Chapter

Exploring the Diversity of Maize (*Zea mays* L.) in the Khangchendzonga Landscapes of the Eastern Himalaya

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Abstract

The Sikkim Himalaya is a distinguished hub of maize biodiversity, housing a wide range of genetic resources cultivated at altitudes from 300 to 2500 m elevations. From 2010 to 2022, a field investigation combined traditional knowledge and scientific methods to morphologically characterize maize, supplemented by relevant literature. The objective was to evaluate indigenous maize varieties in the region since the 1960s. The research classified maize landraces into four groups: primitive landraces, preserved traditional popcorn races; advanced or derived landraces, selectively bred for desirable traits; recent introductions from other regions; and hybrid maize varieties resulting from crossbreeding. About 31 maize landraces were listed, emphasizing the urgent need for in-depth genetic characterization. Notably, *Murali Makai, Seti Makai, Pahenli Makai, Rato Makai, Baiguney Makai, Gadbadey Makai, Tempo-Rinzing*, and *Lachung Makai* adapted well to altitudes of 300–2500 m, showing variations in agronomic and quality traits, as well as resistance to environmental stresses. Primitive maize cultivars in the Northeastern Himalayas of India have generated interest among researchers for their high prolificacy and their link to the origin and evolution of maize. Prioritization at the species level and within specific geographic regions is necessary due to the dynamic demand for germplasm. Conservation of certain maize germplasm is crucial for food security, livelihoods, climate resilience, and research. The study identified potential risks of germplasm extinction or erosion, emphasizing the need for urgent actions to safeguard these genetic resources.

Keywords: Khangchendzonga landscapes, maize landraces, quality traits, genetic diversity, eastern Himalaya

1. Introduction

Maize (*Zea mays* L.) is a significant cereal crop worldwide, widely cultivated and highly valued for its diverse uses. In high-income countries, it serves as a primary source of feed and industrial products, while in sub-Saharan Africa (SSA), Asia, and Latin America, it plays a crucial role in providing food, feed, and nutritional security for some of the world's poorest regions [1]. Originating from Mexico, maize has extended its presence to critical agroecologies in tropical, subtropical, and temperate regions across the globe.

The center of origin for maize has been established as the Mesoamerican region, encompassing present-day Mexico and Central America [2]. Maize cultivation was introduced to the rest of the world during the sixteenth century [3, 4], and in India, it was brought by the Portuguese in the seventeenth century [5–7]. In India, there is speculation that maize was initially introduced in the North-West Himalayas by traders, from where it subsequently spread to the Himalayan region [8]. This includes the introduction of primitive forms of maize in the old world, including the Himalayas during the pre-Columbian period [9].

The exceptional genetic diversity of maize is evident from well-defined landraces found in various countries. Landraces, which serve as a valuable reservoir of useful genes and alleles, are the germplasm preserved by farmers over extended periods. These landraces were developed and selected to thrive under specific environmental conditions and fulfill local food preferences.

India is a significant centre of diversity for maize landraces, with extensive variations observed in plant, ear, and tassel characteristics in the northeastern and northwestern highlands. However, relatively less varietal diversity is found in the plains of India [10]. Anderson [11] was particularly impressed with the diversity of maize in the north-eastern Himalayan region and believed that maize had an ancient Asiatic origin. Dhawan [12] renamed a productive popcorn variety from Sikkim as 'Sikkim Primitive' due to its distinctive characteristics. This landrace exhibits unique physiological features, such as the absence of apical dominance, prolificacy (5–9 ears), uniformity in ear size, erect leaves, a top-bearing habit, and drooping tassels for efficient fertilization [13]. The Sikkim Primitive maize is commonly used as fodder for livestock by local farmers. The primitive maize strain, also known as the SP strain, comprises 13 different strains distributed throughout the NEH region, excluding Sikkim [14].

A significant portion of the genetic diversity in maize remains unexplored, partly due to the challenge of identifying valuable genetic variations within local varieties [15]. This limited utilization of diverse genetic resources can be attributed to the lack of understanding of the agronomic performance and genetic makeup of these landraces. Prasanna and Sharma [10] addressed this bottleneck by conducting the first comprehensive molecular characterization and population genetic analysis of 17 Indian maize landraces sourced from diverse agroecologies. The study utilized 27 microsatellite or simple sequence repeat (SSR) markers to reveal a higher level of genetic divergence among the Northeastern Hill (NEH) landraces when compared to those from other regions.

