Biocultural vulnerability of traditional crops in the Indian Trans Himalaya

Harman Jaggi*[1], Akshata Anand[2], Katherine A. Solari[3], Alejandra Echeverri[4], Rinchen Tobge[2], Tanzin Tsewang[2], Kulbhushansingh Suryawanshi[2,5,6], and Shripad Tuljapurkar[3]

[1]Department of Ecology and Evolutionary Biology, High Meadows Environmental Institute, Princeton University, Princeton, NJ, 08544
[2]Nature Conservation Foundation, Mysuru, India, 570 017
[3]Department of Biology, Stanford University, Stanford, CA 94305-5020, USA
[4]University of California Berkeley, University Avenue and, Oxford St, Berkeley, CA 94720
[5]Snow Leopard Trust, Seattle, WA, USA
[6]CIFAR Fellow in Future Flourishing Program, MaRS Centre, West Tower, 661 University Ave., 12 Suite 505, Toronto, ON M5G 1M1 Canada

Abstract

Traditional agricultural landscapes in mountain communities are critical for conserving biodiversity, biocultural diversity, and agroecological resources. Despite their significance, traditional farming systems are overlooked in modern agriculture and conservation, leading to genetic erosion and reduced cultivation of local crop landraces. Our research focuses on the fragile ecosystems of northwest Himalaya in India, and examines the ecological and genetic resilience of black pea (lesser known and understudied traditional crop) and barley (*Hordeum vulgare*) and compares them to the introduced cash crop of green pea (*Pisum sativum L.*). We conducted field experiments across elevation gradients to assess survival and reproductive traits for the three crops. We performed whole-genome sequencing to investigate the genetic diversity of black pea in relation to other *Pisum* species. Additionally, we analyzed the nutritional profile of black pea in comparison with green pea. Our findings indicate that

*Corresponding author: harmanjaggi@stanford.edu

traditional crops are better adapted to local climatic conditions in terms of their growth performance, and hold considerable genetic diversity and nutritional potential. Our results support the importance of integrating traditional knowledge with modern agroecological research and policy to promote climate-resilient, sustainable food systems. The results also argue for a reevaluation of traditional and often underutilized crops to support small-holding farmers and promote socio-ecological stability in vulnerable mountain regions.

1 Introduction

Traditional farming landscapes and mountain communities are important reservoirs for conservation of biodiversity, biocultural diversity and agro-ecological resources (Fischer et al. 2012; Sarmiento et al. 2018; Fletcher et al. 2021; Reyes-García et al. 2023; Ibarra et al. 2023). Traditional farming knowledge (in the form of, e.g.,, local crop landraces and seedbanks) results from complex cultural and environmental selection (Aguilera et al. 2020) and supports diverse ecosystem services (Jarvis et al. 2011; Brondízio et al. 2021). However, traditional practices have often been overlooked in conservation and modern agronomic research (Antonelli 2023) even as researchers have noted declines in the diversity of landraces and crop genetic erosion (Khoury et al. 2022). This is concerning because traditonal production systems (*e.g* locally adapted crop varieties) may inform nutritional, cultural and ecological stability, especially in adverse climates (Singh 2018; Borelli et al. 2020). Therefore, research on local production systems is likely important for supporting regional livelihoods, sustaining socio-ecological stability and preserving cultural knowledge (Wezel et al. 2020; Antonelli 2023).

The stability and productivity of food systems is increasingly vulnerable to increased variation in weather patterns, and in the frequency of extreme events (such as episodes of drought) often due to climate change (Beniston 2003; Maurer et al. 2019). The high-altitude Trans-Himalayan landscape presents excellent case studies for examining traditional food systems and the impacts of climate change on agricultural production in mountainous communities. In that region, and more broadly over Asian montane rangelands, climate is changing even faster than the global average (Chaudhary and Bawa 2011; Kohli et al. 2021), threatening both the agroecological landscape and local economy. These rangelands provide exceptional biodiversity and cultural richness (Murali et al. 2020; Suryawanshi et al. 2021; Patel et al. 2024), and are also known as the Third Pole, because they hold the next largest reserves of freshwater and glacial ice after the polar regions. The human communities in these cold desert ecosystems share habitat with diverse wildlife, including the iconic but vulnerable snow leopard *Panthera uncia*, and depend closely on ecosystem

services.

Our research examines traditional agricultural systems and their vulnerability in the fragile ecosystems of northwest Himalaya, in the state of Himachal Pradesh (HP), India (map 1) in Spiti district. Agricultural production in Spiti was traditionally subsistence-based (Mishra et al. 2003). The main crops grown were barley *Horedum vulgare* (locally *neh* or (*jau*)), and a local variety of pea called black pea (*sanmoh nako* or *dhoopchum* in Tibetan). The scientific name for black pea remains unclear (as we later explain) and until recently (Sharma and Gupta 2023; Bhatt et al. 2023) there were no scientific research articles on black peas. In 1983, an agro-economic revolution in Spiti was spearheaded by a family that experimentally planted green pea or garden peas *Pisum sativum L.* (Mishra et al. 2003). In the subsequent two decades, the predominantly subsistence-based production of the village communities has been increasingly replaced by the market-oriented production of cash crops (mainly green peas, apples), destabilizing the sustainability of the cropping system (Rahimzadeh 2020; Mukherjee 2020). During our socio-cultural work (*manuscript in prep*), we learnt that black pea and barley are an integral part of ethnodietary recipes and of a climate-resilient farming system, but their cultivation has drastically declined due to market forces and lack of information. The practice of polyvarietal cultivation of barley (*kneu, soha, nenak, and eumo*) is nearly extinct (Mishra et al. 2003). *kneu* is the only variety grown currently with small quantities of *soha* for religious ceremonies.

Grown for many centuries, barley and black peas are likely well adapted to the region's geoclimatic conditions and irrigation regimes. Here, we provide an ecological, genetic and nutritional characterization of black pea, which to our knowledge has not been done before. We compared several aspects of traditional crops (we include black peas and barley) to the cash crops of green peas. The key research questions are as follows: firstly, we examined whether traditional crops are better adapted to changing climatic conditions in terms of their survival and reproductive traits. Secondly, we examined whether black pea differs in genetic diversity from other peas in the *Pisus* genus. Thirdly, we examined the nutritional profile of back pea.

To examine our first question, we performed field experiments (March-September 2023) to compare the three different crops (black pea, barley and green pea) for reproductive and photosynthetic traits under variable water treatments across three elevation gradients (discussed in Methods). We co-designed the experiments with local farmers who advised on sowing depth and bed preparation to ensure optimal growth conditions. We hypothesized that traditional crops are more resilient than cash crops as measured by survival and reproductive traits.

