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Relevance of the production system for the sustainability of conservation and breeding programs for the Creole cattle in Pasorapa, Bolivia

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Abstract
Local livestock breeds play an important role in the food security of smallholders in developing countries in the Global South. They are also a reservoir of potentially valuable genes for adaptation of global animal genetic resources. The Creole cattle population from Pasorapa, Bolivia, is threatened by effects of climate change and unplanned crossbreeding. The aim of this study was to assess the current situation in this population and to evaluate factors to be considered before implementing conservation and genetic improvement programs in order to achieve the sustainable development goals 1, 2, 13 and 15, which refer to no poverty, zero hunger, climate change and life on land, respectively. We examined and analyzed the most important elements related to the production system and farmers' perceptions that could affect the design of such programs. Open-ended and closed-ended questionnaires and interviews were performed with 81 smallholders from 11 communities in Pasorapa. A rearing system based on two stages and animals feeding mainly on native plants during both, involves a strong interaction between the environment and the production system. A survey of farmers' perceptions about diseases, mortality causes, and selection criteria revealed that farmers in Pasorapa consider coat color an important trait when selecting breeding and replacement animals. Half of all interviewees perceived an association between coat color and traits such as temperament, milk yield, and beef production. In a SWOT analysis we discussed the vulnerability of the system to climate change impacts and the contribution of this traditional system to rural mitigation. Overall, this work revealed the importance of this local ecotype and identified key factors to consider when developing breeding and conservation programs.

Keywords Creole cattle · Global South · Climate change · Sustainability

1 Introduction

Animal genetic resources are important in different aspects, from their contribution to the livelihoods of smallholders to their broad social and cultural importance, use in actual breeding programs, potential as a gene reservoir of a wide diversity of traits for future applications, role in the adaptability and resilience of production systems, and as key elements in the achievement of Sustainable Development Goals (SDGs) [1–3]. In developing countries in the Global South, local livestock breeds often play a crucial role in the food security, nutrition, and health of the rural community. In harsh

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environments, these cattle populations offer more diverse ecosystem services, including the possibility of using land not suitable for crop production (Fig. 1). Also, in some communities, animals are still used as draught power and transportation for agricultural work [1]. This variety of functions is a common feature of livestock production in the Global South [4].

In order to design appropriate conservation and breeding programs for local and highly adapted cattle populations, description and analysis of the current production system are required. Incomplete knowledge of the dynamics of the production system and perceptions of farmers can lead to inconsistencies and failure of conservation and genetic improvement programs. The aim of this study was to assess the current situation in a population of Creole cattle in Pasorapa, Bolivia, and to evaluate factors to be considered before implementing conservation and genetic improvement programs in order to achieve SDG 1, 2, 13 and 15. Although the actual information gathered is population-specific, the general approach and considerations may be of use also for other cattle populations in the Global South.

2 Materials and methods

2.1 Study area

The study was carried out in the Pasorapa region in the south-east corner of the Department of Cochabamba, Bolivia. Data were collected from farms located in 11 of a total of 33 local communities in Pasorapa, namely La Aguada, Buena Vista, La Abra, Pasorapa (OTB Norte), Conchu Laguna, Robles, Ruda Pampa, Seibas, Tabacal, Toyota Baja, and Zapallar.

A total of 985 farms keeping cattle in the 33 local communities were registered in the database of the Municipal Government of Pasorapa in 2017. In the 11 communities included in this study, 375 farms were registered but not all of them rear mainly Creole cattle.

2.2 Selection of farms and communities

Farms to be included in the analysis were selected during reconnaissance trips performed at the beginning of the study. Unfortunately, there are no census data available about the proportion of crossbred and Creole animals on each farm. At that moment, no previous written reports about morphological differences between crossbreds and Creole individuals were available. Therefore during the reconnaissance trips, we created a list of typical morphological traits of individual Creole cattle (Small dewlap, upward-forward oriented horns, small ears laterally oriented, small and thin head, absence of hump, straight and medium length hair, long and thin legs), based on interviews performed with the veterinarian in

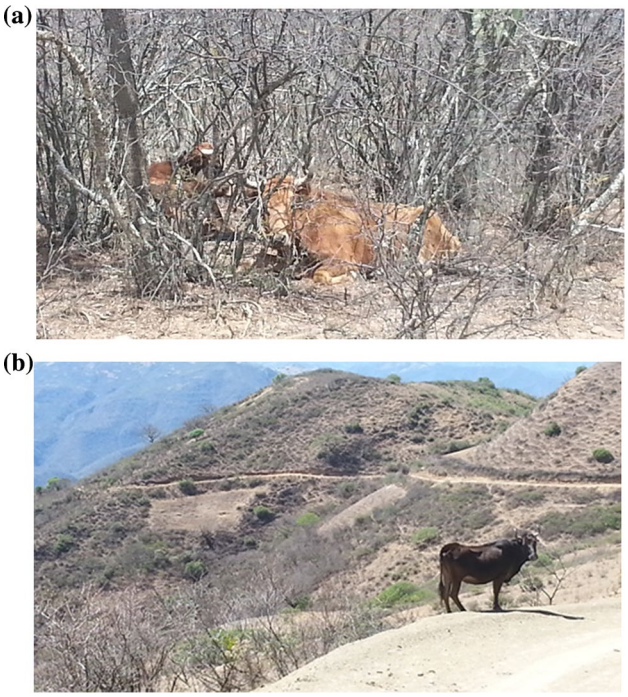

Fig. 1 Images showing the typical environment for Creole cattle in Pasorapa, Bolivia. **a** This population is suggested to be well-adapted to a xerophytic environment and challenging rearing conditions **b** being released onto rangelands for an average of seven months per year

Pasorapa and older farmers in the communities. Once criteria for discriminating between Creole and crossbreed cattle had been established, farms rearing mainly Creole cattle were identified [5].