Maize is a crucial crop in Sikkim, although its current productivity is quite low, with an average of 1750 kg/ha [16]. Given this, it is important to develop varieties that are well-suited to the region's unique conditions. To accomplish this, breeders require an understanding of character associations and path analysis.

Landraces are a type of germplasm that has been preserved by farmers over the course of decades or even centuries. They have been carefully selected to adapt to specific environmental conditions and meet local food preferences. While maize originally came from Mexico, it is now widely grown across the world, and India has a particularly rich array of maize landraces, particularly in the North-Eastern Himalayan region [10]. These landraces contain many valuable genes that could be used for allele mining and population improvement. In recent years, molecular analysis of maize landraces from the Americas and Europe has led to significant insights into their diversity, genetic structure, and global migration routes. It is essential to have a comprehensive understanding of the genetic and agronomic characteristics of

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landraces for effective management and use in breeding programs. In this review, we discuss the extensive diversity of maize landraces globally and in India in Sikkim and NEH, and explore the potential for harnessing this vast genetic resource.

2. Study area

The study area is situated in the Indian part (26°29′13.56″ to 28°7′51.6″ N and 87°59′1.32″ to 89°53′42.96″ E) of the Khangchendzonga Landscape (KL) in the eastern Himalayas, which is a significant global biodiversity hotspot. KL represents a unique blend of biodiversity, bio-cultural richness, and distinctive geo-climatic features. The Indian portion of KL covers 14,061.7 sq. km and encompasses the state of Sikkim and the northern hill region of West Bengal. It stretches across a wide altitudinal range, from 40 to 8586 m (asl).

This region is crucial for sustaining the well-being of its inhabitants, as it provides diverse ecosystems and essential ecosystem services. It boasts a rich floral diversity, with over 5500 identified species, as well as recorded fauna taxa of more than 1500 species. The presence of various socio-economic and cultural diversities further enhances the significance of the region.

The study area falls under the SECURE Himalaya project, implemented by the Forest and Environment Department of the Government of Sikkim (**Figure 1**). Specifically, the project focuses on the Khangchendzonga—Upper Teesta Landscape, covering an approximate area of 4000 sq. km. Local communities hold a deep reverence for this landscape due to the legends and traditions associated with it. The landscape is characterized by its multi-ethnic composition, including Nepalese, Lepchas, Bhutias, and Tibetan Buddhists conserving rich agricultural biodiversity.

