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# Assessment of productivity of spring and winter wheat sorts from China and Pakistan in high mountain Tajikistan

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## Abstract

Wheat is a staple crop and critical for food security in the high mountains of Tajikistan. Despite the local and introduced varieties of wheat, overall yields remain low and crops are vulnerable to diseases and climatic shocks. To improve production, new adapted and disease-resistant crops are crucial. We tested ten spring wheat sorts from Pakistan and seven from China with higher yields, disease resistance, and shorter stems compared to local varieties. Local varieties performed better than foreign varieties in stem length (77% longer), 25% more grains in the main spike, 45% longer main spike, 4% more spikelets in the main spike, and more productive tillers. Foreign cultivars had shorter morphogenic events, 16% higher grain weight in the main spike, 23% higher weight of 1000 grain, and 11% more grains per spikelet. Yield components and morpho-physiological traits for Chinese cultivars were weakly correlated. The main phenotypic traits affecting crop yield components were general and productive tillering. In contrast to Chinese cultivars, the main crop yield component values of local cultivars negatively interacted with most genotypic and phenotypic traits. Foreign cultivars were less susceptible to lodging and diseases; however, their shorter stems made them less attractive to local farmers.

**Keywords:** Breeding parent selection, Disease resistance, Food security, Gorno-Badakhshan, Grain quality, High-altitude agriculture, Lodging resistance, Straw yield.

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**Contribution of this paper to the literature:**
This is the first wheat trial in GBAO that put high-altitude Chinese and Pakistani lines side-by-side with local wheats. Earlier tests used only Tajik varieties. By using local types as controls, we found foreign lines with valuable traits- earlier ripening, strong disease resistance, and heavier grains. These traits are now being crossed into local wheats, a clear and practical outcome of the study.

## 1. Introduction

Wheat (*Triticum aestivum* L.), a member of the grass family Poaceae [1] is the third most important cereal crop behind rice and maize [2, 3] has profound economic and livelihood benefits [4] and is the most widely grown crop worldwide [5, 6]. The increasing demand for wheat increases its planted area, reaching up to 219 million ha with yields ranging from 732.1 to 760.9 million tons globally [7]. Wheat provides about 20% of protein and calories worldwide [8] and its gluten protein is widely used in many foods [9]. Wheat is the highest-ranked cereal crop, accounting for 30% of all cereals, and provides staple food for more than 7.9 billion people in up to 43 nations [10]. In developing countries, the demand for wheat is expected to grow by as much as 60% by 2050 [11].

Wheat is one of Central Asia's most consumable cereal crops; almost every meal includes bread made of wheat [12]. In the Pamir of Tajikistan, located in Gorno Badakhshan Autonomous Oblast (GBAO), both local and introduced wheat varieties have served as a mainstay of food security and livelihood support for many years, but changes in socio-economic conditions together with climate changes have made wheat less attractive due to declines in yields and disease resistance [13]. Lack of knowledge and financial capital prevent local farmers from introducing new varieties that are more resistant to disease and more productive. Moreover, this practice requires a preliminary assessment of introduced cultivars aimed at determining the main characteristics of the introduced varieties in the new location. Therefore, it is important to identify and select the best wheat varieties that can grow in mountain conditions as well as conduct breeding selection in such environments. The overall goal of this research was to assess foreign wheat sorts from China and Pakistan that carried traits such as high yield, disease resistance, and short stems that would not lodge before harvest and compare these to local varieties.

Ancient wheat varieties have been cultivated by local farmers for centuries, but during the last century were replaced by high-yielding sorts [13] which led to the loss of some varieties. Considering the importance of ancient cultivars and to preserve natural agrobiodiversity [14] Pamir Biological Institute (PBI) collected more than 100 local wheat varieties from Tajik and Afghan parts of Badakhshan. The main disadvantage of most local cultivars is their low yields and low baking qualities [15]. PBI with a long history of agricultural research and extension is the only facility in GBAO with enough land to test many wheat varieties focusing on developing and preserving local varieties and their gene pools. Each year PBI provides small farmers in GBAO with top local spring wheat varieties (Safedaki Ishkashimy, Surkhkhusha, Bobillo, Safedaki Bartang, and Kilak Bartangy) along with the proven lines from Afghan Badakhshan, such as Sadiras, Pandaki (facultative), and Bludon from Takhar province [16]. In recent years, PBI scientists and other Tajik breeders have crossed local and foreign wheats at the Ishkashim Experimental Station, producing hybrids that combine valuable traits [13]. Surprisingly, results of tested varieties show that no foreign variety surpassed the local lines in a total dry biomass and yield metrics [13].

Local wheat varieties have some valuable characteristics such as tolerance to local stresses, yield stability, strong adaptability to high altitudes, and important genetic diversity. Many of the local cultivars are ancient wheat. The interest in ancient grains increased during the last decades mainly because of their better nutritional composition [17]. The presence of lipids, trace elements, proteins, and other contents make ancient grains popular among farmers and consumers [18, 19]. Another feature of local varieties is the so-called high "straw to grain yield" ratio (the ratio of the height of the cultivar to yield). This is important for local farmers as the wheat straw is usually used as livestock feed during winter [20]. Therefore, dwarf and semidwarf cultivars are not popular among local farmers. However, local varieties also have disadvantages such as lodging, susceptibility to diseases, and low baking quality. The low baking qualities relegate these varieties to fodder wheat [21]. To support livelihoods and mitigate food insecurity in these mountainous regions, as well as increase the adaptative capacity of local farmers to climate variability, it is essential to improve the yield and the quality of local cultivars by introducing new varieties for screening and dissemination among local farmers. Thus, the main objective of this research was to assess and compare the productivity of foreign spring soft wheat sorts from China and vernalized winter sorts from Pakistan to local varieties in the mountain conditions of GBAO.