The criteria for selection of participants were as follows: ownership of a herd consisting mainly of Creole cattle, access by road to the community and the farm, and willingness of the farmer to participate in the study. Snowball sampling, i.e., where identified participants suggested new participants, was performed. Because more distant communities are accessible only by motorbike or by horse, and the condition of roads is not always good, accessibility was a necessary criterion for selecting a community [5]. After the snowballing procedure, we had a set of 81 farms. These amounted to 22% of all farms in the target communities, but would constitute a larger proportion of herds with mainly Creole cattle.

2.3 Field observations

During the farm visits, direct observations about infrastructure in paddocks and the main characteristics of the cattle management practices were documented as field notes and pictures. During visits scheduled between June and October (Paddock stage), tours were made in the farms surroundings to observe cattle behavior and feeding options. For interviews scheduled between November and June (ranch management stage), and depending of the availability of a guide, tours were made across the rangelands to observe cattle behavior, feeding options, eating behavior, places to sleep (*dormideras*), water sources in the rangelands, and walking ability of Creole cattle in rugged terrain. Information from the rangeland tours was documented in field notes, pictures, and video recordings. With the help of a guide, who was always a farmer from Pasorapa, native plant species consumed by the cattle were collected and identified by their common name with the support of at least three different farmers. Taxonomic identification was performed at the Universidad Mayor de San Simon (UMSS), Bolivia [5].

2.4 Questionnaires, interviews and SWOT analysis

Questionnaires and interviews were performed in two stages between 2014 and 2016. The first stage consisted of open and closed-ended questionnaires (Q1) applied to all 81 farmers. In Q1, qualitative and quantitative data relating to householders, farm location [including a map and means of road access (horse, motorbike, or car)], herd structure, animal health management, feeding strategies, causes of mortality, and information on the production system were collected. The second stage consisted of open-ended questionnaires (Q2) and face-to-face in-depth interviews (Int-A), following a semi-structured approach, with a subset of 16 farmers identified as being the most traditional Creole cattle breeders and belonging to eight of the 11 communities included in the study. Data saturation, i.e. when no more new information was obtained, was reached before all 16 farmers had been interviewed. This second stage was performed to obtain additional qualitative data to understand the reasons behind rearing and management practices. The questions in Q2 were related to calf management, selection criteria of sires and replacements, improvements in infrastructure, workforce, and association between coat color and production and temperament of the animals. During the interviews (Int-A), the main topics covered were: main concerns about the production system, perceptions of the value of the breed, diseases and treatments, and differences between crossbred and pure Creole individuals.

In January 2018, 10 of the subset of 16 farmers were interviewed once more (Int-B), to identify possible differences to the responses in Int-A. Because of time restrictions on this last piece of field work, it was not possible to contact and arrange to meet with all members of the subset of 16 farmers from the second stage.

All questionnaires and interviews were in Spanish. Interview responses were transcribed in full and analyzed with the QSR International's NVivo 10 software, to identify the most frequent expressions and terms given by the farmers regarding a specific topic or variable. Basic descriptive statistics were calculated for quantitative data using Excel and R version 3.5.1. Copies of the questionnaires and semi-structured interviews are available upon request.

A SWOT analysis was performed to identify the key factors influencing the Creole cattle production system in Pasorapa. After brainstorming and discussion, we identified the strengths, weaknesses, opportunities and threats of the system. Unique and important advantages were identified as strengths, while disadvantages when comparing with industrial livestock systems of highly productive breeds were listed as weaknesses. Field observations allowed us to recognize factors to be improved and elements that could contribute to enhance productivity and reach a sustainable management, such were cataloged as opportunities. Finally, factors risking the system were documented as threats.

3 Results and discussion

3.1 Household characteristics and livestock workforce

The farms were all smallholders operating mixed low-input crop-livestock production systems or, in some cases, solely landless livestock systems. Most respondents (39%) were aged between 60 and 70 years, followed by a group aged between 50 and 59 years (35%), and a group aged between 40 and 49 years (22%). Only 4% of the farmers were below 30 years old, and no respondents between 30 and 39 years old were identified. Most households had a male head (86%), with the remaining 14% having a female head. Women participated in milking, carrying water, cheese processing, herding, vaccination, and calves.

Around 33% of householders only had the help of their wives to manage their cattle, while 24% reported that they sometimes had help from a neighbor, friend, or relative, 14% hired one cowboy, and 5% hired two cowboys during the Paddock stage (See Sect. 3.2). Most livestock keepers did not hire employees all year round. Hiring of cowboys during the Paddock stage was more common, but most smallholders depended almost exclusively on help from family members. According to Rapsomanikis [6], the use of hired labor for smallholders in Bolivia is very limited, and investment of family labor is greater than the use of capital for production.

Lack of hired workers (cowboys) could also be explained by unavailability of a suitable and committed workforce. Most young people go back to Pasorapa only during the paddock stage, around the Festivity of San Juan on June 23, to help with farm activities. But, once vaccinations are done or cattle are released to the rangelands, they go back to the city. An in-depth study of the effects of migration from rural to urban areas on the Creole cattle production system of Pasorapa is lacking, but the main reasons for people moving out of rural areas appear to be poverty and food insecurity, lack of employment and income-generating opportunities, limited access to social protection, and weather-related disasters.