To examine the second question, we performed whole-genome sequencing (shotgun sequencing

using the Illumina platform) for a black pea sample. We then used a chromosome-wide Principal Component Analysis (PCA) to compare our black pea sample with pea accessions published in Yang et al. (2022). We expected genetic differences between black peas and green peas, but did not have a prior on the magnitude and nature of those differences. For the third question, we collaborated with the Central Food Technological Research Institute (CFTRI) in India to provide a standardized nutritional profile for black peas. Nutritionally, we expected that black peas have a distinct and high nutritional profile in comparison to green pea because cash crops are consistently selected for particular nutritional values and sold in markets for that trait (Santalla et al. 2001).

Our findings suggest that black peas and barley are not only better adapted to local conditions (with higher survival, flowering and pod production) but that black pea also holds significant untapped genetic and nutritional potential. Our research aligns with a growing body of evidence that advocates for a reevaluation of traditional and Indigenous agricultural practices (Antonelli 2023). In the next sections, we describe the study system, research methods, results and recommendations. We close with a discussion on integrating local knowledge and modern science to examine lesser-known and under-utilized crops to foster food systems that are environmentally sustainable and adaptable to changing climatic conditions.

2 Study site

2.1 Region

In the state of Himachal Pradesh (HP), about 26,000 km^2 area is potential snow leopard habitat (Suryawanshi et al. 2021). Within this habitat, we focused on Lahaul-Spiti district (Figure 1). The area lies in the rain-shadow of the main Greater Himalayan range, within the Trans-Himalaya region, bordering Tibetan plateau in the east. The landscape is typically above the treeline, between 3000-6000 m elevation range. Temperatures range from -30°C in peak winter to 30°C in peak summer. The landscape is mountainous cold desert and rocky, with steep slopes largely dominated by grasses and shrubs. Precipitation is received primarily in the form of snow in between November and March, and starts to melt by April.

The major river system is the Spiti river that originates from Kunzum range and travels 150 km in Kinnaur district before its confluence at Khap with Satluj river (from Tibet). Spiti river flows in deep chasms and gorges for most of its length with a catchments area is about $\sim$ 12000km^2 (Sri-

vastava et al. 2013), most part being barren rocky land covered with thick moraines. The heavy snowfall in the winter months contributes to the Satluj's flow in spring. The Pin is the largest tributary of the Spiti River and Lingti, Parechu are other important tributaries. The townships and settlements are clustered close to the river systems or near a glacier from which they harvest water.

Spiti valley has a low human population density (c. 1 person/km^2). Agriculture is the backbone of the economy, in addition to animal husbandry and tourism and 80% of the population in Spiti and Kinnaur are predominantly agro-pastoralists (Murali et al. 2017). According to the 2011 census, the per capita annual income of the district is 2,289.57 USD (1,92,292 INR).

Ecologically, there is a robust community of small and large carnivores (Patel et al. 2024), including the vulnerable snow leopard (*Panthera uncia*). The two main prey species of the snow leopard – blue sheep *Pseudois nayaur* and ibex *Capra sibirica* – mostly occur in high altitude pastures and in relatively rugged terrain (Bagchi and Mishra 2006). The livestock reared are sheep *Ovis aries*, goat *Capra hircus*, donkey *Equus asinus*, yak *Bos grunniens*, cattle *Bos indicus*, dzomo (a yak-cattle hybrid), and horses *Equus caballus*. The community has access to grazing pastures near the village over an area of approximately 70–100 km^2 with traditional grazing and collection rights in the pastures, where cultivation is not permitted. Relatively smaller-bodied livestock such as goats, sheep, donkeys, cows and dzomo are taken grazing every day during the summer months while larger bodied livestock such as yak and horses are left to free-graze over most of the year except for a few weeks during extreme winter (Murali et al. 2022). All livestock are stall fed during the winter months. Fodder is collected from the pastures and crop fields and stored as winter forage.

3 Methods

We used a multidisciplinary approach to study traditional production systems in the Indian-Trans Himalaya. We first used an ecological lens to perform field experiments comparing green pea, black pea, and barley on their growth performance. We then examined the genetic and nutritional diversity for black pea to assess how well these results align with farmers perceptions.

3.1 Field Experiment

The field study was conducted in March-September 2023 to evaluate the growth performance of three crop species: green peas, black peas, and barley under variable water treatments across al-

titudinal gradients. The experiment was carried at three sites characterized: low (4000m), mid (4200m), and high (4500m) elevations. The experiment was laid out in a randomized block design with a factorial arrangement, incorporating three factors: crop species, water treatments, and elevation levels. Each treatment combination was replicated three times, and thus a total of 81 plots were monitored. The seeds were sown uniformly across all plots and spacing was determined by interacting with farmers. The sowing density for green pea was lower than black pea seeds since black pea seeds are relatively smaller. The farmers also advised on sowing depth and bed preparation to ensure optimal growth conditions.

We set up plots for green, black pea, and barley (1.5 by 1 meter) along a climate gradient in three villages (at elevations 4000m, 4200m, 4500m) with three water treatments. The water treatments represented varying levels of water availability: low, medium, and regular. The low water treatment simulated drought conditions, medium represented the less than standard recommended irrigation practice for the region, and regular simulated conditions of water used by farmers. The adjustment was made by altering the number of irrigation times rather than the quantity of water.

Throughout the cropping season, we monitored the plants for photosynthetic, non-reproductive and reproductive traits such as, germination rate, flowering time, height at maturity, leaf coloration (disease infestation), and flower/pod production. Data on growth parameters (plant height, leaf area, and biomass) were collected at regular intervals (every 7-10 days). Yield components were assessed at the time of harvest. Data were analyzed using ANOVA to determine the effects of the crop type, water treatment, elevation, and their interactions. Post hoc tests were performed to locate differences between treatment means at a significance level of $p<0.05$. All statistical analyses were carried out using R software.

3.2 Genetic diversity

For the genetic analysis, we first sampled fresh leaves and performed DNA extraction using DNeasy Plant Pro kit (Cat #69204). Illumina libraries were constructed using KAPA HyperPrep Kit and whole genome sequencing was performed at Medgenome labs (based out of Delhi, India) on an Illumina NovaSeq platform using a paired 150bp configuration. Illumina reads were mapped to the *P. sativum* reference genome (accession GCF_024323335.1) using BWA-MEM (Li 2013) and depth and breadth were calculated using SAMtools (Li et al. 2009). We want to note that the whole genome sequencing data generated for the black pea as part of this study has been deposited on NCBI - BioSample accession SAMN44380099.