In developing countries, people depend on cereal crops as a main nutrient source, therefore production of sufficient grain crops to ensure food security remains significant [22]. Recent studies attempted to identify mechanisms to increase yields [9, 23, 24] but wheat yield depends on many factors [25, 26]. Thus, the introduction of new cultivars is important because the variety genotype is a key factor affecting yield [27]. On the other hand, only proper selection and introduction of new varieties and their tolerance towards agroecological conditions can guarantee high yields and high-quality grains [28]. Therefore, comparative analyses of the performance of introduced varieties in local conditions are important.

## 2. Materials and Methods

### *2.1. Site Characteristics*

Ishkashim District is situated in the southern part of GBAO (Figure 1) and is characterized by a continental and arid climate. The summers are warm and dry, and the winters are cold with little snow. Annual precipitation is low, only 80-120 mm. Precipitation mainly falls during the winter and spring (80%), with negligible rain in summer and autumn. March is the wettest month and August is the driest month of the year. The amount of solid precipitation is quite low, ranging from 10 to 20% of total precipitation. The difference in precipitation between the driest and wettest months is 78 mm [29]. During the growing season (May to September) in this arid area, the relative air humidity is no more than 40%. The average annual temperature in Ishkashim is 7.5 °C. July is the warmest month of the year with an average temperature of 19.5 °C, and January is the coldest month with an average temperature of −6.0 °C. The average monthly temperature varies by 25.5 °C throughout the year [30].

During the research period (2019-2021), no significant differences in mean annual air temperature were observed for the research area (Figure 2). Precipitation was higher in 2020 (91 mm) compared with the other two years, but the difference was insignificant.