3.2 The management system

As is true for many low-input production systems in the Global South, livestock management is adapted to the natural ecosystem. The management system in the study region is divided into two stages per year: a Paddock stage (dry season) between June and October and a Ranch stage (rainy season) between November and June (Fig. 2) [7]. The Paddock stage starts in connection with the festivity of San Juan, on June 23, when most cattle are collected. After crop residues are finished and there is no more feed available, the animals are taken to the ranchlands, which in most cases are located far away from the paddocks. Availability of feed is the main determining factor extending or decreasing the time for which the animals are kept in the paddocks. Lactating, old, or sick cows and calves are usually kept in the paddocks for the longest time. If there is no feed left they are sold or released to the ranch land, where they often become easy prey for predators (Int-A).

During the Paddock stage, cattle spend time feeding on the crop fields or in the farm surroundings, where they search for water, browse and graze native pastures and native plants (water troughs were present only in some cases). The most common crop used to feed cattle is maize (*Zea mays*). A feed blend called *T'aqo*, made from ground maize grains and ground pods and seeds of algarrobo (*Prosopis alba*), is prepared and used as a traditional balanced feed and given to

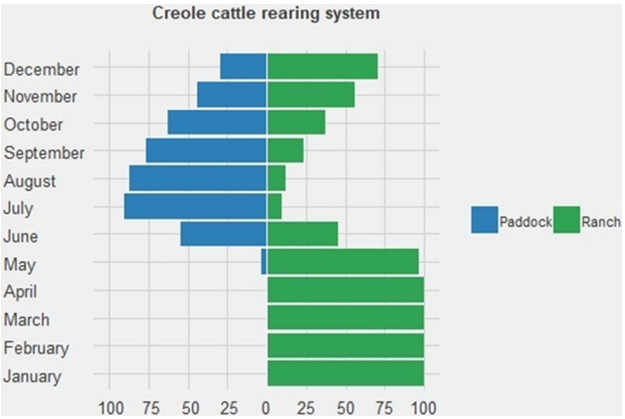

Fig. 2 Percentage of Creole cattle located in paddocks or on rangelands around Pasorapa, Bolivia, in different months of the year

milking cows, calves, and sick or lean animals. Some farmers produce maize silage on a small scale. By 2018, 200 families in the study region had planted 1000 plants of prickly pear cactus (*Opuntia ficus-indica*) and half a hectare of Gatton panic grass (*Megathyrsus maximus*) as optional feedstuff to prevent feed shortages during drought periods. This initiative was supported by Pasorapa's Mayoralty, the NGO *La Parroquia*, and the Centro de Investigacion en Forrajes-Universidad Mayor de San Simon (CIF-UMSS).

None of the farmers surveyed used any special feeding treatment tailored for a certain animal category. Milking cows were kept in corrals only for a limited time in the morning, before being taken to grazing and browsing areas elsewhere on the farm. Black rocks of salt were made available in the paddocks and across the ranch as a mineral supplement. Commercial balanced feed was not provided, unless a specific animal had to gain weight rapidly in order to be sold for beef production.

Throughout the Ranch stage, cattle spend most time browsing and searching for food and water. They feed only on native pastures, shrubs, and forage trees. The native species most frequently used as forage for cattle according to questionnaire (Q2) are listed in Table 1. It is relevant to mention that the local shrub species *Heterophyllaea lycioides* (Rusby) Sandwith, which causes skin photosensitization, is still consumed by cattle during feed shortages. Consumption of the plant species listed in interviews as being used by the cattle was confirmed by field observations.

Water ponds (*atajados*) have been built in different places across the ranchlands and these may be private or for communal use. They are filled by rain water or by using water wagons. During drought periods, these water ponds completely dry up, forcing animals to walk long distances until they find a watering point. During the Ranch stage, groups of animals of the same herd are found using the same place to sleep every night (*dormideras*).

3.3 Purpose of rearing Creole cattle

Adaptability, disease resistance, and good walking ability of Creole cattle, as well as tradition, low labor requirement and "less care" needed, were mentioned by most interviewees as the main reasons for rearing Creole cattle (Int-A, Int-B). All farmers interviewed considered Creole cattle to be a dual-purpose breed (milk and beef), but no fattening practice was identified. Milk was produced only for self-consumption and production of cheese, occasionally sold at a winter festival (Dry season). According to interviews (Int-A, Int-B), meat and cheese are not produced in large quantities, owing to lack of infrastructure and equipment. Creole cows were reported to produce between 3 and 5 L of milk per day (Q2). Farmers and workers from the only slaughterhouse in Pasorapa reported that the quantity of beef produced per animal

Table 1 List of native plant species consumed by cattle in Pasorapa, Bolivia

Common name	Scientific name
Achuma	*Trichocerus bridgesii*
Achupalla	*Eryngium paniculatu*
Algarrobo	*Prosopis alba* Griseb
Carapari	*Neoraimondia herzogiana* Backeb
Cegadera	*Heterophyllaea lycioides* (Rusby) Sandwith
Chacatea	*Dodonea viscosa* (L.) Jacq
Jarka/Arca	*Senegalia visco* (Lorentz ex Griseb.) Seigler & Ebinger
Khayara/K'jayara	*Bromelia sera*
Khari (Cari cari)	*Senegalia bonariensis* (Gillies ex Hook. & Arn.) Seigler & Ebinger
Kiñi	*Vachellia aroma* (Gillies ex Hook. & Arn.) Seigler & Ebinger
Melendre	*Gochnatia palosanto* Cabrera
Melendrillo	*Gochnatia boliviana* S.F. Blake
Munchuelo	*Senegalia gilliesii* (Steud.) Seigler & Ebinger
Paja brava	*Stipa ichu* (Ruiz & Pav.) Kunth
Pasto	*Digitaria californica*
Quina quina	*Myroxylon peruiferum L*
Soto	*Schinopsis haenkeana*
Tipa	*Tipuana tipu* (Benth.) Kuntze
Villca	*Anadenanthera colubrina* (Vell.) Brenan
Yareta	*Azorella compacta*

ranges between 120 and 180 kg. Unfortunately, none of the farmers surveyed kept records relating to cattle production or reproduction traits.