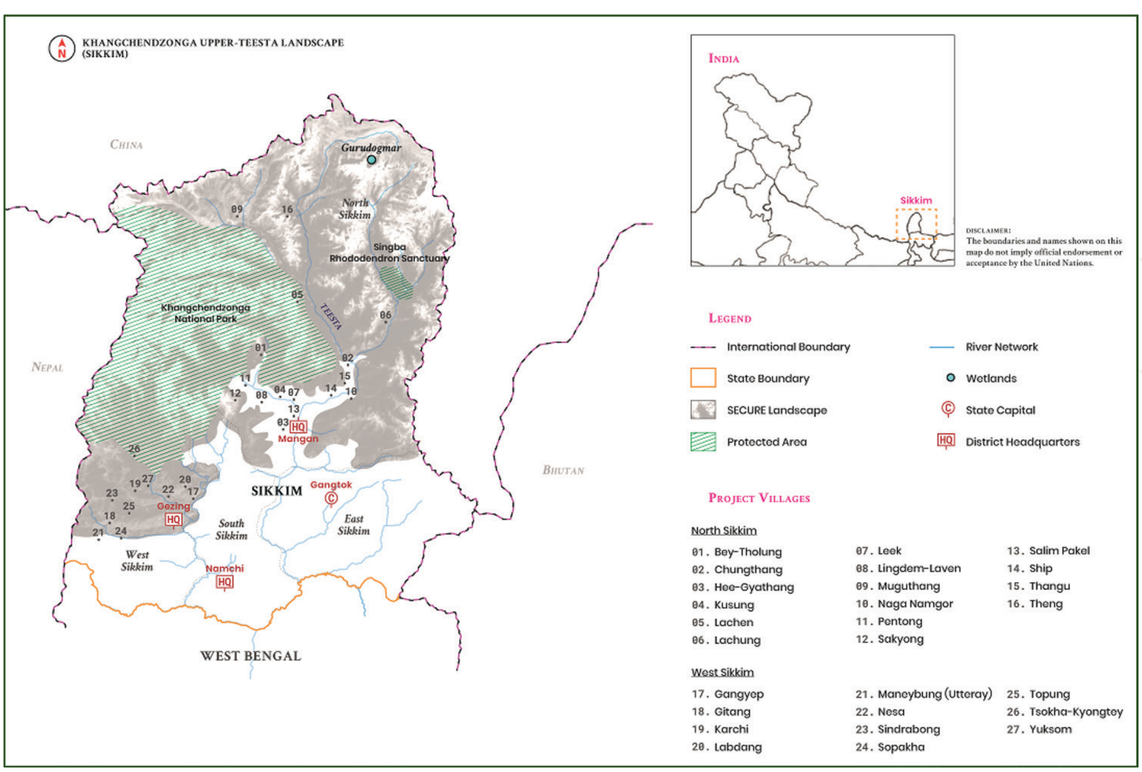

Figure 1.
Study area in the Khanchendzunga landscape based on the secure Himalaya project (https://securehimalaya.org/sikkim-landscape/).

3. Genetic diversity of maize in NEH

Singh [17] reported 10 indigenous maize varieties from the northeastern Himalayan region, namely *Nilip Mekop*, *Mikir Merakku*, *Khasi Riewhadem*, *Silken Tipang*, *Tista Mendi*, *Maidani Makka* (sub-race *Ganga*), *Cachar Gomdhan*, *Shyam Nahom*, *Asht Samsung* (sub-race *Tsungrhu*), *Mayong Sa-ah*, *Manipuri Chujak*, *Alok Sapa*, *Arun Tepi*, *Tirap NagSahypung*, and *Poorvi Botapa* (sub-race *Murli*).

As per Singh [17], *Astha Samsung*, a maize variety well adapted to high elevations above 1500 m, was commonly found in Sikkim and Nagaland. The name "Asht" refers to the presence of eight rows of kernels, a distinctive trait of this particular maize race. Samsung, on the other hand, refers to the specific location in Sikkim where this maize race was commonly cultivated. Another subrace of maize variety reported from Sikkim was *Tsungrhu*, which was also cultivated above 1500 m. The term "*Tsungrhu*" derives from the regional language of the Lotha Tribe in Nagaland, where it was extensively grown and its name signifies "maize" in their language. Similarly, *Tista Mendi* was another indigenous maize variety cultivated in the elevated regions above 1500 m along the famous River Teesta.

The races mentioned in the preceding paragraphs can be categorized into four groups for convenience: Primitive, Advanced or Derived, Recent Introductions, and Hybrid varieties. The Primitive group encompasses several races of popcorn that have differentiated at various altitudes and under diverse conditions. These races include *Poorvi Botapa*, *Murli subrace* of *Poorvi Botapa*, *Tirap NagSahypung*, *Arun Tepi*, and *Alok Sapa* [17]. The races belonging to the Primitive group display distinct traits such as popping grain morphology, prominent kernel striations, reduced kernel rows, smaller ears with higher ear numbers, tassels with fewer branches, shorter internodes, narrower leaves, and relatively higher ear placement. These races are widely distributed across the eastern Himalayan region, specifically in Assam, Nagaland, Manipur, Arunachal Pradesh, Sikkim, and Bhutan. They thrive at elevations ranging from 60 to above 2000 m, under the conditions of traditional cultivation. One fascinating aspect of the *Murli* subrace of *Poorvi Botapa* is its remarkable similarity to the reconstructed ancestral form of maize, as documented by Mangelsdorf and his collaborators [18, 19]. Notably, evidence suggests a significant differentiation in the cytoplasm between the primitive subrace of Murli and the evolved types, as evidenced by reciprocal variations in various traits observed in Sikkim and Assam [20]. The *Tirap Nagsahypung* race possesses distinctive characteristics concerning leaf size, shape, arrangement, and number. Its leaves are erect, small, numerous, and tend to cluster toward the tassel.