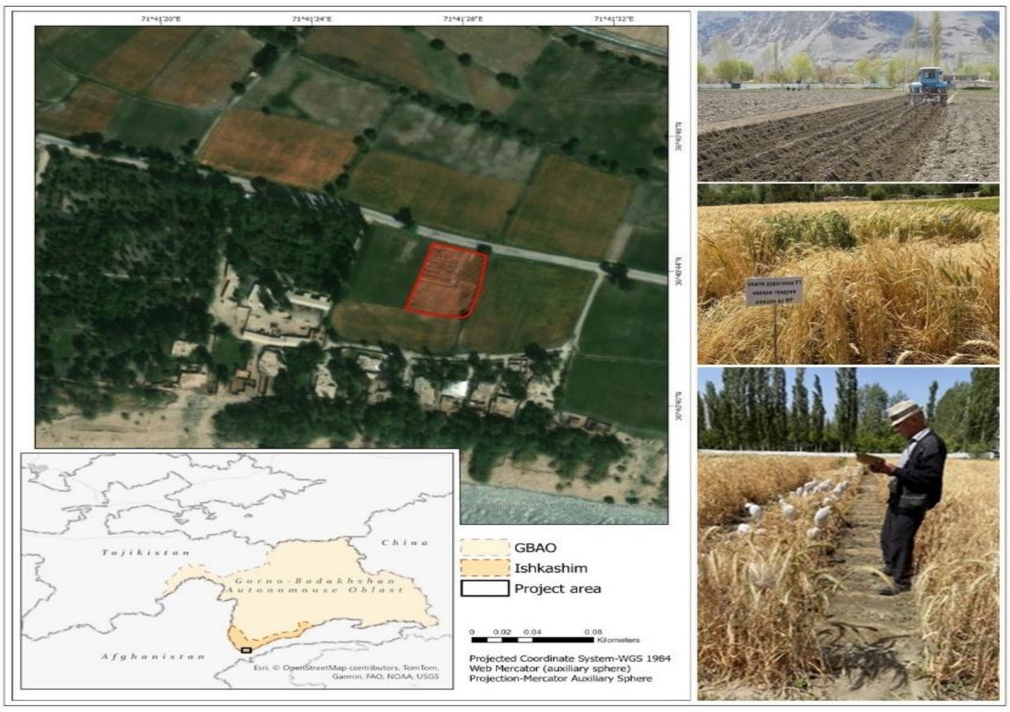


**Figure 1.** Location of the study area and experimental plot in Ishkashim District, GBAO, Tajikistan.

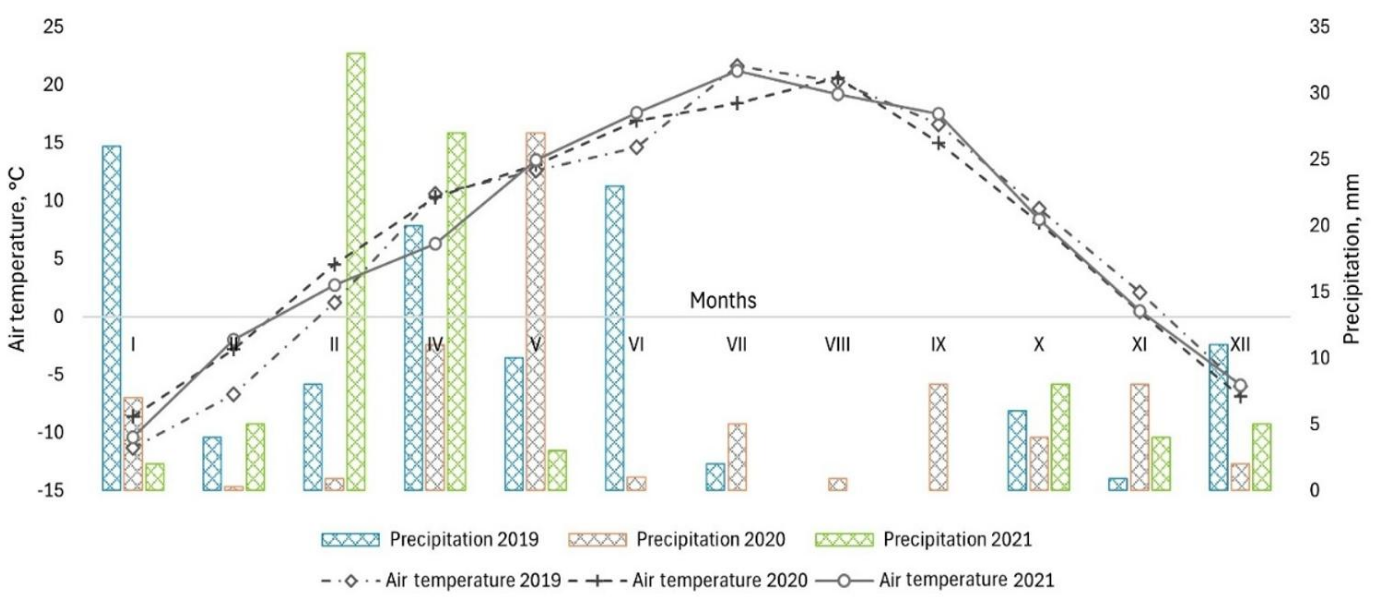


**Figure 2.** The distribution of mean annual air temperature and precipitation within the research period based on data from Ishkashim meteorological station.

## *2.2. Experimental Design, and Agronomic Practices*

The research was conducted at the PBI Experimental Station in Ishkashim, GBAO, Tajikistan (36°40'42"N, 71°41'22"E) (Figure 1). Seven breeding sorts (CRBW1, CRBW2, CRBW3, CRBW4, CRBW5, CRBW6, and CRBW7) were provided by the Agronomy Department, University of Chengdu, China. Ten breeding sorts (Trjata, No. 63, No. 76 skd, No. 75, No. 78 skd, No. 105, No. 141, No. 142, No. 144 and No. 147) were provided by the Pakistan Agriculture Research Council (PARC). The Pakistani winter wheat sorts were tested and successfully cultivated in the Skardu region (above 2000 m a.s.l.) of Gilgit Baltistan Province, Pakistan. As a control local variety, Safedaki Ishkashimy was compared with the Chinese wheat varieties and local varieties Joydori and Bludon were compared with varieties from Pakistan. Local varieties were included because they have evolved under the local conditions and are adapted to high altitudes (2000-3250 m a.s.l.).

In October 2019 local winter wheats Joydori and Bludon and ten Pakistani lines were sown at the Ishkashim experimental site. All plants tillered but later froze because the 2019-2020 winter had little snow cover. In March 2020 some Pakistani lines and the two local varieties were vernalized in a freezer (below 0°C for 86 days) and sown in spring. Because seeds was limited, the final lines kept only three Pakistani lines (No. 75, No. 144, and No. 63) plus Joydori and Bludon.

Soil is a sandy loam over pebbles, giving good drainage and high natural fertility [31, 32]. The second-year trail was planted in the third week of April and harvested in late September. Before ploughing, we applied 200 kg/ha of nitrogen-phosphorus fertilizer and 100 kg/ha of urea. Rows are 50 cm apart, each 1 m strip was separated by 60 cm. We hand-sowed two rows per strip (100 seeds per row, 2 cm between plants, 17 cm between the paired rows). Each 0.5 $m^2$ plot was replicated three times, and the replicates were arranged at random.

### *2.3. Data Collection*

The key growth staged such as germination, tillering, stem elongation, heading, and stage of ripeness (milk and dough stages, and full ripening) were tracked. The time from germination to heading and from heading to ripening was recorded, and some plants showed yellow rust during ear emergence and flowering. At harvest we sampled ten plants per variety and measured plant height, general and productive tillering, length of the main spike, number of spikelets on the main spike, number and weight of grains in the main spike, number of grains per spikelet, grain weight of the main spike, grain weight of one plant, and weight of 1000 grains. Each of the 12 traits was tested with a one-way ANOVA in XLSTT, with LSD use to separate means. Pearson correlations among traits were run in R Studio (https://posit.co/download/rstudio-desktop).

## 3. Results

### *3.1. Comparative Analyses of Spring Soft Wheat Sorts*

As a widely adapted crop, wheat grows in most environments but thrives in cool environments [33]. The main parameters of the spike that determine productivity (i.e., number of spikelets per spike, number of kernels per spikelet, and weight of individual kernels) are determined genetically but can be affected by environmental conditions [34]. In this study, all relevant parameters related to crop yield were analyzed.

The comparative analyses amongst all Chinese and local sorts show that the mean plant height of the control variety Safedaki Ishkashimy ranged from 90.6 to 96.0 cm during the 3-yr period, significantly higher compared to Chinese sorts (Figure 3a). The height of wheat is an important factor for Tajik farmers as the straw is used for winter cattle forage. Height of Chinese sorts during this period ranged from 52 (CRBW-7) to 62 (CRBW-6) cm, significantly shorter than controls. All Chinese sorts were semidwarf. Local varieties Surkhkhusha and Pandaki showed slightly better results than the control (Safedaki Ishkoshimi), but these height differences were not statistically significant. Pandaki produced the tallest plants of all varieties tested.

During the 3-yr period, Safedaki Ishkashimy (control) had the highest mean of the general tillering, a specialized branching that occurs from the basal node and grows independently of the mother stem [35] (3.5-3.7 pcs), significantly higher than sorts from China (Figure 3b). The general tillering of sorts from China in the 3-yr period ranged from 2.4 to 2.9 pcs. Local varieties were not significantly different from the control, except in 2020 when Surkhkhusha was significantly higher.

The mean number of productive tillers (number of tillers that produce spikes and seeds) [36] of the control variety was 3.4 pcs. Similar to general tillering, the control variety had a higher number of productive tillers compared to all sorts from China. Productive tillering of Chinese sorts ranged from 2.3 to 2.7 pcs during the 3-yr period (Figure 3c). Also, similar to general tillering, local varieties were not significantly different from controls, except in 2020 when Surkhkhusa was significantly higher.