In the most remote communities, oxen or even breeding bulls were reported to be still used for draught power. On all farms surveyed, cattle were occasionally sold to generate income. Male calves were sold before 1.5 years of age. Females were used for calf production and stock replacement, and were kept in the herd for as long as possible. Old or sick cows and heifers with abnormalities were offered for sale. Animals were sold on-farm to traders, for either slaughter or sale in the markets of Aiquile, Punata, Totora, and Omereque in the Department of Cochabamba. Young bulls were taken mostly to markets in the neighboring Department of Sucre.

3.4 Breeding strategies and selection criteria

During the Ranch stage, animal mate mainly at random. Females arrive in the paddocks already pregnant, or accompanied by their calf, after the Ranch stage. Although farmers understand the importance of not mating females before 1.5 years of age, some females are pregnant already at one year of age. Such animals stop their development and remain smaller than the average size. Our field surveys revealed that breeding bulls were only Creole cattle on two-thirds of the farms visited, while on the remaining one-third either crossbred or exotic breeding bulls were used. These bulls were purchased from the Department of Santa Cruz. In the past few years, bulls of Holstein, Brown Swiss, Gyr, Nelore, Pinzgauer, Limousin, Simmental, Brahman and other zebu breeds have been introduced. A group of farmers reported purchase of 11 Creole bulls from the Centro de Investigacion Agricola Tropical (CIAT) Saavedreño herd in 2017–2018.

The criteria applied by farmers to select breeding bulls (Q2), in order of importance, were: body size, body conformation and milk yield of dams, body size and conformation, thickness and length of the neck, not born from a first calving, small navel, big and well-shaped horns, and aggressive temperament of males. Sires were selected either from the same herd or purchased from other farms, or even from Chaco Creole herds. Contacts between farmers about purchasing a bull were very common. Bulls were also used on loan between related farmers in some cases. Interviews (Int-A) revealed that all farmers understood the consequences of inbreeding.

Replacement females and calves came from the same herd. Young females with good milk yield, good calving rate (one calf per year), docile, and with a "feminine appearance" were kept. Old, sick, and sterile animals, as well as those with poor udder and teat conformation, were sold.

Although coat color was not mentioned by farmers as a criterion in selecting breeding bulls or replacement heifers, in responses to subsequent questions in Q2 the importance of coat color in selection of Creole breeding cattle came to light. Farmers' opinions regarding this issue are summarized in Table 2. In Q2, 44% of farmers agreed that coat color was a criterion used to select breeding bulls, with black, "*hosco*" and dark red coat colors being the preferred colors. White and brindle-coated animals were usually not selected as breeding bulls. More than half of the farmers interviewed (52%) mentioned preferences for black, red, and *hosco* coat color when selecting replacement heifers. As with bulls, brindle and white-coated females were more frequently discarded. White animals are considered to be more susceptible to the disease *cegadera* and brindle animals are rejected by traders. Half of the farmers interviewed described an association between temperament and coat color of animals. In this way, coat color can influence the selection of replacement animals, and therefore genetic diversity indirectly. A previous study on Nellore cattle in Brazil found that the temperament of animals was influenced by many environmental factors, such as frequency of handling and interaction with humans [8]. Genetic studies to clarify the genetic relationship between coat color and temperament or productive traits in Creole cattle should be carried out, to avoid a potential misconception becoming a risk factor for genetic diversity. A study performed in Holstein cows for example, showed that cows with predominantly white coat produced 394 kg more fat-corrected milk, comparing with predominantly black-coated cows [9].

3.5 Farmers' perceptions of causes of mortality, health, welfare, and general conditions

According to Bottani et al. [7], predator attacks are the main cause of cattle mortality in Pasorapa (30% of all deaths). This was the cause most frequently mentioned in interviews, followed by several causes with rather similar level of occurrence, i.e., accidents (13%), piroplasmosis (12%), feed shortage (11%), the disease *macurca* (10%), diarrhea (9%), and anthrax (8%). Other less frequently cited causes were water scarcity, stick insects, rabies, and the disease *chullpa* (about 2–3% each). The disease *chullpa* is actually an inflammation of the joints.

Farmers' perceptions about common diseases and animal treatments were collected during interviews (Int-A, Int-B) and can be summarized by the following statements: "We know mastitis as *chupado de vibora* (snake suckling)", "Fat animals

Table 2 Frequency of interview responses about the relationship between Creole cattle coat color, performance, and temperament

Item	Answer	Frequency %	Farmer opinion
Importance of conserving coat color variability in Pasorapa Creole cattle	Yes	65	To recognize animals
			Black, *hosco* and red-coated animals are better. They have thicker hairs
			It is more beautiful. It is traditional. More appreciated for trading markets
			It is important. But no white color
	No	35	It depends on the place. Black animals are good for places with *cegadera* disease, white animals are good to be identified from long distances
Association between coat color and beef production or milk yield	Yes	39	Spotted (*overo*) and *hosco*-coated animals produce more milk
			Black animals are bigger, so they produce more meat. White animals are smaller and produce less milk
			Traders reject brindle animals because their meat is more red, as it would be stained
			Grey animals produce more beef
	No	61	
Association between coat color and temperament	Yes	48	Black bulls are more aggressive
			Black and red-coated bulls are more docile for breeding
			Brindle-colored animals are more stubborn and gruff
	No	52	Temperament depends on management

get anthrax when vegetation in the ranches is too green", and "Brucellosis does not kill the animals fast, that is why we do not vaccinate against it". An important cause of cattle mortality in Pasorapa was reported to be the disease *macurca*. Farmers explained it with the following statement: "After the rain, the heat from the ground evaporates and makes the cows sick". The actual cause of *macurca* is still unknown. Affected animals die two days after the symptoms appear, usually early in the morning during the first rain of the season. Affected cows have all four legs paralyzed and die owing to thirst and starvation, after having eaten all the grass close by. Animals are usually found dead in the *dormideras*. According to the interviewees, the ranchlands most affected are those located at the highest altitudes. Farms using high-altitude ranchland reported high numbers of cow deaths because of *macurca* every year [5].

