equipment and financial resources (p. 5).

Prince (2015) raises socio-cultural issues, noting a "cultural reluctance to culling as a management method" and that democratic "changes to leadership and politics in different communities can potentially jeopardise the longevity of any initiative" (p. 14) comprise two "barriers to production and intervention strategies" (p. 14) for alpaca breeding; Prince (2015) also states that farmers "not knowing about modern medicine can lead to *superstitions*" (p. 14, emphasis added) about starting vaccination programs for alpacas, despite also noting that farmers had reported concerns about alpacas becoming ill after being vaccinated. One hopes that framing Andean indigenous people's "aversion to risk" (see Reyna, 2005 below) as "superstition" and their traditional cultural/political practices as "barriers" is not intentionally dismissive; either way, it illustrates how indigenous peoples' culturality and identity can become framed as "obstacles" (see Astacio, 2022 below, but also; Bello-Bravo, 2020; Desai, 2017; Nemutandani et al., 2016; Sanya et al., 2018; Watson, 2001).

In another publication, Reyna (2005) contextualizes why "the Andean inhabitant has an 'aversion to risk' . . . that is [a] product of [the] broken promises of the politicians in the past" (p. 3):

> Andean people prefer to keep their current technology and not to try something new as they are afraid [of] adverse results . . . [Also] in the political area, . . . legislation has been created to promote the breed of formed species like cattle and sheep, and the resources available were oriented to develop techniques in these species, failing to remember the importance of the camelids for the Andean inhabitant (pp. 3-4).

Lastly, Quispe et al. (2011) indirectly captures a social sustainability element when contrasting communal (collective) breeding strategies compared to centralized ones in Huancavelica. Specifically, although communal approaches showed a *slower* rate of genetic progress toward breeding goals, they had *higher* levels of farmer participation compared to centralized approaches (especially ones that used artificial insemination) (p. 111). Perhaps this decreased participation reflects a "risk aversion" to adopting artificial insemination as a technological innovation or continuities with a traditional

valorization and interpersonal relatedness at play between alpacas and alpaqueros in Peruvian pastoralism (Alaica and Gonzalez de La Rosa, 2019; Curatola and Szeminski, 2016). Either way, the observed preference for communal approaches itself suggests linkages to Andean *ayni* (Shepard, 2005), i.e., one of the many forms of traditional collective practices of reciprocal assistance to others in a community, like Rwandan *umuganda*, Kenyan *bulala*, and Amish *frolics* (Lutomia et al., 2018; Shepard, 2005).

Since increased participation is valuable both intrinsically and for fostering more equitably distributed social benefits, drawing on the social sustainability of this cultural collectivity may disclose pathways toward greater economic and environmental sustainability, including a potential for *faster* genetic progress. Culturally and practically, Quispe et al. (2011) also emphasize the need to incentivize farmers' participation in breeding programs (by highlighting the financial advantages of doing so), even if some additional costs will result from expenditures to prevent cross-herd disease contamination, especially given farmers' cultural habit of loaning males for breeding purposes (p. 117; also see Wurzinger et al., 2008). Viewing these preferences for collective action and mutual assistance as socio-cultural strengths can enhance economic sustainability by producing higher-valued, finer and more uniform fiber and promote environmental sustainability by maintaining genetic diversity, increasing alpacas' resilience to disease and environmental changes, and supporting the long-term viability of herds.

Social sustainability

Outside of Espinosa-Heywood (2010), only 1 already-referenced article by Astacio (2022) explicitly focuses on *economic and environmental factors affecting the social sustainability of traditional Peruvian alpaca herding*. This is not to suggest a lack of attention (in English) to broad issues affecting alpacas generally, e.g., 1) the international marketization of indigenous goods (like alpaca fiber, shea butter, or cocoa) (Bello-Bravo and Lutomia, 2023; Elias, 2003; Lovett, 2010; Striffler and Moberg, 2003), 2) environmental and ecosystems studies into genetic biodiversity and conservation (Belew et al., 2016; Oguh et al., 2021), or 3) more effective zootechnical control (of breeding, animal health, and hygiene) globally for sustainable (economic) development generally. It seems, rather, to reflect less consideration of these issues' *intersection* as well as other findings that sustainability's *economic* axis typically receives disproportionately greater emphasis (Afful et al., 2020), and that, for key terms in international development, "'economic' perspectives dominate 'sustainability' and 'social' perspectives by a factor of 2 and 4.67, respectively" (Luetz and Walid, 2019, p. 301).