The mean of the length of the main spike in the control variety was significantly greater than the range reported for Chinese types. The spike length of the Chinese types ranged from 5.5 to 7.5 cm (Figure 3d). Local types did not differ significantly from the control, except for Surkhkush in 2021 (7.40 cm) and Pandaki in 2020 (7.7 cm), which were both shorter than the control.

Safedaki Ishkoshimy, the control, also had significantly more spikelets per main spike than the Chinese types. Nevertheless, CRBW7, CRBW6 CRBW5 and CRBW2 had higher values than the control in 2020 (Figure 3e). On average , the Chinese types had from 11.2 to 15.1 pcs spikelets per main spike . Local varieties Surkhkusha and Pandaki had significantly fewer spikelets than the control.

No significant differences were observed between the control and Chinese varieties for the number of grains per spikelet. There were about 2.2 to 3.20 pcs grains per spikelet among the Chinese varieties (Figure 3f). The sorts from China (CRBW7, CRBW6, CRBW4, CRBW5 and CRBW2) recorded somewhat higher values than the control in 2029, but the 3-year averages were not significantly different..

The control plants carried about 38–42 grains on the main spike. CRBW1 always produced fewer grains than the control. CRBW7, CRBW6, and CRBW5 matched the control in 2019 but fell below the control in 2020 and 2021. CRBW3 and CRBW2 followed the same pattern. CRBW4 was the only line with more grains than the control in 2019 (about 44), yet it dropped below the control in 2020 and showed no difference in 2021. Both local sorts equaled the control in 2019 and trailed the control in the next two seasons.

The control's 1000-grain weight ranged from 29.8 to 34.7 g. In 2019, grain weights for CRBW1, CRBW4, CRBW5, and CRBW2 were clearly heavier (40–43 g), while CRBW7, CRBW6, CRBW3, and the local varieties showed no statistical difference from the control.

Local varieties needed the most time to reach heading, about 53–61 days. Chinese lines headed sooner at roughly 52–55 days, so they were significantly earlier than the control in 2019 and 2020. In 2021, heading in two of those lines extended to 58–59 days, and the rest matched the control. Surkhkhusha reached heading later than the control only in 2019, whereas Pandaki was slow every year (65–72 days).

The time period from heading to full ripening was shorter for local wheats (51–53 days). Most lines mirrored the control in 2019 and 2021, except CRBW6, which took slightly longer to ripen in 2019. During the 2020 season all sorts needed 59–62 days from heading to full ripening, outpacing the control. Local varieties ripened more rapidly than the control in 2019–2020 but slower in 2021.

The germination to ripening period is longer for local varieties compared to foreign sorts (112 and 106 days, respectively; Figure 3k). During the 3-year study, this period ranged from 104-113 days. The mean germination to ripening periods for all sorts in 2019 and 2021 were a bit slower compared to the control but not statistically different (Table 1). In 2020, all sorts were not significantly different from the control. Surkhkhusha was not significantly different from the control in all years, whereas the local variety Pandaki had significantly higher values in 2019 and 2020 (109 and 119 days, respectively).