Most farmers showed understanding about the importance of colostrum intake by calves to give them protection by the antibodies transmitted by the mother (Int-A). Nevertheless, farmers did not monitor colostrum ingestion during the first 6 h after birth, even for calves born during the Paddock stage. Lack of supervision of colostrum intake can lead to failure of passive transfer of immunoglobulin, or a lower amount than recommended being ingested. This leads to an increased risk of calf mortality and diseases such as diarrhea and respiratory illnesses [10]. This might also partly explain the death of calves with symptoms similar to anthrax disease reported by the farmers and the vet of the communities In-depth studies should be carried out to determine the proportion of calves in the percentage of all animals reported to die from diarrhea (9%), and whether the possible cause of calf mortality is inadequate colostrum intake.

Animal welfare concepts must be introduced to the farmers in the study region in order to change their perception that vaccination is only important if the disease kills the animal fast. However, the economic factor also has to be taken into account, as interviewees mentioned cost as the main reason for not vaccinating or providing adequate treatments and supplements. Changes to some painful surgical procedures, such as male castration and dehorning, would also be required to improve welfare. Farmers' perceptions related to the strength of Creole animals and lack of awareness of pain in their animals are reflected in the following statements: "We do it by ourselves. Creole animals are strong, they recover quickly" and "We use *llanten* (*Plantago major* L.), verbena (*Verbena officinalis* L.), or *achuma* (cactus) [as pain relief]". Education of farmers on animal welfare and proper medication, such as anesthetics, should be provided to change these practices. According to Hötzel et al. [11], low understanding about the pain inflicted in some husbandry practices can prevent farmers from changing to more appropriate management practices based on affordable drugs.

The greatest general concern among all farmers surveyed was water scarcity. In 2016, Pasorapa farmers reported the death of more than 400 head of cattle due to a severe drought. Animal corpses were found in the surroundings of completely dried-up water ponds. When farmers were asked about the specific improvements they would make if help were provided, the most frequent response was sowing pasture and crops for forage. Building more water ponds, paddocks, and pens, more roads to have better access to the rangelands, and wire fences on rangelands were also mentioned, but at much lower frequencies. A few farmers (13%) stated that they did not want any improvement (Q2). Low level of trust in government institutions was also a concern, and lack of continuity and noncompliance from such organizations was a common complaint (Int-A, Int-B).

3.6 Improving sustainability of production system before introducing a breeding or conservation program

There are many factors that influence the sustainability of the Creole cattle production system, and others similar to it throughout the Global South. The most important factors identified in the present study and their inter-relationships are summarized in Fig. 3. In general, we believe that good knowledge of the production system and of farmers' perceptions is necessary before starting to implement conservation or breeding programs. Based on our surveys, there are three main factors affecting the sustainability of the Creole cattle production system in Pasorapa: *productivity*, *ecosystem services*, and *income*.

Among the factors affecting *productivity*, the most immediate impact comes from management practices. Productivity is not only important for the income, but also for producing food for the farmers and their families. Enhancing productivity of the production system of Creole cattle in Pasorapa should contribute to achieve SDGs 1 and 2. The low productivity of livestock in developing countries has been attributed to low standards of management, feeding, and housing [12, 13]. In addition, smallholder farming systems in low-income countries in the Global South are already experiencing impacts of *climate change* [14, 15]. Impacts of climate change are associated with deterioration in yield and quality of feed crops and forage, water availability, diseases, and reproduction [16–18]. Increasing *forage production* on-farm is considered a driving factor for more sustainable agricultural systems [19]. This is also in line with the desired improvements expressed by the farmers in the present study, namely sowing pasture and crops for forage. When suggesting changes in management to increase productivity, it should be kept in mind that farmers tend to adopt low-cost innovations, with low