Singh [17] examined the second group, which included *Manipuri Chujak*, *Mayong Sa-ah*, *Asht Samsung*, *Tsungrhu* subrace of *Asht Samsung*, *Shyam Nahom*, *Cachar Gomdham*, *Mainani Makka*, and its subrace *Ganga*. These cultivars displayed distinct characteristics, such as large flinty grains exhibiting a wide array of endosperm colors, including white, cherry, red, purple, and various shades in between. They featured a smaller number of but larger ears and exhibited an earlier maturation compared to the races found in the primitive group. The leaf structure of these cultivars varied, ranging from semi-erect to flat. The collected varieties from the region exhibited limited diversity, predominantly consisting of early-flint types that closely resembled Cuban flints and northern flints. Consequently, they were classified within the *Maidani Makka* race and its subrace *Ganga*.

Singh [17] classified the third group, which includes races such as *Tista Mendi* and *Silken Tipang*. *Tista Mendi*, primarily found at higher elevations, demonstrated semi-dent grains in shades of yellow and red, accompanied by fewer but larger ears. Singh noted that *Tista Mendi* was a recent introduction that not only established itself as a distinct race but also underwent hybridization with older races, leading to the emergence of new hybrid varieties. On the other hand, *Silken Tipang* exhibited grains that exhibited popping characteristics when subjected to heat, along with a reduced number of ears. It stood out with its larger ear surfaces and more distinct grain characteristics compared to the primitive group. Singh believed that *Silken Tipang* was introduced during the early 1960s from neighboring countries like Burma and is currently confined to specific regions in Arunachal Pradesh, bordering Burma.

Singh [17] discussed the fourth group, comprising *Khasi Riewhadem*, *Mikir Merakku*, and *Nilip Mekop*. According to Singh's classification, these races were the outcome of hybridization between primitive types and advanced races. Notably, certain collections belonging to the *Tista Mendi* and *Tirap Nag-Sahypung* races exhibited remarkable resistance to the corn borer, *Chilo Zonellus*, even under natural infestation. Furthermore, varieties such as *Arun Tepi*, *Alok Sapa*, and all collections belonging to the *Tirap Nag-Sahypung* race displayed notable resistance to leaf blight caused by *Helminthosporium maydis*. Furthermore, it is worth noting that all entries from the *Manipuri Chujak* and *Mayong Sa-ah* races, along with the collections forming the *Tirap Nag-Sahypung* race, exhibited notable resistance to downy mildew, which is caused by the pathogen *Sclerospora philippinensis*. These varieties show great potential for cultivation under organic conditions, given their inherent resistance to this devastating disease.

The aforementioned discussion highlights the need for in-depth research on the genetic characterization of each variety, which remains unexplored in the region. Further investigation into the genetic traits, molecular markers, and population structure of these maize races is crucial for a comprehensive understanding of their genetic composition and diversity. Such research endeavors would contribute significantly to the conservation, utilization, and improvement of these indigenous maize varieties in the region.

4. Some basic characteristics of maize varieties

In the last 30 years, Sikkim and other Northeastern region have documented several fascinating local variations of maize that possess unique traits specific to each type of landrace. Some notable examples include *Bancharey-makai*, which is a high-altitude maize variety with yellow, flint kernels. *Badam-topo* stands out as a popcorn variety, while *Chakhou chujak* is known for its aromatic, soft, and sticky properties. *Chepti-makai* is a white, dent-type maize with distinct kernels. *Chujak* is an aromatic popcorn variant, whereas *Darikincho* is characterized by its small, yellow, hard kernels. *Fingdong* is an aromatic popcorn with a distinctive *flavor*. *Gadbade-makai* displays white kernels with occasional purple flint kernels, while *Kaali-makai* is recognized for its dark purplish-black color. *Kholakitti* is a sticky variety, while *Kuchung dari* is an orange-colored popcorn with flint kernels. *Kuchung takmar* exhibits a mix of yellow, white, purple, and red kernels with a flint texture. *Kukharey-makai* is dwarf, high-altitude maize, and *Kukidolong-makai* is a flint variety. *Lachung-makai* variety displays multiple colors and possesses tolerance to cold conditions. *Nepali Sappa* is unique with three cobs per plant, *Pahenli-makai* features yellow/orange flint kernels, and *Pahenli-makai* is a light dent type. *Phensong-makai* stands out with its cob length of up to 30 cm, while *Putali-makai* is characterized by its multi-colored appearance.