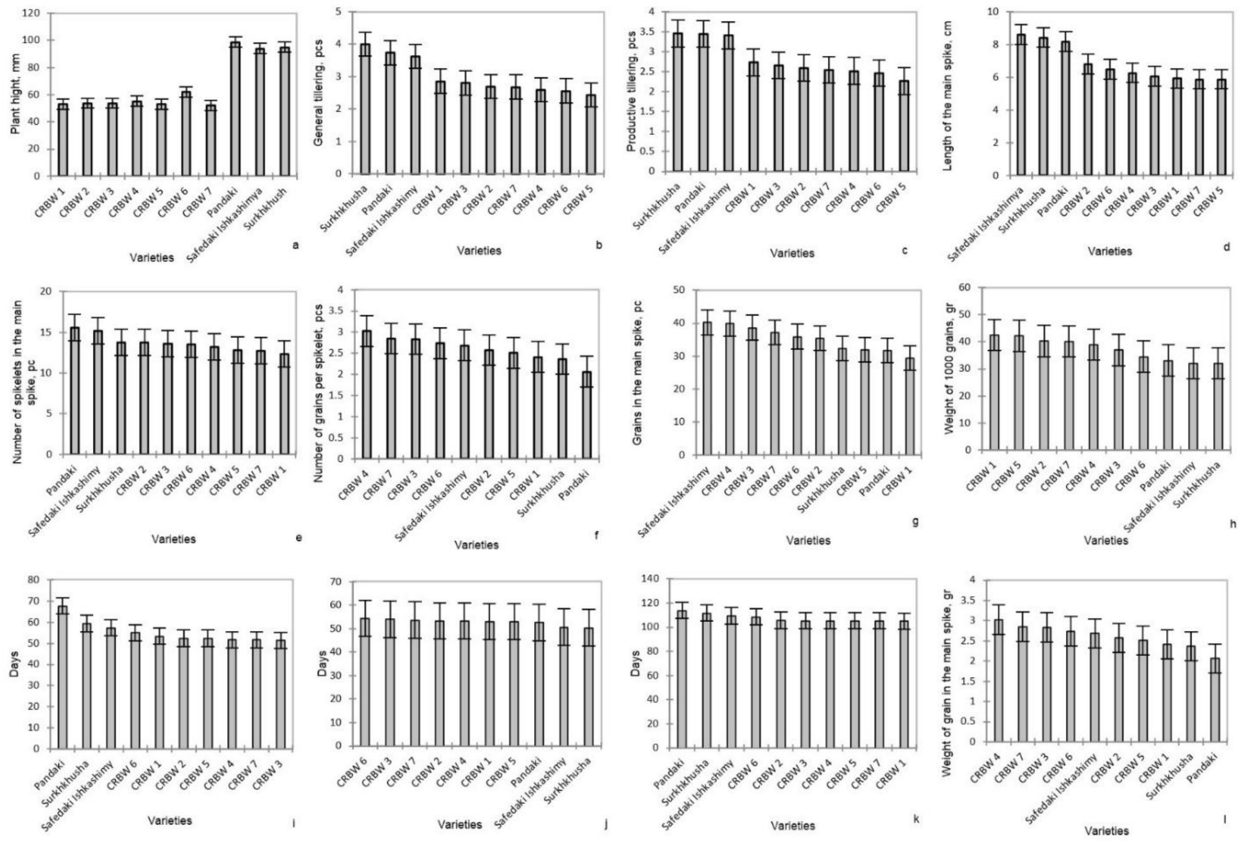


**Figure 3.** Main parameters of the Chinese and local sorts; a) plant height, b) general tillering, c) productive tillering, d) length of main spike e) number of grains in the main spike. f) number of grains per spikelet, g) number of grains in the main spike h) weight of 1000 grains, i) germination to heading period, j) heading to ripening period, k) germination to ripening period, l) weight of grains in the main spike.

There were no differences in the weight of grains in the main spike of the control compared to foreign sorts (Figure 3l). Grain weights in the control ranged from 1.2 to 1.3 g. Some Chinese sorts (CRBW2, CRBW3, CRBW4, CRBW5, CRBW7) showed better performance than the control variety but these changes were not significant ($p<0.05$). Surkhkhush and Pandaki had significantly lower weight of grain in the main spike compared to the control.

### *3.2. Comparative Analyses of Vernalized Winter Sorts*

Local cultivars were taller than introduced sorts from Pakistan. Control height ranged between 85.9 to 105.6 cm (Figure 4a), generally higher than sorts from Pakistan (74.4 to 95 cm), except sort №63 in 2019. The local variety Bludon was not significantly different from the control in all years.

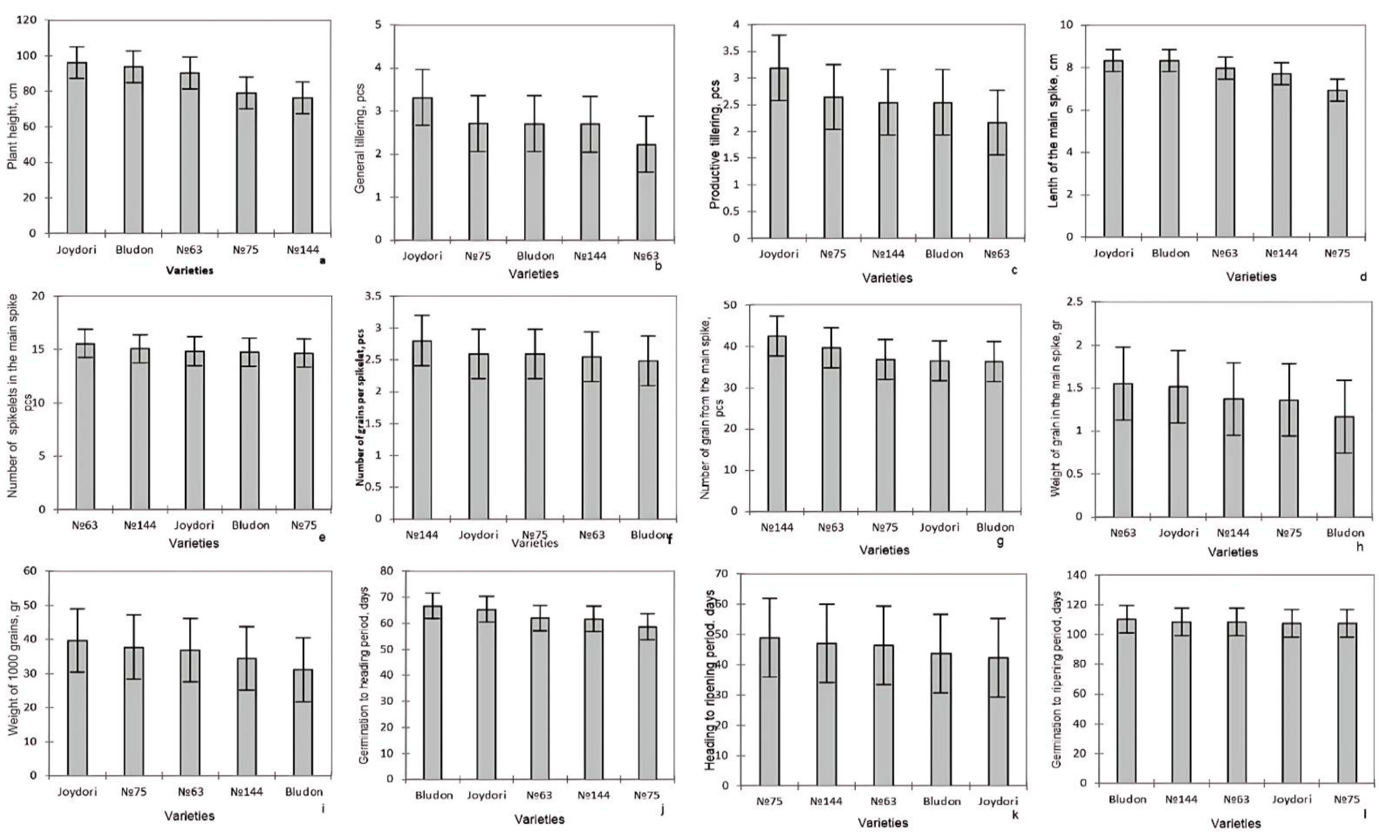


**Figure 4.** Main parameters of the Pakistani and local varieties; a) plant height, b) general tillering, c) productive tillering, d) length of the main spike, e) number of kernels in the main spike, f) number of grains per spikelet, g) number of grains in the main spike h) weight of grains in the main spike i) weight of 1000 grains, j) germination to heading period, k) heading to ripening period, and l) germination to ripening period.