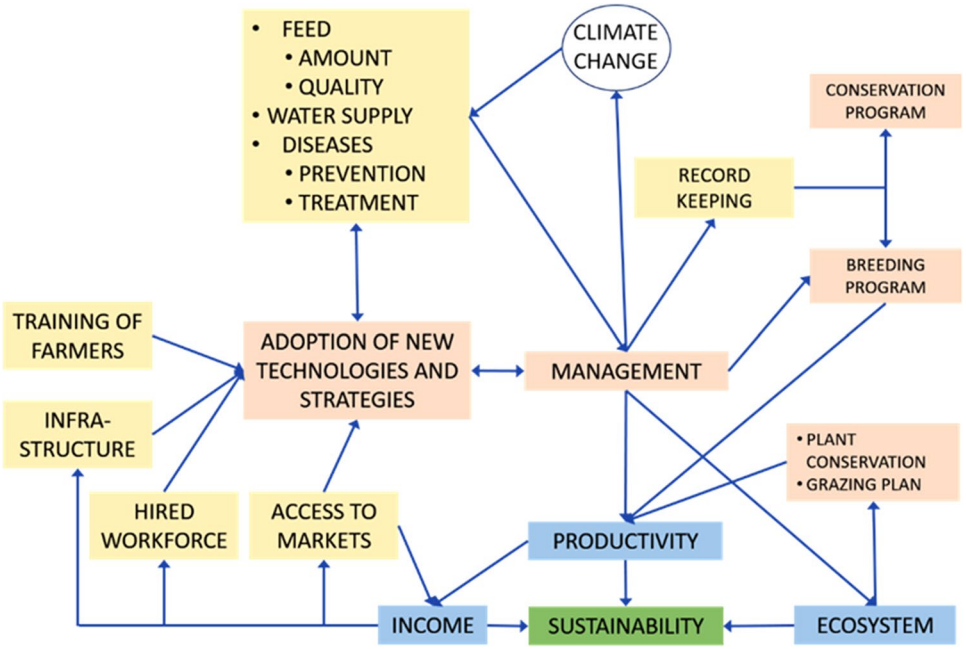

Fig. 3 Schematic diagram of interacting factors required to achieve sustainability in the Creole cattle production system in Pasorapa, Bolivia

demand for resources, labor, and land [20]. For instance, establishment of cultivated fields with Gatton panic grass and prickly pear cactus by some farmers in Pasorapa contributed to reduced mortality of cattle during the drought period in 2018 (F. Cabrera, personal communication, October 2, 2018).

Another main factor affecting productivity and causing concern to farmers, and which is common throughout the Global South, was *water scarcity and drought*. Drought threatens feed and water supply, and therefore animal survival, thus risking conservation of genetic diversity and productivity. Severe drought periods force farmers to sell cattle without considering sex and age or properly selecting replacement individuals. The farmers surveyed reported that they prefer to sell their animals, even cows with calves, at very low prices, before the animals die owing to water and feed shortages. Because of this strong interaction between the production system and the environment, the vulnerability of the system to the impact of climate change increases at the same time as animal traits related to survival, adaptation and resilience become more important. Therefore, if a continuous water supply is not ensured for the animals, no other improvement in the production system can be expected to have a positive effect on productivity (Fig. 3).

Increased temperatures also have other effects apart from drought, e.g., the water demand of animals is increased at higher temperatures. Water intake of cattle (*Bos taurus*) at 10, 30, and 35 °C has been shown to increase from 3 to 8 and 14 kg/kg DM, respectively [21]. Increased temperature also increases lignification of plant tissues, thus reducing their digestibility, which leads to decreased nutrient intake for animals. This will affect the productivity of both rangeland and mixed-crop systems [21], and Pasorapa cattle would thus be affected in both the Ranch and Paddock stages.

Climate change is also associated with the increased occurrence of *diseases* [16, 21], with associated impacts on productivity. Farmers in the study area should be educated about the causes, prevention, and treatment of the most common diseases, a need exemplified in farmers' perceptions about diarrhea in calves. Most interviewees believed this disease to be a consequence of excess milk consumption, when in fact their focus should be on monitoring effective ingestion of sufficient quantities of colostrum soon after birth, as this is key in improving calf health and survival [22]. These issues highlight the importance of training programs to help animal farmers recognize the main diseases, apply adequate treatment, and recognize the importance of proper health management and its impact on productivity. However, improved monitoring and provision of medical assistance to animals would require more workers to be available for tracking and handling animals.

Livestock production can be a real threat to environment and biodiversity. However, its critical role for livelihoods of family farmers from the Global South, where most people are under the recommended nutrition standards [25], need to be taken into account. There is a complex interaction between the Creole cattle population investigated here and *the ecosystem*. A considerable proportion of these cattle feed on native plant species even during the Paddock stage. During this stage animals are herded for vaccination or deworming, and then usually released into the crop fields to feed on crop residues. The remaining time, the animals are kept in the farm surroundings, where they feed on bushes and other

native plant species mentioned in Table 1. Therefore, pressure on the environment is maintained throughout the year. Under these conditions, appropriate conservation programs for native plant species and plans for grazing and browsing areas are required (Fig. 3) in order to address targets 15.2 and 15.4 of SDG 15. It has been reported previously that the beneficial effect of grazing for diversity depends upon the level of grazing pressure exerted, i.e., too much grazing is harmful [23, 24].

Positive effects of Creole cattle on the local ecosystem must also be considered. Factors such competition with other herbivores, a role in the survival of carnivores, nutrient cycling (manure) and its effects on the diversity and distribution of plant species in the rangelands should be analyzed. Without grazing, all ecosystems inevitably undergo a succession process, which transforms plant communities [23]. The current landscape in Pasorapa is thus the result of the strong interaction between the environment and the cattle.

It is well known that rangelands play an important role in mitigation of climate change, e.g., management of rangelands can be used to counteract rising atmospheric carbon dioxide concentrations because they store large amounts of carbon in aboveground vegetation and soils [26]. From this perspective, traditional systems like the Creole cattle production system in Pasorapa may be important for climate change mitigation.

It has been suggested that applying an adaptive multi-paddock grazing system can improve animal and forage productivity, and also contribute to climate change mitigation through soil carbon sequestration [27]. Extending the time animals spend in the Paddock stage might have a positive effect on productivity and conservation of native pastures. According to Schlecht et al. [28], herding reduces the damage to vegetation caused by overgrazing, by distributing grazing pressure more homogeneously across a given area. Cattle also waste less energy on browsing and walking when herded in paddocks than they do during the Ranch stage. Studies have also established that the frequency of watering may be affected by herd management, with free-grazing animals requiring water more often than herded animals [28]. However, extending the Paddock stage would require availability of a workforce to handle animals and to produce forage to feed them, and would also require farmers to have sufficient income to pay workers. Feed availability, conservation of native plant species, and soil carbon sequestration can probably be maximized by using appropriate management practices for Creole cattle grazing during both the Paddock and Ranch stages.