We downloaded additional whole genome sequencing data from the recent paper (Yang et al.

2022) for P. sativum II, P. sativum III, P. sativum IV, and Pisum sativum var. arvense and also mapped these data to the reference genome using BWA-MEM. Table 2 lists the whole genome sequencing data that was used for the PCA analyses. The resultant alignment files (.bam files) were then run through ANSGD with the following flags "-uniqueOnly 1 -remove_bads 1 -only _proper_pairs 1 -trim 0 -C 50 -baq 1 -minMapQ 20 -minQ 20 -doCounts 1 -GL 1 -doMajorMinor 1 -doMaf 1 -skipTriallelic 1 -SNP_pval 1e-3 -doGeno 32 -doPost 1" to generate posterior probability of genotypes. We then used the ngsCover function from NGStools (Fumagalli et al. 2014) to generate a covariance matrix for each of the 7 chromosomes (2n=14) and visualised this data in a PCA using R.

3.3 Nutrition

The nutritional analysis for the black pea samples was done in collaboration with CSIR- Central Food Technological Research Institute (CFTRI) based out of Mysuru, India. The aim was to create a nutritional profile for black peas that includes the percentage per 100g of protein, carbohydrates, energy (kCal), and micronutrients such as zinc, magnesium, and iron.

4 Results: Traditional production systems

4.1 Results from field experiments

We first want to note that the results are averaged across water treatments because of high rainfall in the summer of 2023. The drought treatments received rainfall and we therefore treated different treatments as replicates. Our first result from the field experiment shows both black peas and barley have higher survival probability (or establishment rate since few seeds are eaten by birds, livestock and ungulates) in comparison with green peas across all sites. The results are consistent across three different ecological settings as shown in Figure 2. The site Kiamo (at 4000m) has highest average establishment rate for black peas with 0.51 overall. The high establishment rates for black peas (evidenced by the higher mean value) underscore a possible genetic or phenotypic advantage over green peas. These findings suggest that black peas may possess attributes that confer greater survival advantages under the diverse conditions represented by the study sites.

Except Tashigang, barley establishment rates are lower than green peas across all sites. Please note there are no error bars for barley because some of our barley plots were destroyed and we were only able to preserve one plot per site. We also added another experimental site Thinam at

4600m without replicates to note seed survival in high elevation. Farmers noted they had been experimenting growing crops at even higher elevation (4600m) due to better availability of snow melt and access to water. We find low success at this elevation across all crops at Thinam as shown in last panel of Figure 2.

Next, we evaluate non-reproductive traits such as average stem height and average number of leaves (correspond to higher photosynthetic activity). As shown in the Appendix figures .1 and Figure .2, black peas outperform green peas consistently across all sites. The average stem height for black peas is 38.12cm, 24.3cm, 25cm compared to 18.2cm, 12.48cm, 10.7cm, across Kiamo, Kibber, and Tashigang, respectively. We do not consider barley in these plots because barley is a grass species from *Poaceae* family.

Important covariates for farmers include the reproductive traits such as proportion of flowering plants and pea pods. Figure 3 describes the distribution of survival-weighted proportion of flowering plants. Through the cropping season, we noted the proportion of flowering plants and weighted it by survival. We find black peas have higher proportion of flowering plants for black peas than green peas. Similarly, the average number of pods per individual plant are also higher for black peas than green peas as shown in Figure 4. Finally, we evaluate the growth rate for all crops by taking stem stem height as a predictor and find black peas, barley and green peas have growth rates 0.83, 0.6, and 0.38 as shown in Figure 5.

4.2 Genetic diversity of black peas

Pea belongs to the most ancient set of cultivated plants and is known to be domesticated about 10,000 years ago in the Middle East and Mediterranean region (also known as Fertile Crescent) (Abbo et al. 2010; Smỳkal et al. 2015). Although the taxonomy of *Pisum* genus is complex and still under debate (Yang et al. 2022; Rispail et al. 2023), there is consensus that the genus consists of two species- wild *P. fulvum* and *P. sativum* (Naim-Feil et al. 2017). *P. sativum* includes wild (subsp. *elatius*) and domesticated taxa (subsp. *sativum*).

We have generated the first whole genome sequencing data for the black pea and have mapped it to the P. sativum reference genome. The average depth of coverage of our black pea data was 15X with a breadth of coverage across the reference genome of 86.6% . We combined this data with data for pea accessions in (Yang et al. 2022), and performed a chromosome wide-PCA analysis to infer the structure of Pisum collection. Since we were interested in our black pea subpopulation, we used samples from *P. sativum* and admixed accessions. In addition, we included *Pisum sativum var. arvense* (Accession SRR19543725) and performed a PCA for each chromosome to

compare the samples. PCA results reveal the three principal components (PCs) explain almost 33.3% of the observed genetic variation in the collection.

We find pea accessions were separated based on the *P. sativum* subspecies consistent with previous studies (Jing et al. 2010; Yang et al. 2022). However, our black pea sample clustered distinctly away from *P. sativum subsp. sativum var. arvense* sample. In addition for chromosome NC_066581 and NC_066585 (as shown in Figure 6) our sample clusters neither with domesticated varieties nor the wild germplasms. Although our morphological study of black pea plant supports two recent studies (Bhatt et al. 2023; Sharma and Gupta 2023) from Himalayan region that identify the local black pea to be *Pisum sativum var. arvense*, a winter legume belonging to the Fabaceae (Leguminosae) family, our genetic results question the claim. Our research emphasizes the high-altitude Himalayan mountains to be a relevant secondary centre of pea diversity, rich in primitive cultivated forms of field peas (Jing et al. 2010).

4.2.1 Nutritional composition of black peas

Anecdotally, black peas are known for their diverse nutritional profile but the nutrient content for black peas from the Trans-Himalayas has been unclear. We collaborated with CFTRI based in Mysuru, Karnataka, India to create a nutritional profile for black peas. We find these legumes are rich in a variety of essential nutrients and offer a diverse combination of protein, fiber, vitamins, and minerals, making them not only culturally and ecologically important but also a valuable addition to a balanced diet. Table 1 provides a measure of nutrients and daily recommendation averages taken from NIH for a adult of body weight 70kg. Firstly, black peas are notably high in protein, with approximately 21.20% protein content per 100 grams. This makes them an excellent plant-based protein source, especially beneficial for individuals following vegetarian or vegan diets. Furthermore, black peas are a good source of dietary fiber (15.9% per 100 grams) in addition to crude fiber at 6.23% per 100 grams. Black peas also provide a range of essential vitamins such as Vitamin C (13.1 mg/100g), Vitamin B1 (0.61 mg/100g), Vitamin B3 (1.62 mg/100g). They are a good source of minerals such as iron (9.11 mg/100g), zinc (2.48 mg/100g), calcium (108.09 mg/100g), and magnesium (109.28 mg/100g).