The mean value for general tillering in the control was 3.3 pcs., not significantly different from foreign sorts. This value for the sorts from Pakistan ranged from 2.2 to 2.7 pcs. (except №144 in 2020) and was not significantly different from the control (Figure 4b). Local variety Bludon had a lower tillering value in 2019 and 2021 (2.2 and 2.6 pcs.) but was not significantly different (3.3 pcs.) from the control in 2020. The mean of productive tillering in the control was 3.2 pcs. For Pakistani sorts, productive tillering ranged from 2.2 to 2.6, which was not statistically different than the control (Table 1). The local variety Bludon had lower values ranging from 2.2 to 2.9 pcs (Figure 4c).

There was no difference in the length of the main spike among the control and foreign sorts (Figure 4d). The mean value of the main spike of the control was 8.3 cm, significantly longer compared to Pakistani sorts (6.9 to 8.0) (Table 2). Local cultivar Bludon was not significantly different than the control.

The mean number of spikelets in the main spike of the control ranged from 14.5 to 16.2 pcs (Figure 4e). All foreign sorts and Bludon were not significantly different from the control in all years. No statistically significant differences were found among cultivars.

The mean number of grains per spikelet in the control ranged from 2.3 to 2.8 pcs. (Figure 4f). Sorts №75 and №63 did not differ from the control values in all years. Only sort №144 had more grains per spikelet compared to the control, but this was not statistically significant. In 2019 and 2021, local cultivar Bludon had a higher value compared to the control, but in 2020 it had significantly lower values. The control had an average of 36.5 grains in the main spike during the 3-year study (Figure 4g). Sort №75 and Bludon were not significantly different from the control. Sorts №144 and №63 had significantly higher grains per spikelet in all years except 2019 (№144) and 2020 (№63). The Pakistani variety № 63 had the highest mean weight of grains in the main spike (1.6 g) and the local variety Bludon had the lowest value (1.2 g), although the difference between the cultivars was not statistically significant (Figure 4h). On an annual basis, the highest value was recorded in 2021 (1.7 g) and the lowest in 2020 (1.2 g).

The mean weight of 1000 grains in the control ranged from 35.9 to 48.1 g (Figure 4i). Sorts №75 and №144 had higher values in some years but mean values were not significantly different (Table 2). Local cultivar Bludon had the lowest mean value.

The germination to heading period was 65 days for the control, slightly longer but not significantly different from Pakistani sorts (59 to 62 days, Figure 4j, Table 2). Local cultivar Bludon had the longest germination to heading period (67 days). The control cultivar Joydori ripened first (42 days). The Pakistani cultivars had a longer heading to ripening period (46-49 days) but this was not significantly different from the control variety (Figure 4k). For local cultivar Bludon, ripening occurred after 44 days.

The germination to ripening period was similar for all varieties (108 to 110 days) (Figure 4l). The ripening period varied throughout the 3-year study period. For instance, in 2019 all sorts had significantly lower values (ranged from 98 to 104 days), while in 2020 all sorts and the local cultivar Bludon had higher values (ranged from 111 to 112 days) compared to the control. In 2021 all sorts and the local cultivar Bludon were not significantly different from the control.

### *3.3. Pearson Correlation Analyses Between the Crop Parameters*

The results of Spearman's coefficient of rank correlations between various crop yield parameters of Chinese, local, and Pakistani cultivars are shown in Figure 5. Among the phenotypic and genotypic variance affecting the grain yield, the influence of yield components, namely the number of grains per spike, weight of the kernel, and spikes per unit area are significant [37]. We observed a weak correlation between the yield components and morpho-physiological traits for Chinese cultivars (Figure 5a). The length of the main spike (LMS) was negatively correlated with weight of 1000 grains (W1000G), number of grains per spikelet (NGPS), and general tillering (GT). LMS was positively correlated with the number of spikelets in the main spike (NSMS), but had a non-significant positive correlation with plant height (PH), number of grains in the main spike (NGMS), and weight of grains in the main spike (WGMS). Among the main phenotypic traits affecting the NGMS are GT and productive tillering (PT). The interaction between them is highly significant ($p<0.001$). A negative correlation was detected for W1000G with morpho-physiological traits, especially with HRP ($p<0.01$), and GRP ($p<0.05$). However, W100G had a negative non-significant correlation with NGMS and NSMS. In contrast, NSMS was positively correlated with almost all traits, while the level of the interaction between these traits was low. WGMS and NGMS were also not well correlated with morpho-physiological traits.

For local spring wheat cultivars, the highest correlation was detected between the NGPS and GT, NGMS and WGMS, NGMS and PH, and between W1000G and PT (Figure 5b). The main phenotypic traits affecting the yield components were PT, LMS, and GT. In contrast to Chinese cultivars, LMS, PH, WGMS, and NGMS values of local cultivars negatively interact with most genotypic and phenotypic traits. The grain yield components WGMS and NGMS correlated well with PH and LMS, though the coefficient of the correlation is not significant ($p\geq0.05$). The height of the plant (PH) of local wheat cultivars had a high negative correlation with most morpho-physiological traits (GRP, PT, GHP, HRP) and yield trait components (W1000G, NGPS).

For the Pakistani sorts, a high correlation was detected between some phenotypic traits (GRP, GHP and LMS) and yield components (NGMS, WGMS) (Figure 5c). Other phenotypic traits (GT, PT and HRP) showed a negative interaction with most genotypic and phenotypic traits. The 1000 grain weight had a moderate positive correlation with WGMS, PH, and HRP, but a non-significant negative correlation with yield components (NGMS and NGPS). PH and LMS interacted significantly with WGMS. The main morpho-physiological traits affecting the crop yield components are PH, GHP, and GRP.