Rato-makai is a dark red maize variant, *Sathiya-makai* is an early-maturing type, and *Seti-makai* is a white, soft variety. *Tanee-makai* is a popcorn type, and *Tista Mehdi-makai* is a flint variety.

The existence of primitive maize landraces in Sikkim and other Northeastern states of India, situated in the Himalayan region, implies a possible alternative origin for this crop. The presence of a diverse collection of maize landraces in Sikkim further strengthens the notion that the Northeastern states may serve as secondary centres of origin for maize. These landraces exhibit significant morphological diversity, as documented by Sharma et al. [21]. This observation highlights the importance of studying the genetic and morphological characteristics of these landraces to unravel their evolutionary history and conservation significance.

In this region, a variety of intriguing local types and landraces with distinct traits have been documented. They include:

1. Aromatic and sticky kernels: *Fingdong* (aromatic popcorn), *Chujak* (aromatic popcorn), *Chakhou chujak* (aromatic, soft, sticky), *Kholakitthi* (sticky).

2. Popcorn varieties: *Badam topo, Tanee*.

3. Flint types: *Kukidolong*, *Kuchung dari*, *Bacherey*, *Kuchung tamar*, *Kukharey* (dwarf, suitable for high altitudes).

4. Dent kernel varieties: *Gadbade*, *Seti*, *Chepti makai* (soft opaque cap), *Pahenli* (light dent).

Apart from these, sporadic collections of early local types have also been made, such as *Ambo*, *Riewhadem* (early maturing), *Vaimin* (3 months), *Pahari makai* (adapted to mid-to-high altitudes and cold-hardy), *Nepali Sappa* (3 cobs/plant). Furthermore, modern cultivars and newly introduced landraces like *Mampokmendi, Taminlamendi, Maromendi* have been documented (**Figures 2–5**).

A germplasm exploration and collection program conducted in Sikkim has revealed the existence of a large number of indigenous maize cultivars suitable for different altitudes and purposes. During 2003–2004, approximately 58 local

(a) (b)

Figure 2.
(a) Paheli makai and (b) Seti makai.

Figure 3.
Maize diversity grown in the Sikkim Himalaya.

Figure 4.
Kali makai, Ribdi, West Sikkim.

germplasms were collected by Indian Agricultural Research Institute at Tadong Gangtok Sikkim from four districts (now six districts) in Sikkim at different altitudes (**Figure 6**) [22].

The local germplasm collection program in Sikkim has identified a variety of indigenous maize cultivars, including white kernel maize known as *seti makai*, yellow kernel maize referred to as *pahenli makai*, orange to red kernel maize known as *rato makai*, and purple kernel maize named *baiguney makai*. There are also high-altitude maize types such as *Lachung makai*, *sehrung*, and *tempo ringing*, as well as *sano makai* which is a type of popcorn. The *seti makai* has variations and is grouped as *Seti*