5 Discussion

We find great potential for lesser-known and underutilized traditional crops such as black peas in terms of their survival and reproductive traits. We find black peas outperform green peas (cash crop) in terms of their establishment rates, average stem height and survival-weighted proportion of flowering plants (Figures 2, .2, 3). The findings align with our socio-cultural research during which local farmers underscored black peas are better adapted and more resilient (in terms of ease of growing, and drought resistance) than green peas. Our multi-pronged approach provides a comprehensive baseline for traditional crops in high-altitude Trans-Himalaya as these food systems are crucial to the stability of humans and their ecosystems (DeClerck et al. 2016; FAO 2021; Perfecto and Vandermeer 2024).

Further, we generated the first whole genome sequencing data for black peas from the Trans-Himalayan region to assess how genetically similar they are to other pea species. As shown in Figure 6 our sample clusters neither with domesticated varieties nor the wild germplasms. We expected genetic differences between black peas and green peas, but did not have a prior on the magnitude and nature of those differences. Although researchers identify black pea to be *P. sativum subsp. sativum var. arvense*, our findings show black peas to be distinct from *arvense*. Our research aligns with previous research (Jing et al. 2010) that emphasizes the high-altitude Himalayan mountains to be a relevant secondary centre of pea diversity, rich in primitive cultivated forms of field peas (Jing et al. 2010). We also find black peas have high nutritional profile, offering high percentage of protein, dietary fiber, zinc, magnesium, among others. This makes them an excellent plant-based protein source, especially beneficial for individuals following vegetarian/vegan diets.

Locally inclusive development may enhance the sustainability of a traditional agricultural system, addressing both its conservation and its development. Our research emphasizes greater recognition of and research on lesser-known traditional crops in collaboration with communities who have long been using them, and who can be the main beneficiaries. Many studies have noted (Kosterin et al. 2020; Gufi et al. 2022) wild pea diversity in peripheral regions is insufficiently represented in the existing germplasm collections. Kosterin et al. (2020) found two small populations of the wild pea *Pisum sativum subsp. elatius* in the Zagros Mts, Iran. They note wild pea populations are rare, small in size and suffer from climatic change and land exploitation. Another example is *Pisum sativum subsp. abyssinicum*, locally known as Dekoko peas, a unique subspecies endemic to Amhara and highland areas of Tigray, Ethiopia and to South Yemen. Dekoko

peas are an important crop, widely mixed with the main cereal crops such as, sorghum, barley and teff (Gebreslassie and Abraha 2016; Gufi et al. 2022). The crop qualifies for species status on the basis of its phenotype (early flowering and strongly serrate leaflets) and biological isolation (Keneni et al. 2013). Although cultivation of Dekoko peas had drastically declined due to drought and political disruption, in the past 10 years, there has been a considerable renewal of interest, resulting in new collections of Dekoko germplasm, characterization studies aimed at crop improvement and extending the areas of cultivation (Tsegay and Gebreegziabher 2019).

Looking beyond the *Pisum* genus, we can find many other examples of species may also be useful in addressing different effects of climate change. Thus, *Coffea stenophylla* can tolerate higher temperatures than the commercial species *Coffea arabica*, under threat from climate warming. Communities in Sierra Leone helped researchers at the Royal Botanic Gardens (Kew) to find coffee berries from *Coffea stenophylla* in the wild (Davis et al. 2020). In southwestern Ethiopia, the banana-like Enset (*Ensete ventricosum*)has starch-filled stems that are a main source of calories and nutrients, while the leaves are used for basket making, to feed cattle, and to provide shade and build roofs. Additionally, this species is remarkably tolerant of drought and short-term temperature variations (Antonelli 2023). And as a final example, we note that the UN recognized 2023 as the International Year of Millets (Verma 2023), calling attention to their many nutritional and health benefits, their suitability for cultivation under adverse and changing climatic conditions, and their potential to contribute to the UN 2030 Agenda for Sustainable Development.

Environmental and conservation outcomes could improve by recognizing and honoring the relationships between people and their landscapes, and proposing actions based on local priorities (Dudgeon and Berkes 2003; Mogomotsi et al. 2020; Dudgeon and Berkes 2003). Traditional agricultural systems are known for providing the communities with self-sustenance and sufficiency, while conserving the agroecosystems and associated biodiversity. Globally and/or Nationally Important Agricultural Heritage Systems (GIAHS/NIAHS), identified by the Food and Agriculture Organization of the UN, recognize and designate bioculturally important sites to safeguard agrobiodiversity, protect agricultural heritage and recognise the knowledge and practices of local communities (Koohafkan and Altieri 2011; Santoro et al. 2020; FAO 2021; Antonelli 2023). These declarations have triggered the development of different tourism activities related to biocultural inheritance. In India the Indigenous 'Bari System of Farming' practiced by the native people of North Eastern India (Assam) is recognized from the perspectives of consumption, conservation, and biodiversity management (Borthakur and Singh 2020). The campesino cooperatives in Mapuche-Pewenche territory (southern Andes) practice community-based tourism in-

corporating Mapuche rural culture and agricultural practices that support local food systems and economy with a strong identity component (Kaulen-Luks et al. 2022). We recommend the Trans-Himalaya for recognition as a GIAHS/NIAHS given the fragile ecosystems, high cultural and ecological diversity.

There are important limitations to out work. Most notably, we present findings from only one year of data collection. A consistent study over multiple years is needed to identify effects of climate change on the agroecosystem. The long-term datasets may also shed light on other demographic patterns- which stage in life-cycle of crop is most vulnerable to water stress and plant pathogens? What makes traditional crops more resilient? A quantitative understanding of such demographic linkages will yield important insights for farmers and management interventions. Further research is needed to identify the level of genetic variation and what genes and loci may be associated with adaptive traits. We recommend future research using introgression techniques to improve adaptive traits for green peas via hybridization with black peas. This may improve the ability to expand the cultivation of cash crops such as green peas into adverse environments, such as under drought conditions and extreme environments (Warschefsky et al. 2014).