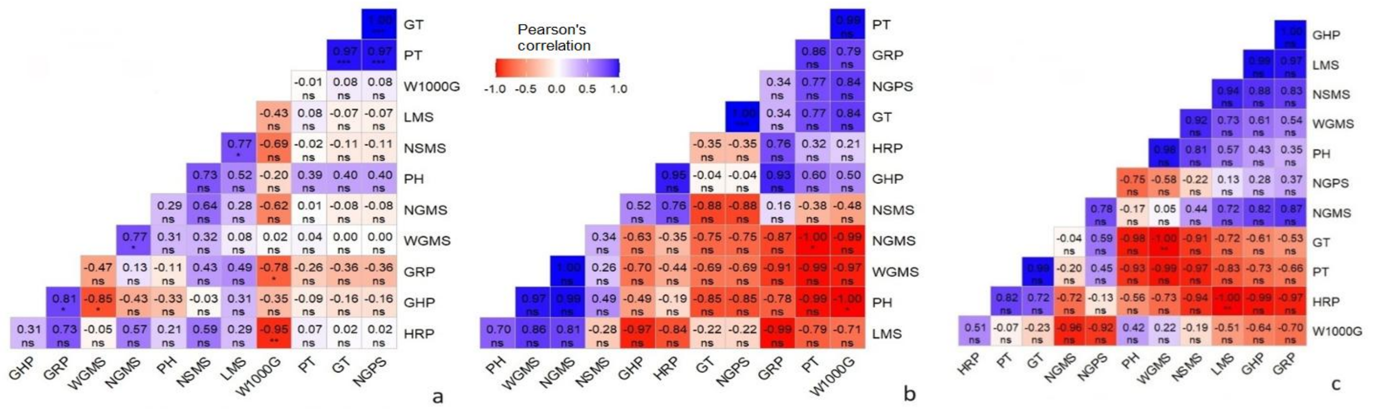


**Figure 5.** Correlation between the main crop yield parameters of Chinese (a), local (b), and Pakistani (c) cultivars. PH-plant height, PT-productive tillering, NSMS-number of spikelets in the main spike, HRP- heading to ripping period, GRP- gemination to heading period, LMS- length of the main spike, W1000G- weight of 1000 grains, NGMS- number of grains in the main spike, NGPS-number of grains per spikelet, and WGMS- weight of grains in the main spike.

**Note:** ns p>=0.05; *p<0.05; ==<0.01; and ***<0.001.

## 4. Discussion

Varieties with long adaptation periods to local stresses favor local cultivars if the high mountain setting is not well suited to newly introduced crops. An ideal cultivar that best fits the local context and contributes to food security in this mountain region must possess ideal traits, including long straw; high numbers and mass of kernels per spike; high numbers of productive tillers; early maturity; and resistance to local environmental shocks and diseases.

Our findings show that local varieties have some advantages over imported cultivars, especially for crop height, number of spikelets on the main spike, length of the main spike, and number of grains in the main spike. Introduced cultivars have higher numbers of grains per spikelet, higher weight of 1000 grains, and matured earlier. These results indicate that despite having longer spikes and longer axes, local cultivars produce small grains diminishing total cultivar yields (Table 1). Local cultivars produce longer stems and more tillers, which are important for the local farmers because they use wheat straw for cattle fodder during the long winters. The local cultivar Safedaki Ishkoshimi was 72% higher than the average value of the Chinese cultivars. The height of the plants was recognized as a main feature of ancient wheat [14]. On the other hand, tall plants are susceptible to lodging [38] causing decreases in yields because the lodged plant becomes susceptible to diseases. Therefore, to keep the stem standing, the spikelets have undergone significant changes during domestication, mainly expressed by changes in their shape and decreases in kernel weight [14]. Thus, despite local wheat cultivars producing more grains in the main spike, the weight of grains is lower compared to foreign varieties.

Local cultivars had longer periods of morphogenic events ranging from 109 to 114 days. Chinese cultivars matured somewhat earlier, but results were not statistically significant (Table 1). Early cultivar maturation is an important trait because of the harsh local climate.

The growing season in Ishkashim is short, varying from 150 to 155 days, and the sum of effective daily temperatures (>10°C) range from 1000 to 1100°C per year [39]. Rain can occur in September making cereal crops vulnerable to microbial diseases, thus farmers prefer to harvest earlier before the onset of September rains. As such, early maturation of the cultivars is significant. In the overall heading stage in 2019 and 2020, five wheat sorts ripened 5 to 11 days earlier compared to the control. In contrast, the heading to ripening period for the local variety (Pandaki) was 8 to 13 days later compared to the control. The heading to ripening period in the five sorts in 2020 was 2 to 7 days longer than for the control; however, in other years these differences were not significant. The germination to heading periods for the five sorts were 2 to 7 days shorter than the local variety Surkhkusha.

The main characteristics of the spike, such as length, number of spikelets and grains in the spike, and size and weight of grains are important to biologists and breeders [40]. Local cultivars had higher spikelet counts and higher numbers of grains in the main spike, but the weight of grains per spike was lower than in Chinese varieties. Thus, total yields of local cultivars were lower. The number of spikelets is generally determined genetically, although they could be influenced by the environment [34].

Grain productivity in local wheat varieties is formed based on characteristics such as productive tillering, spike length, number of spikelets, and number of grains in the main spike. In contrast, grain productivity in Chinese sorts was based mainly on weight of 1000 grains and a longer heading to ripening period.