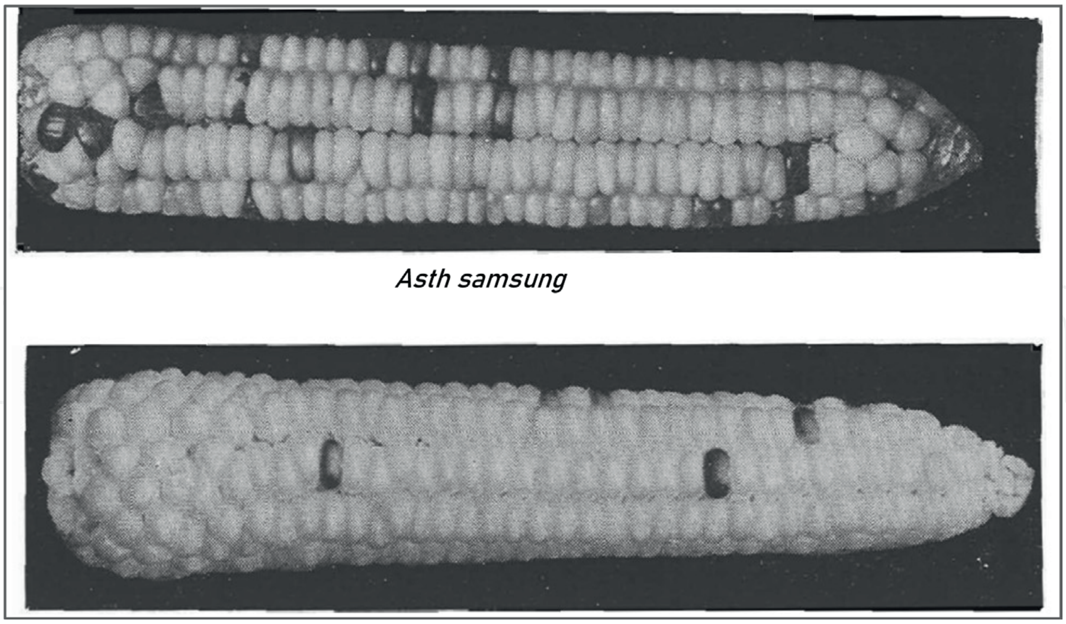

Figure 5.
Tsungrhu a sub-race of Asth Samsung (picture scanned from Singh, [17]).

Figure 6.
Diversity of different traditional varieties of maize.

Makai-1 to 4, while *Pahenli makai* has six sub-types designated as *pahenli makai* 1–6. *Rato makai* has four sub-types named as *rato makkai* 1–4, and *sanu makai* has three sub-types referred to as Sikkim Popcorn 1–3. Finally, *baiguney makai* has two sub-types: *sano baiguney* and *thulo baiguney*. However, there are also many nondescript cultivars without specific names [22].

Over the past 30 years, the Sikkim Himalayan regions have documented a multitude of intriguing local variations of maize, each possessing distinct and specific traits, including *Badam-topo* (popcorn variety), *Baiguney Makai* (purple, soft variety), *Bancharey-makai* (high-altitude maize with yellow, flint kernels), *Chakhou* *chujak* (aromatic, soft, and sticky maize), *Chepti-makai* (white dent-type maize with distinct kernels), *Chujak* (aromatic popcorn variant), *Darikincho* (small, yellow, hard kernels), *Fingdong* (aromatic popcorn with a distinctive flavor), *Gadbade-makai* (white kernels with occasional purple flint kernels), *Kaali-makai* (dark purplish-black colored maize), *Kholakitti* (sticky variety), *Kuchung-dari* (orange-colored popcorn with flint kernels), *Kuchung takmar* (mix of yellow, white, purple, and red kernels with flint texture), *Kukhurey-makai* (dwarf, high-altitude maize), *Kukidolong-makai* (flint variety), *Lachung-makai* (variety with multiple colors and tolerance to cold conditions), *Nepali Sappa* (unique with three cobs per plant), *Pahenli-makai* (light dent type), *Pahenli-makai* (yellow/orange flint kernels), *Poorvi Botapa, Phensong-makai* (cob length of up to 30 cm), *Putali-makai* (multi-colored appearance), *Rato-makai* (dark red maize variant), *Sathiya-makai* (early-maturing type), *Seti-makai* (white, soft variety), *Tanee-makai* (popcorn type), *Tista Mehdi-makai* (flint variety), *Asthra Samsung*, *Tsungrhu*, *Sikkim Primitive I*, and *Sikkim Primitive II*. These maize variations exemplify the abundant diversity and unique characteristics found in the region.

The local germplasm displayed significant variation in cob orientation, cob size, kernel color, leaf orientation, silk color, height at which ear arises, cob length, number of kernels per row, and kernel yield per plant. *'Lachung makai'* exhibited para-mutation (multi-colored cob) and showed tolerance to cold weather. Some of the *seti makai* and *pahenli makai* had thick husk coverage and oblong cob orientation, which impart resistance against ear rot in the rainy season. The high-altitude maize *tempo ringing* matures in 85–90 days in mid-hills when other maize did not complete silking, indicating an extraordinary early maturity trait in mid and high-altitude maize. Local germplasm such as *murali makai*, *tempo ringing*, and *seti makai* are being utilized in the ongoing breeding programme at the Indian Council of Agriculture Research (ICAR) Sikkim Centre. In a nutshell, the maize genetic resources in Sikkim are rich, which is why the Sikkim Himalaya is considered a secondary centre of diversity for maize (**Figure 7**).