Studies evaluating the sustainability of small-scale farms have shown that low *income* is the main limiting factor [29]. Improved management practices and increases in productivity can increase farm income (Fig. 3). However, improving smallholder access to reliable *markets* for milk, beef and byproducts is also needed to address the low income of farmers [30]. The taste of milk and meat produced by Pasorapa Creole cattle is highly valued by consumers and farmers (Int-A, Int-B) and these products could potentially be marketed with a *price premium* compared with corresponding products. Nevertheless, it has been established that growing urban populations across the Global South and persistent constraints for long-distance food distribution, increase market opportunities for urban and peri-urban agriculture instead of rural production [31]. This situation might hamper the access to markets of smallholders from Pasorapa.

Higher income is also necessary for several of the desired changes in management (Fig. 3), to some extent creating a vicious circle. Without higher income, it is impossible to hire workers or install the infrastructure (e.g., fences) needed for improved management leading to higher productivity and higher income. On the other hand, if one part of the circle could be improved, e.g., access to markets or a price premium for Creole beef, it would hopefully become a virtuous circle instead.

3.7 Considerations for breeding and conservation programs

A breeding program is a well-established method to increase animal productivity, including yield, health, reproduction, and other functional traits. However, a breeding program needs to be accompanied by improvements in non-genetic factors, such as feeding and health management [32, 33]. In addition, an efficient way to conserve a population is to make sure that it is economically competitive.

Native cattle populations are important owing to their cultural value and their adaptation to local environmental conditions [12, 34]. The Creole cattle population in Pasorapa can be expected to be a reservoir of genes related to heat tolerance, resistance to parasites, and sufficiently high fertility rates in harsh environments, as has been shown for other Creole cattle populations [35–37]. Such traits are important for breeding programs involving productive exotic breeds and native populations [38].

According to our field observations and interviews, it is very difficult for introduced temperate breeds to succeed or even survive under the conditions in the study area. The exotic cattle breeds are severely affected by ectoparasites and endoparasites, are less able to walk and search for food, and usually do not become pregnant or have successful

calvings, most likely because they are more sensitive to the higher levels of environmental stress they experience [35]. It has been suggested that the use of temperate-breed genetic stock in developing countries could lead to greater vulnerability to increasing temperatures. Growth, reproduction, and milk yield become compromised due to drastic changes in biological functions under heat stress conditions [18]. Creole cattle have gone through a natural selection process since their arrival in the Americas, and are therefore better adapted to deal with heat stress [35]. Nevertheless, with the aim of improving milk yield in Creole cattle, farmers from Pasorapa have introduced dairy breeds, such as Holstein. Genetic studies are required to evaluate the effects of this unplanned crossbreeding on the adaptability of the cattle population to conditions with high temperature and scarcity of water.

Apart from the threat of uncontrolled crossbreeding, Creole cattle are also threatened by increased periods of feed shortages and drought episodes, which, depending on the severity, may cause population bottlenecks. Fluctuating environmental conditions can influence the population structure and consequently lead to a decrease in the effective population size. Bottlenecks have resulted in loss of genetic variation from genetic drift in many species [39]. Thus, improving management conditions and avoiding these bottlenecks is a conservation method in itself.

Conservation and breeding programs must consider the importance of keeping favorable alleles related to adaptive traits and behavior, that allow Creole cattle to survive and maintain good fitness under prevailing conditions [40]. This is especially important in places like Pasorapa, where animals are frequently exposed to challenging conditions and there is a limited control over the environment in which the animals live [41]. Breeding goals should therefore include traits related to reduced sensitivity to environmental variation and resilience to high temperatures, low quality feed, and diseases, making it easier to achieve target 13.1 of SDG 13.

If selecting for improved milk yield or growth, it is important to also avoid deterioration of the perceived high milk and meat quality of Creole cattle. These traits might be partly governed by genetics, but also by the current feeding strategies in the system. Therefore, these quality traits should be recorded and monitored.

Keeping records related to important traits and pedigree is an important precondition for carrying out breeding programs (Fig. 3). Development of methods (routines) to collect reliable data must be compatible with the management practices in both the Paddock and the Ranch stages.

3.8 SWOT analysis of the system

It has been suggested that performing a SWOT (strengths, weaknesses, opportunities, threats) analysis is useful in identifying breeding objectives and strategies for small cattle populations with inferior economic performance [5, 42]. Figure 4 illustrates strengths, weaknesses, opportunities and threats identified in the Creole cattle production system in Pasorapa based on the interviews and surveys conducted in the present study. Elements identified in each factor of the analysis might also be recognized in similar production systems of native cattle populations throughout the Global South.

One *strength* of the system is that, although the productivity is at a low level, it is still enough to ensure the livelihood of farmers and is the main or sometimes only source of income. The Creole population is probably the most suitable cattle ecotype for production under these challenging conditions, and it is most likely a useful global genetic resource for favorable alleles related to adaptive traits. Creole cattle also have high cultural value for these rural communities.

The main *weaknesses* of the system are low standards of management and suboptimal infrastructure, both of which are partly related to the low possibilities for hiring workers. The latter is partly related to the lack of available workers, but also due to low farm income levels, which in turn can be attributed to low access to markets. Another weakness is the high dependence on the environment, which can result in variation in both the amount and quality of products, both across years and seasons. The lack of records on performance and pedigree is a weakness hindering the development of breeding and conservation programs. A weakness affecting sustainability is the age structure of farmers in the region, with very few young farmers (< 40 years).