Thus, in an address at the Tufts Hoch-Cunningham Environmental Lecture Series in 2022, Astacio (2022) cautions:

> Despite its over two-hundred-year existence, the alpaca wool industry relies on the herding and animal care practices of Quechua-speaking herders in the Peruvian highlands. I argue that this persistence of indigenous forms of breeding and animal care are not only read by fashion industry actors as an assurance of sustainability, but *this essentializing view of indigenous peoples as stewards of the environment* obscures the ways in which extreme poverty, state abandonment, and climate change make alpaca herding itself an unsustainable practice (p. 1, italics added).

In our reading of Astacio (2022), she highlights how the romanticization of indigeneity—even when well-intentioned or enthusiastic—creates a problematic framework that "pins" indigenous cultures to a permanently static time and place, which is not only inaccurate but also politically disenfranchising and threatens the practice with cultural extinction (Bandi, 2013; Bello-Bravo, 2019; Bendix, 2000; Corntassel, 2010; Watson, 2001). However, indigenous cultures have never been purely static and have engaged, like any other culture, with endogenous and exogenous influences as they emerge.

Notably, 0 results were found for a search of the baseline and the non-IDS term "social sustainability" itself; removing the intitle-delimitation for "alpaca OR alpacas," 65 results were returned, with 55 results for non-IDS term "farmers OR farmer" and 57 for the non-IDS term "indigenous." Thus, while all of the articles at least allude to alpacas and alpaca pastoralism, it is often not the focus of the article; in fact, an IDS for "Peru" specifically returned only 8 results, none focused specifically on alpaca pastoralism (e.g., seed quality in perennial grasses, green interventions for urban water infrastructures, Canadian mining companies in Peru, institutional science and technology policy, and terrace farming for potatoes); what Bhattacharya (2021) concludes in a Masters' thesis "Heritage-Led Planning for Rural Community Resilience: Terrace Landscapes in Peru," certainly applies to indigenous experiences generally:

> Research results indicate that heritage in rural Andean communities in Peru is defined by strong social relationships which are sustained over generations. Results corroborate that terraces [traditional practices] contribute to community resilience through increased social bonds, closeness with the environment and economic stability (p. 2).

Even broadening the cast of the net, the majority of studies concern non-alpaca sectors of the Peruvian economic landscape under the banner of social sustainability (e.g., the asparagus and cocoa value-chains, impacts from road development projects,

ecological and gastronomic tourism, frameworks or critiques of the fashion industry, global agricultural digitalization, historical/political analyses of the Peruvian scene generally, and technology policy, especially for adaptation to climate change). Direct references are scant. Becchetti et al. (2011) utilize a social wellbeing framework and metrics to analyze one of their study's case studies on Peruvian women's textile weaving traditions. Cancino et al. (2022) use a social capital framework to note that indigenous farmers can (and should be) allies in soil conservation efforts. As part of UNEP's *Toolkit to Support Conservation by Indigenous Peoples and Local Communities*, Corrigan and Hay-Edie (2013) highlight traditional Peruvian kite-making as a way to photograph and document the impacts of extractive mining.

The near-total absence of women's experiences is particularly striking, not only because of the central role of women's labor in traditional alpaca pastoralism (Arrosquipa, 2014; Oliveira, 2022), but also due to the critical importance of social sustainability for women (Wheeler and Nye, 2024) and their extensive involvement in agricultural, domestic, and birth services labor (Bello-Bravo, 2016; Bello-Bravo, 2023c; Bello-Bravo et al., 2015; Bello-Bravo et al., 2017); in fact, narrowing the baseline search with the term "gender" gives more results for alpaca females than humans. Again, while these issues are not unacknowledged—though clearly less prevalent and specific compared to other topics—the connection between social sustainability and (indigenous) women's knowledge and practices is rarely made. Considering the generally greater poverty faced by (indigenous) Peruvian women (Bourque and Warren, 2010), further exacerbated by neoliberal economic policies from 1990 to 2000 (Boesten, 2010), sustainability efforts that prioritize the world's poor must recognize that interventions centered on women are inherently more sustainable than those that treat gender neutrally or exclude gender considerations. Moreover, while greater educational attainment can provide Peruvian women with more resilience against major social shocks (Glewwe and Hall, 1998), it is important to recognize that residual confounders, such as socioeconomic status, may obscure or distort the true relationship between education and policy outcomes (Langa and Bhatta, 2020; Sorjonen et al., 2021). This distinction matters because it influences where solutions are directed—whether toward providing more information and education or addressing poverty reduction more directly.