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6 Figures

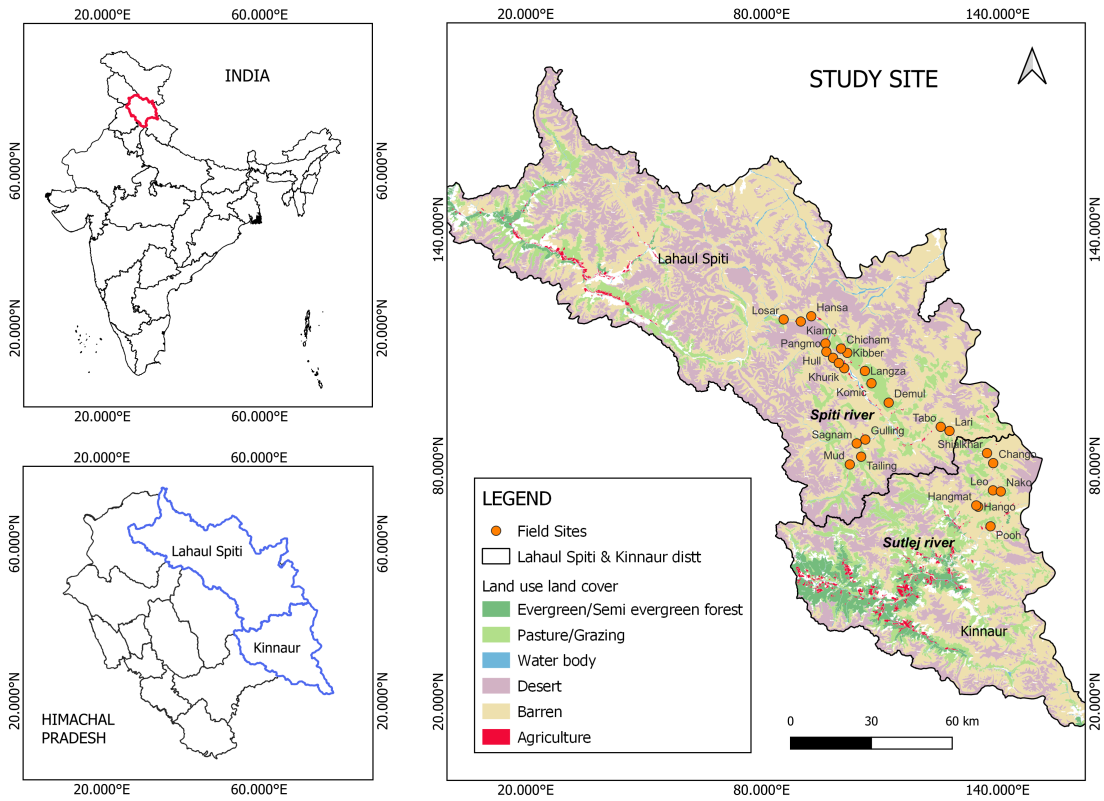

Figure 1: The right panel shows location of the sites within Spiti Valley and Kinnaur district where we interviewed local community members across 26 villages and helped co-design experimental plots at the three sites discussed in the Methods section. Different colors correspond to land use characterizations such as agriculture, grazing pastures, and barren among others. The orange solid circles correspond to villages sampled. The bottom-left panel shows the extent of Spiti and Kinnaur district within the state of Himachal Pradesh, India.

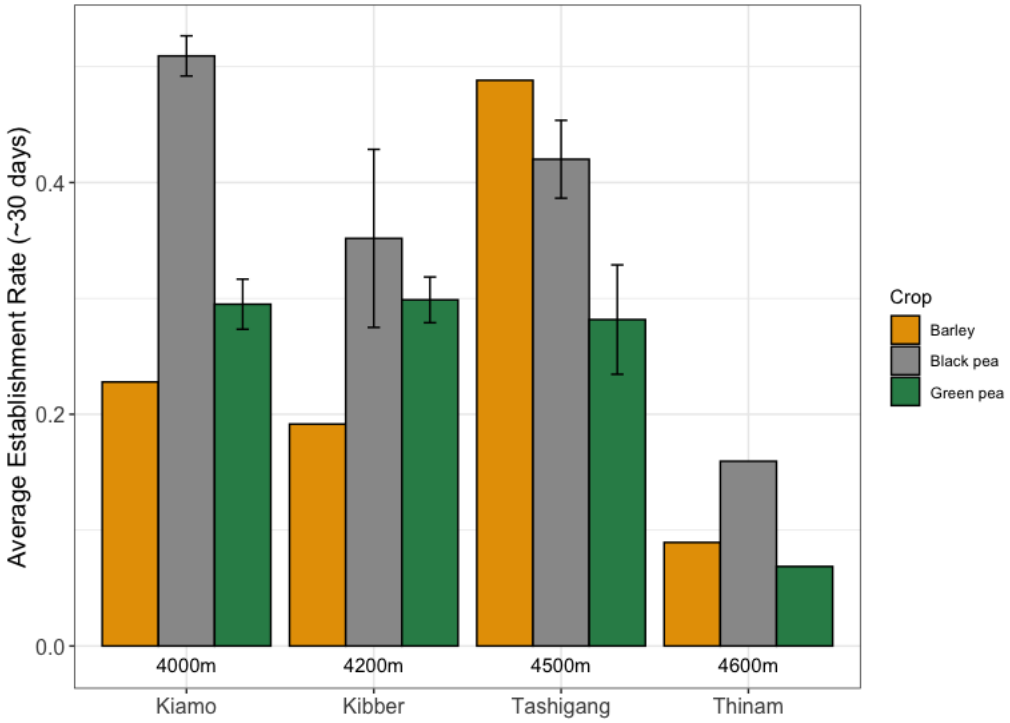

Figure 2: Establishment rate (survival probability) of black peas, green peas, and barley after 30 days. The x-axis corresponds to four sites at different elevations: Kiamo (4000m), Kibber (4200m), Tashigang (4500m), and Thinam (4600m). The y-axis corresponds to average establishment rates for the crops. Each color corresponds to different crops: black peas, green peas and barley. The lack of error bars indicate there was one replicate.