**Table 1.** Analyses of variance of main crop parameters of the local and foreign spring cultivars from China.

| Parameter | A | *F* | *Pr > F* | *p-values signification codes* |
|---|---|---|---|---|
| Plant height | 0.05 | 127.5 | 0.0001 | *** |
| Length of the main spike | 0.05 | 15.27 | 0.0001 | *** |
| Number of grains per spikelet | 0.05 | 4.39 | 0.003 | ** |
| Number of grains in the main spike | 0.05 | 6.81 | 0.00018 | ** |
| Number of spikelets in the main spike | 0.05 | 1.78 | 0.13 | ° |
| Grain weight of the main spike | 0.05 | 1.75 | 0.142 | ° |
| Weight of 1000 grains | 0.05 | 50.38 | 0.069 | . |
| Heading to ripening period | 0.05 | 5.27 | 0.99 | ° |
| Germination to ripening period | 0.05 | 0.95 | 0.505 | ° |
| Germination to heading period | 0.05 | 7.74 | 0.51 | ° |
| General tillering capacity | 0.05 | 9.904 | <0.0001 | *** |
| Productive tillering capacity | 0.05 | 8.02 | <0.0001 | *** |

**Note:** Computed against model Y=Mean(Y).
Signification codes: 0 < *** < 0.001 < ** < 0.01 < . < 0.1 < ° <1.

The highest-yield traits, such as number of grains per spike, grain weight of the main spike, and weight of 1000 grains, were found in six Chinese lines (CRBW1, CRBW7, CRBW4, CRBW5, CRBW3 and CRBW2). These lines also stood up well to lodging, pests, and diseases and have good baking quality, making them useful parents for crossing with local wheats. The main disadvantage of these sorts in this region is that they have shorter stems with a lower straw-to-grain yield ratio. Therefore, they should be used in the breeding and hybridization rather than released directly.

During the three-year test, Pakistani winter lines (No. 75, No. 144, and No. 63) grew shorter, tillered less, and had shorter main spikes than the local Bludon. Spikelet and grain counts were mostly similar to the control, except that No. 144 had more grains per spike. All three Pakistani lines reached heading 4-10 days sooner and matured 5-7 days earlier than the control, while Bludon reached heading later but ripened at the same time. Sort No. 144 and No. 63 also produced more grains per main spike than the control.

**Table 2.** Analyses of variance of the local and foreign winter sorts from Pakistan.

| Parameters | A | F | Pr > F | p-values signification codes |
|---|---|---|---|---|
| Plant height | 0.05 | 4.892 | 0.019 | * |
| Length of the main spike | 0.05 | 6.10 | 0.009 | ** |
| Number of grains per spikelet | 0.05 | 0.46 | 0.759 | ° |
| Number of grains in the main spike | 0.05 | 1.56 | 0.257 | ° |
| Number of spikelets in the main spike | 0.05 | 0.367 | 0.827 | ° |
| Grain weight of the main spike | 0.05 | 0.64 | 0.65 | ° |
| Weight of 1000 grains | 0.05 | 0.61 | 0.659 | ° |
| Heading to ripening period | 0.05 | 0.209 | 0.927 | ° |
| Germination to ripening period | 0.05 | 0.068 | 0.990 | ° |
| Germination to heading period | 0.05 | 2.06 | 0.161 | ° |
| General tillering | 0.05 | 1.79 | 0.207 | ° |
| Productive tillering | 0.05 | 1.80 | 0.204 | ° |

**Note:** Computed against model Y=Mean(Y).
Signification codes: 0 < ** < 0.01 < * < 0.05 < . < 0.1 < ° <1.

The Pakistani sorts produce smaller grains but are noted for resisting lodging, pest, and diseases, and for their good baking quality (this was not tested but based on the sort characteristics). Local wheats lack these strengths, so the Pakistani sorts are useful breeding materials and can be included in the hybridization process with local varieties.

## 5. Conclusion

Comparative analysis of productivity of foreign wheat sorts with local varieties in GBAO revealed important insights into the suitability of different sorts for the high mountain region. The research aimed to identify the ideal wheat cultivar that best fits local conditions and contributes to food security in this challenging region. The findings revealed that local varieties had certain advantages over foreign sorts. The local varieties showed better performance in terms of crop height, number of spikelets on the main spike, length of the main spike, and number of grains in the main spike. Additionally local cultivars had longer stems and more tillers, which are valuable traits for local farmers who use wheat straw as cattle fodder during the long and harsh winter months in high mountain areas. However, foreign wheat sorts also exhibited favorable characteristics, such as higher number of grains per spikelet, higher weight of 1000 grains, and early maturation. These traits are important and could be beneficial for withstanding the challenging local environment where the growing season is short and unpredictable weather conditions occur; particularly rains in September may make cereal crops susceptible to diseases. Early maturation of wheat sorts is desirable in such conditions to avoid the impact of September rainfall; some of the foreign wheat sorts demonstrated this trait.

Local varieties have longer periods of maturity indicating a longer adaptation period to the local conditions. On the other hand, foreign sorts mature somewhat earlier, though not significantly different from the local varieties. The productivity attributes of local wheat varieties are mainly associated with productive tillering, spike length, number of spikelets, and number of grains in the main spike. In contrast, the productivity attributes of foreign sorts focus on weight of 1000 grains and longer heading to ripening periods for grain productivity.

A separate comparison was made with vernalized winter wheat sorts from Pakistan during spring sowing under local conditions. The Pakistani sorts were generally shorter with lower general and productive tillering and shorter main spikes compared to local variety Bludon. However, some Pakistani sorts have higher numbers of grains in the main spike and better resistant to lodging, pests, and diseases, making them potential candidates for hybridization with local varieties.

In conclusion, the study shows that local wheat varieties in GBAO have specific advantages, especially in terms of their adaptability to local stresses and their importance for providing cattle fodder during prolonged harsh winters. However, introduced wheat sorts also have attributes, including higher grain yield, early maturation, and resistance to lodging, pests and diseases. The results suggest that a combination of local and foreign wheat sorts through hybridization could lead to the development of ideal wheat varieties that can thrive in these unique environmental conditions and contribute to food security. Further research and breeding efforts should focus on selecting and developing cultivars with the most desirable traits to address the specific challenges of wheat cultivation in this high mountain region. In this study, the genotype by environment interaction (GEI) or differential genotypic expression across environments was not considered. GEI affects the performance of the tested cultivar in multiple environments. Identification of superior genotypes is difficult because of GEI [41] therefore it is important to test the introduced cultivar in different locations of the region to identify the area where the cultivar performs similarly [42]. This limitation should be considered in future research.

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