Lastly, the life of traditional pastoralism in Peru is acknowledged as vanishingly difficult—if not now unsustainable (Astacio, 2022). In Spanish, Fernandez et al. (2016) summarize the situation and one solution:

> At one end of the camelid value chain in the high Andean lands, at least 34,000 shepherd families live as part of Peru's poorest and most vulnerable rural population. With an average herd of 150 alpacas, the annual net income of a shepherd family does not exceed 1,500 soles (less than 500 USD) after deducting the production costs of fiber and meat. On the other side of the same alpaca chain, two industrial companies in an oligopoly position process 90% of the fiber produced in the country, with the remaining 10% distributed between COOPECAN-Peru and several small family businesses. In addition to facing extreme weather and soil conditions, the vast majority of these families do not belong to an organization strong enough to face the market, nor do they benefit from the results of research conducted to improve their current conditions. Without access to formal credit due to a lack of real guarantees, they also lack capital to invest. (p. 25, my translation) . . . Through a dual strategy that affects both the management of natural resources and camelids as well as social organization, the Cooperative for Production and Special Services of Andean Camelid Producers Ltd. (Coopecan-Peru) has succeeded in increasing the productivity and net income of its members, positioning itself in the camelid value chain by altering traditionally unfavorable conditions. The practice changes described in this article, in addition to being socially and financially sustainable, have a positive environmental impact by reducing overgrazing in the high Andean lands (p. 24, my translation).

These harsh conditions, coupled with decades of urban displacement and the allure of better opportunities—whether real or perceived—in urban centers, have led younger generations to abandon alpaca herding in search of more promising prospects in cities. This trend, marked by a decline in intergenerational knowledge transfer, is a key factor contributing to the erosion of traditional pastoral practices.

María Elena Garcia has noted the complex interweaving and transformations to identity that such displacement entails for younger generations (García, 2000; García, 2005). de la Cadena (2000) traces the 20th century's arc of these developments, while Planas et al. (2016) explores its more recent, highly nuanced shape for Quechua women. These transformations are not simply unilinear "losses" of indigenous culture but are ongoing iterations of a reshaping of cultural identity in response to contemporary events. Nonetheless, the disappearance of intergenerational knowledge is explicitly unsustainable, as its extinction ensures that future generations will no longer benefit from its value. A straightforward intervention into this situation would be to include the recording and conservation of traditional practices and knowledge—just as one might bank germplasm to preserve alpaca genomics—as a basic part of any breeding or genetic improvement program. Efforts do exist to preserve Peruvian indigenous knowledge, including for alpacas (Bhattacharya, 2021; Corrigan and Hay-Edie, 2013; Gutiérrez et al., 2014); it would be more sustainable for this to be ubiquitous.

Limitations, recommendations, and future directions

Limitations

Like all reviews, the central limitation here hinges on capturing an adequate range of publications on the topic (Moher et al., 2009); this limitation is offset by a thorough, iterative, and creative search approach and the emergence of data saturation, i.e., when varying searches begin to yield only the predominantly same themes (Francis et al., 2010). For the present conceptual review (in English), this necessarily excludes Spanish-language peer-reviewed and grey literature (especially reports on alpaca biodiversity and conservation efforts under the pressure of international market demand for particular qualities of alpaca fiber) (e.g., Chupillón Vásquez and López Cotrina, 2019; Córdova Flores et al., 2023; Espinosa-Heywood, 2010; Inocente Valverde and Miranda Diaz, 2021; Jara Ortega et al., 2019; Makini et al., 2020; Mercado Herida, 2023; Rosas, 2013; Salas and Belén, 2019; Salas, 2003; Sandi Ochoa, 1998).

For the overall state of knowledge in English publications on *the social sustainability of potential impacts from efforts to preserve or improve the genetic biodiversity of alpacas in Peru*, this review finds 1) considerably more focus (prioritization) on work addressing the host of technical (genetic and environmental) processes and "by-products" introduced along the industrialized alpaca value-chain and 2) little to no focused prioritization on impacts to traditional knowledge and practice. This reflects not only the documented general deprecation of social sustainability itself (Afful et al., 2020; Luetz and Walid, 2019) but also a subordination of efforts and issues related to social sustainability (e.g., cultural practices, identity, and community wellbeing) that treat these as resources to be used (sustainably or not) to support more prioritized economic and environmental sustainabilities.

Recommendations and future directions

Overall, this conceptual review's recommendations and directions for future research call for more strategies for prioritizing social sustainability when researching, designing, and implementing (technical) economic and environmental problems. These recommendations can be applied to any of the technical issues identified in this review along the alpaca value chain, including 1) genomic losses to alpaca biodiversity, 2) selective breeding to meet international market demand, and 3) the long-term viability and adaptability of alpacas facing forage changes due to climate change.