7 Appendix A: Supplement figures

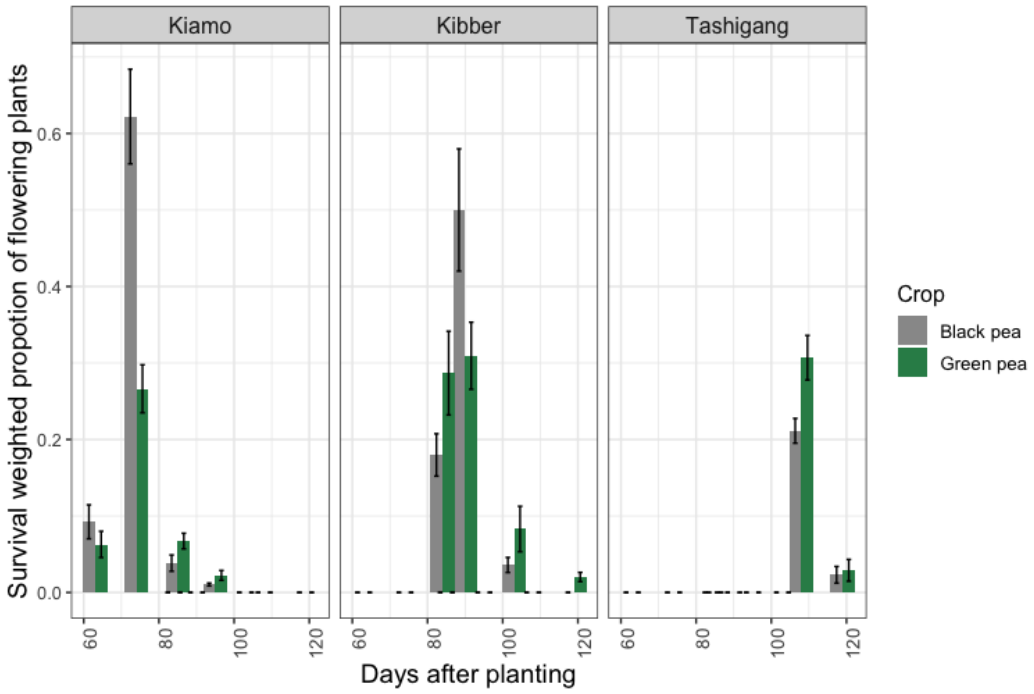

Figure 3: Survival-weighted proportion of flowering plants. Each panel corresponds to three sites at different elevations: Kiamo (4000m), Kibber (4200m), Tashigang (4500m). The x-axis corresponds to days after planting the seeds and the y-axis corresponds to survival-weighted proportion of flowering plants. Each panel corresponds to three sites at different elevations: Kiamo (4000m), Kibber (4200m), Tashigang (4500m). The x-axis corresponds to days after planting the seeds and the y-axis corresponds to survival-weighted proportion of flowering plants. The color corresponds to black peas and green peas.

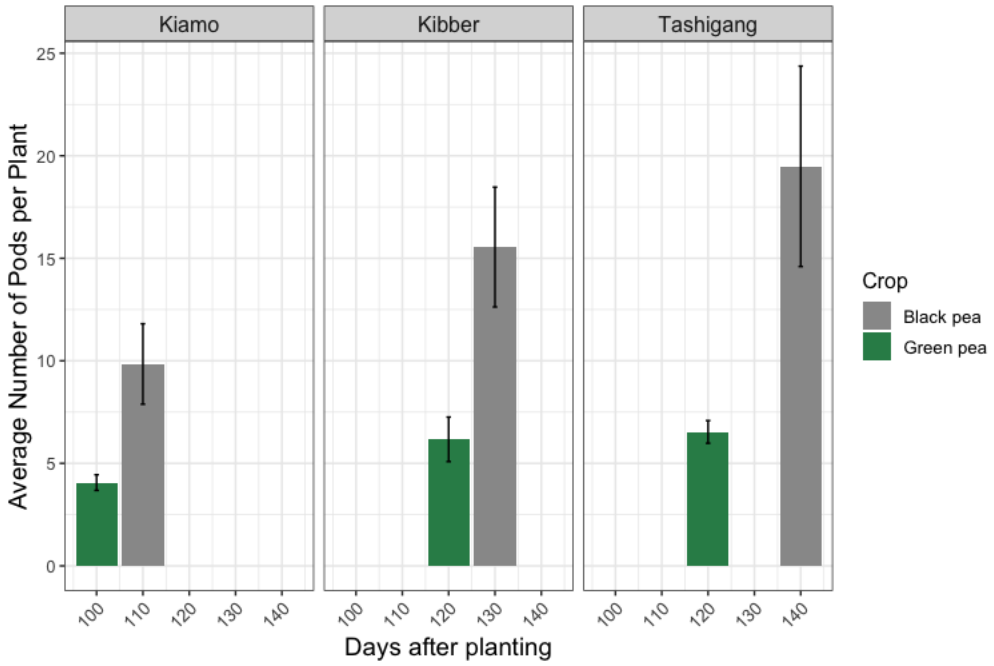

Figure 4: Number of pods per individual. Each panel corresponds to three sites at different elevations: Kiamo (4000m), Kibber (4200m), Tashigang (4500m). The x-axis corresponds to days after planting the seeds and the y-axis corresponds to number of pods per individual plant. The color corresponds to black peas and green peas.

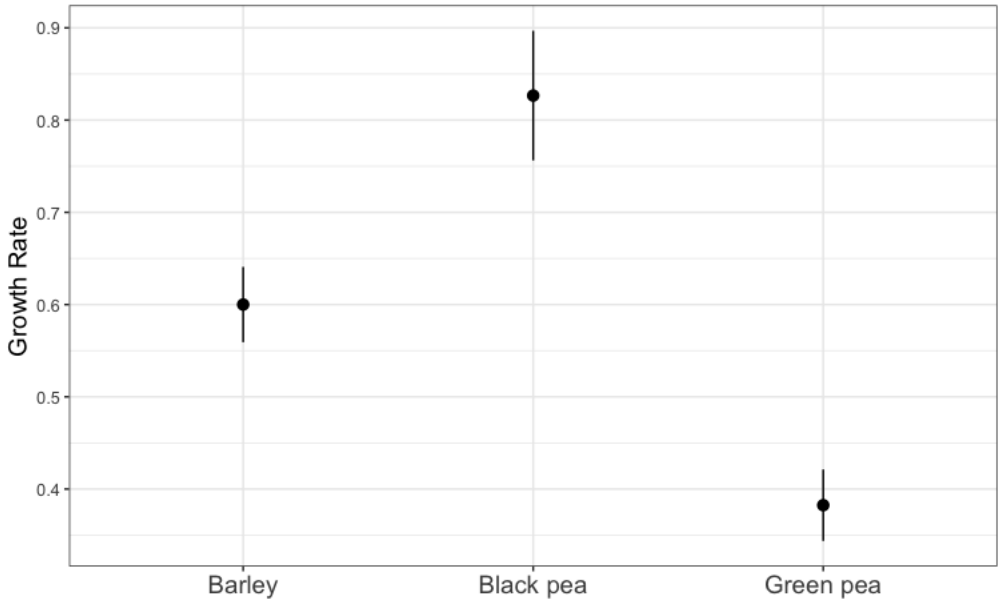

Figure 5: Growth rate of each crop: black peas, green peas, and barley for all sites. The y-axis corresponds to the log growth rate and x-axis corresponds to the three crops.