The main short-term *opportunities* relate to extending the Paddock stage and developing plans for grazing and browsing and for conservation of native plants. In the longer term, breeding and conservation programs can be developed to further increase productivity and farmer income, and to conserve genetic diversity (SDG 1 and 2). The availability of molecular genetic information might provide opportunities for both purposes.

The main *threats* to the system relate to the environment and can be expected to worsen with climate change. These include variations in environmental conditions between seasons and years, with high associated risks of water and feed shortages. These shortages can also have genetic consequences, leading to loss of genetic diversity. A further threat is the introduction of temperate breeds for uncontrolled crossbreeding, which may lead to loss of favorable alleles for adaptive traits.

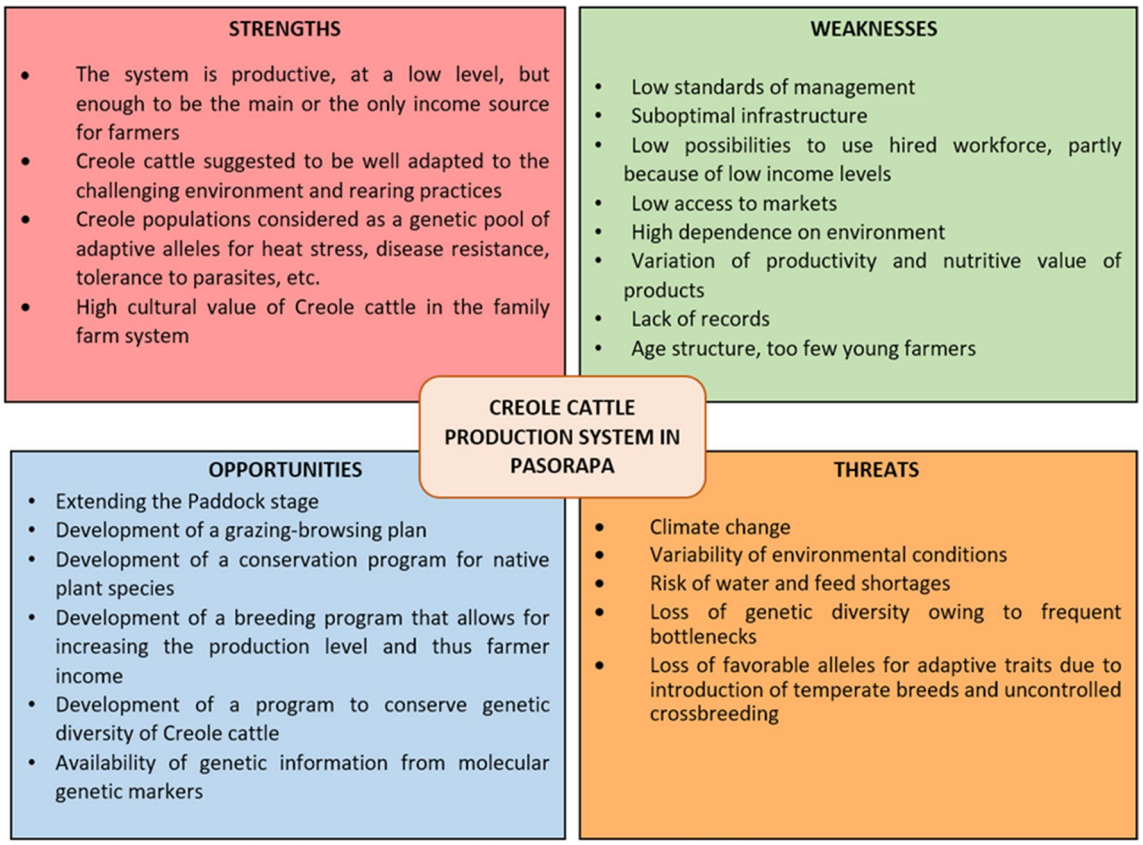

Fig. 4 Results of SWOT analysis on the Creole cattle production system in Pasorapa, Bolivia

4 Conclusion

The Creole cattle in Pasorapa is an example of a low-input production system in the Global South that has been adapting to environmental variations for centuries. Since the cattle population was introduced to the area, a complex interaction between herds and environment has been built up. The system has long been the main or even the only source of income for smallholders in Pasorapa, even though the productivity achieved within the current management system is low. With the future threats of climate change and loss of genetic diversity and important genes related to resilience, disease resistance and adaptation traits, there is an urgent need to describe in detail, this and other similar production systems throughout the Global South, identify their interactions with the environment, and suggest potential improvements in the management.

Adoption of new technologies and strategies is important to mitigate the effects of long drought periods and the impacts of climate change on the system. This will also have a positive impact on productivity and therefore on smallholder income levels, allowing farmers to hire workers or invest in infrastructure. Future breeding and conservation programs must bear in mind that it is important to retain those traits that allow Creole cattle and other native populations to succeed under the harsh environment in Pasorapa and similar regions, making it possible to achieve target 13.1 of SDG 13. Initiatives focusing on improving animal productivity should exploit the characteristics of these traditional systems and their benefits for mitigation of climate change through carbon sequestration. Enhancing productivity of the production system in Pasorapa considering factors discussed in this study should contribute to achieve targets 1.1, 1.2, 2.3 and 2.4 of SDGs 1 and 2. Given the strong interaction between the Creole cattle population and the ecosystem, a native plant conservation program and grazing plans should be designed in order to accomplish targets 15.4 and 15.5 of SDG 15.

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Data availability The authors declare that all data supporting this study is available on reasonable request.

Declarations

Ethics approval and consent to participate This study was performed in line with the principles of the Declaration of Helsinki. Informed consent was obtained from all individual participants included in the study and no individual or farm can be identified from the paper.

Competing interests The authors declare they have no conflict of interest.

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