Accordingly, the first recommendation is to prioritize greater attention to the social dimensions that arise as consequences of solving technical solutions. For example, even when innovative approaches to distributing information, resources, or solutions are developed, they often fail (again) to reach historically marginalized demographics—those isolated by poverty, remote locations, or barriers related to gender and educational access (Bello-Bravo et al., 2023b). Equally, the lack of integration between the alpaca literatures in English and Spanish (and other languages') and the vastly more abundant attention given to economic and environmental sustainability indicates a *social* problem itself (Afful et al., 2020; Hensley and Steer, 2019; Luetz and Walid, 2019).

Although the obvious recommendations (as solutions to these problems) are better bridges between the literatures across languages and giving overwhelming priority to social sustainability as per Brundtland et al. (1987) from nearly 40 years ago, the persistence of these issues is telling; analogies with the challenges of implementing inter-disciplinary and trans-disciplinary research practices are illustrative (Gidley, 2013; Milena et al., 2024; Van Biljon, 2011). Future research might qualitatively investigate 1) perceptions and beliefs that lead to such deprioritization, 2) case studies of successful implementations where social sustainability was prioritized, and 3) practical applications of those findings for ameliorating technical *and* social problems in projects, including breeding programs for high-quality alpaca fiber in Peru.

Second, we recommend that solution designers amplify the goodwill of their efforts by spending time to explore a prioritization of the social sustainability of traditional alpaca knowledge and practices when imagining solutions for technical problems. This is especially germane for the (social) problem of mandates for alpaqueros (and alpacas) to abandon traditional behaviours and practices if they would participate in (technical) solutions on offer. By centering the social sustainability of traditional alpaca herding, programs for solving technical problems might also dedicate resources to documenting and preserving traditional herding knowledge, practices, and even languages of the local communities involved (UNESCO, 2022; UNESCO Liaison Office in New York, 2016).

Equally, against the tendency to disregard or even denigrate indigenous (traditional) knowledge and practices around the ecological stewardship (Gandugade et al., 2017; Kimmerer, 2013; McGrath et al., 2004; Nemutandani et al., 2016; Waller and Reo, 2018), it seems expressly irrational not to give decision-making and agenda-setting priority to the participation, experiences, and ideas of traditional stakeholders, even in service of non-traditional innovations. Much research documents the socially and practically negative impacts of overly hierarchical collaborative relations and advocates for less vertical power relations (Corntassel, 2012; Eisler, 2007; Eisler, 2015; Eisler and Potter, 2014; Jackson, 2020; Kimmerer, 2002; Lawrence and Dua, 2005; Lutomia et al., 2020; Mangena, 2016). Such advocacy already resonates with the traditional pastoralist understanding of a more horizontal, mutually

beneficial *relationship* that exists between a herder and the herd, the community, and the world.

Third, echoing Astacio (2022), research must find ways to navigate treacherous conceptual and practical waters so as not to condemn currently unsustainable traditional alpaca herding to extinction by overly romanticizing its social knowledge and practices on the one hand while, at the same time, not transforming it so completely in response to industrialized fiber production pressures that it disappears. If we are not going to accept that Peruvian pastoralism *should* die out, then the principle of sustainability mandates that our use of it now to meet our needs in the present must leave it still available for generations in the future. Besides encouraging or requiring the documentation and preservation of traditional knowledge and practices by any project that directly or indirectly affects Peruvian alpaca pastoralism, future research must 1) investigate and develop solutions to remediate the degraded environmental and economic landscape making pastoralism unfeasible, 2) more actively support traditional pastoralist *leadership* in projects that directly affect their culture, and 3) especially investigate existing, and potential, efforts to rebuild the lost bridge of intergenerational knowledge and identify what perceptions and beliefs can make being an alpaca pastoralist attractive.

Conclusion

Throughout this review, we have offered suggestions for more sustainably intervening into the potential impacts of efforts to preserve or improve the genetic biodiversity of alpacas. These are not criticisms or deprecations of such efforts but potentially an amplification of the benefit(s) they aim at, amplifications that more accurately align with the commitments to sustainability that inform so many efforts around the world today.

Even only as a design principle used when developing technical innovations for the alpaca value chain, prioritizing social sustainability (and the people most affected by the world's inequalities) asks us to pause and not immediately dismiss the solutions that come into view. At a minimum, possible additions to our own knowledge and practices will become productively visible. Even if we cannot then fully implement those solutions, such an approach is not a benefit solely for the traditional pastoralists we place ourselves in solidarity with, but our own long-term sustainability as well.

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JB wrote the initial draft, and all authors then contributed, reviewed, and revised the text. JB-B, LB, and DP edited the revised text. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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