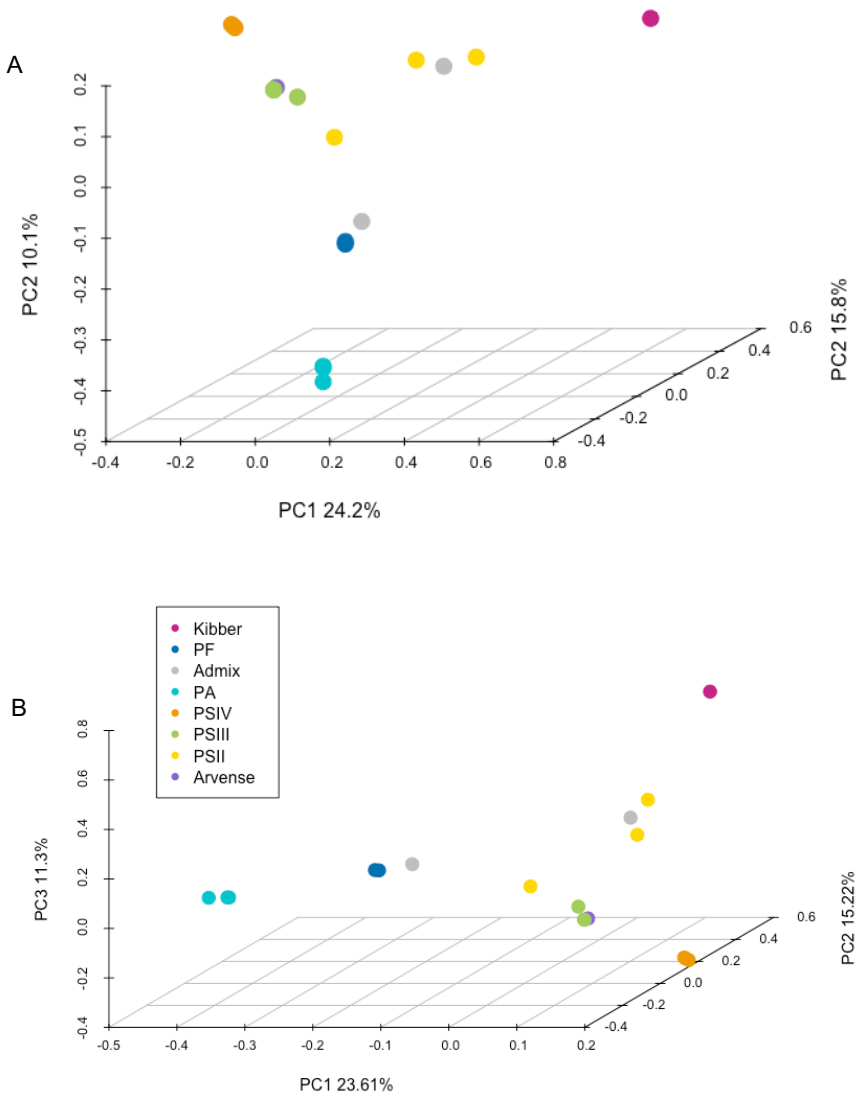

Figure 6: The figure shows PCA results for chromosome NC_066581 in panel A and NC_066585 in panel B. Kibber (in pink color) represents our sample and is distinct from *arvense* (in purple color) and other domesticated samples such as Pisum II and Pisum III (in green and yellow).

Table 1: Nutritional Profile for black peas and Recommended Daily Intake (RDI) taken from National Institutes for Science (NIH) for an average adult of body weight 70 kg. The tests were performed at Central Food and Technological Research Institute, Mysuru, India. The % by wt corresponds to percentage of nutrient per 100 g.

Nutrient	**Value per 100g**	**RDI (Unit per 100g)**
Vitamin A	109 µg	900 µg
Vitamin E	2.74 mg	15 mg
Calcium	108.09 mg	1000 mg
Iron	9.11 mg	8 mg
Magnesium	109.28 mg	400 mg
Zinc	2.48 mg	11 mg
Fat	1.03%	-
Dietary Fiber	15.9%	25-35
Crude Fiber	6.23%	-
Protein	21.20%	10-36%
Vitamin C	13.1 mg	75.6-100mg
Vitamin B1	0.61 mg	-
Vitamin B2	0.09 mg	-
Vitamin B3	1.62 mg	-

Table 2: Whole genome sequencing data for PCA analyses

Run No.	**Accension No.**	**Original taxa**	**Country**	**Type**	**Genetic groups** SNPs at K=5	**Genetic groups** SVs at k=5
SRR19543730	PI 164779	P. sativum	India	Traditional Cultivar/Landrace	PSII	PSII
SRR19666966	AGG4020	P. sativum asiaticum	Afghanistan	Traditional Cultivar/Landrace	PSII	PSII
SRR19543737	G917	P. sativum	China, Tibet	Traditional Cultivar/Landrace	PSII	PSII
SRR3138890	PI180693	P. sativum sativum	GERMANY	Cultivar/Landrace	PSIII	PSIII
SRR19543723	AGG4064	P. sativum asiaticum	Algeria	Traditional Cultivar/Landrace	PSIII	PSIII
SRR19543716	AGG2380	P. sativum subsp. transcaucasicum	Former Soviet Union	Wild/Landrace	PSIV	PSIV
SRR19543715	AGG2384	P. sativum subsp. transcaucasicum	Sweden	Wild/Landrace	PSIV	PSIV
SRR3138882	JI281	P. sativum sativum	ETHIOPIA	Landrace	Admixture	Admixture
SRR19543696	AGG4107-1	P. sativum asiaticum	Tajikistan	Traditional Cultivar/Landrace	Admixture	PSII
SRR19543725	AGG190	P. sativum arvense	Finland	Traditional Cultivar/Landrace	PSIII	PSIII
SRR6702454	CGN3277	P. sativum sativum	HINDU KUSH	Landrace	PSII	PSII
SRR19543742	G626	P. sativum	China, Qinghai	Traditional Cultivar/Landrace	PSII	PSII
SRR6702455	JI103	P. sativum sativum	AFGHANISTAN	Landrace	Admixture	Admixture
SRR19543696	AGG4107-1	P. sativum asiaticum	Tajikistan	Traditional Cultivar/Landrace	Admixture	PSII
ERR10478763	BACCARA	P. sativum		Uncertain	PSIII	PSIII
ERR10478950	DARK SKIN PERFECTION	P. sativum sativum		Cultivar	PSIII	PSIII
SRR19543723	AGG4064	P. sativum asiaticum	Algeria	Traditional Cultivar/Landrace	PSIII	PSIII
ERR10478829	DP	P. sativum sativum		Landrace	PSIII	PSIII
SRR19543719	ZW6	P. sativum		Breeding	PSIII	PSIII
SRR6702458	ATC6937	P. sativum sativum	MONGOLIA	Landrace	PSII	PSII
SRR14698499	G2686	P. sativum	China, Inner Mongolia	Traditional Cultivar/Landrace	PSII	PSII
SRR19543732	PI 116944	P. sativum	Afghanistan	Traditional Cultivar/Landrace	PSII	PSII
SRR19543731	PI 143485	P. sativum	Iran	Traditional Cultivar/Landrace	PSII	PSII

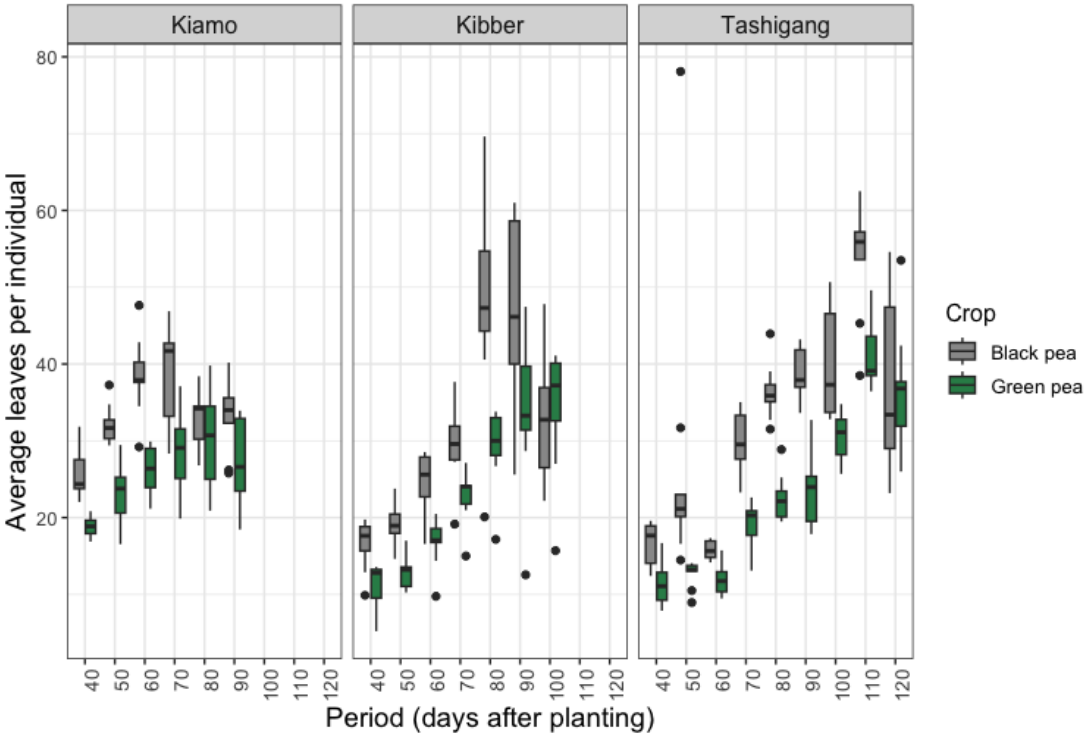

Figure .1: Average number of leaves per individual (across treatments and replicates) for black peas, green peas, and barley across the three sites Kiamo (4000m), Kibber (4200m) and Tashigang (4500m).

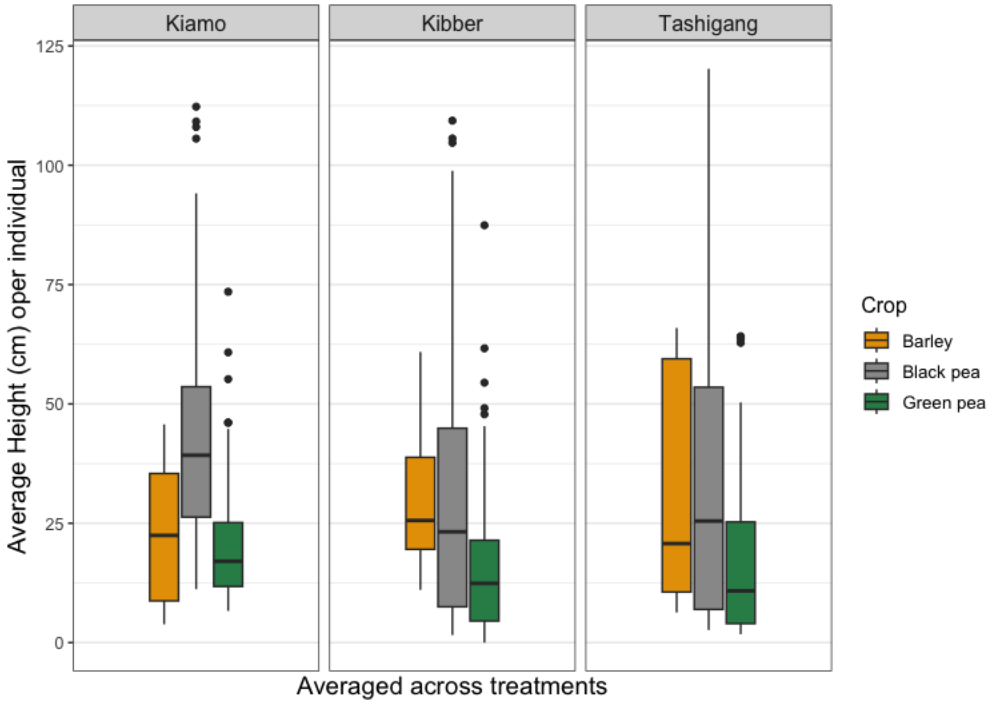

Figure .2: Average stem height per individual (across treatments and replicates) for black peas, green peas, and barley across the three sites Kiamo (4000m), Kibber (4200m) and Tashigang (4500m).