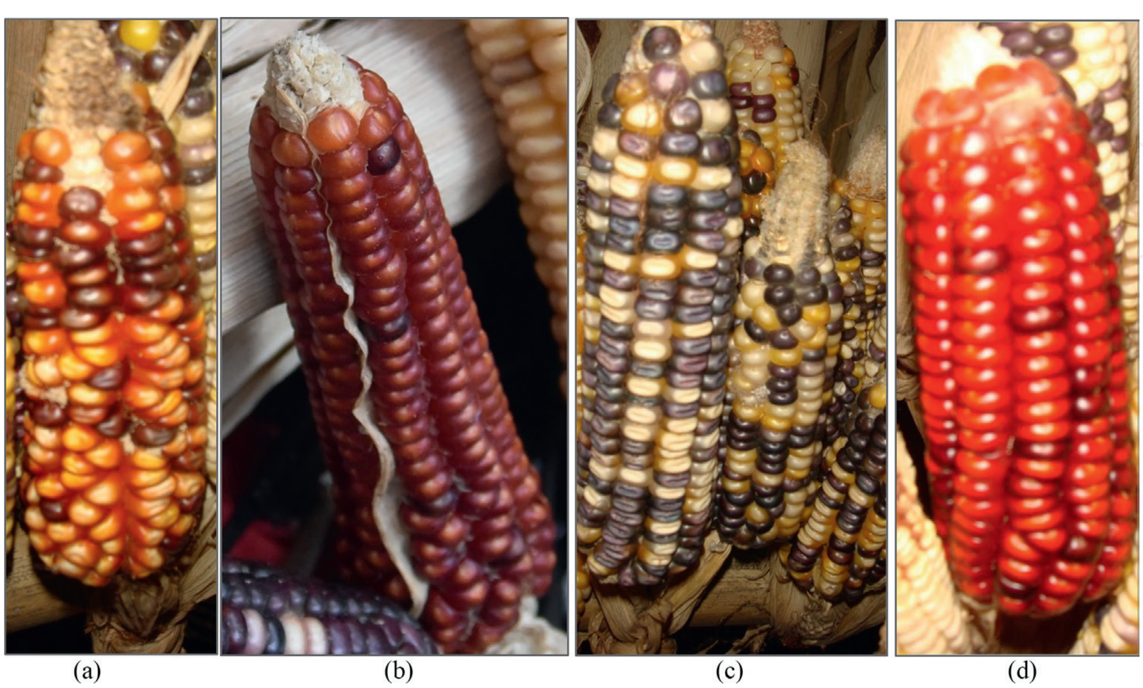

Figure 7.
(a) Gadbadey makai, (b) Rato makai, (c) Thulo-baiguney makai and (d) Raato makai.

Lachung makai, characterized by its paramutation trait (multi-colored cob) and tolerance to cold weather, stands out among the local varieties. This maize variety is grown in a high temperate agroclimatic range between 2200 and 2600 m elevations. Additionally, other notable landraces such as Sikkim Primitive, *Tirap*, *Naga Sahyup* (Arunachal Pradesh), and *Tistamehdi* (Sikkim) have been previously collected and evaluated by other researchers, amounting to over 200 landraces studied (**Figure 8**) [10].

Murali makai is a crop that grows well in high altitudes (between 1000 and 1800 meters above sea level) and can withstand moisture-stress conditions, although it has slow vegetative growth. It has the potential to contribute adaptability and multiple cob-bearing traits to otherwise desirable varieties of maize grown in mid and high hills. Unfortunately, this rare genotype is gradually disappearing from cultivation and is considered an endangered cultivar (**Figure 9**).

5. Sikkim primitive maize variety

The economy of North-eastern India relies primarily on rice cultivation; however, in Sikkim, maize is the dominant crop. This underscores the crop's significance, although there has been a recent shift toward more profitable crops. Maize originated in Mexico, but India harbors considerable genetic diversity. The maize landraces in Sikkim can be classified into four groups based on their historical origin: primitive, advanced or derived, recent introductions, and hybrid races. The primitive group

(a) (b)

Figure 8.
(a) Sikkim Primitive 1, Murali makai grown in Dzongu (photo courtesy: Dawa Lhendup Lepcha) and (b) Tempo Rinzing, Lachung, North Sikkim (photo courtesy: Hishey Lachungpa).

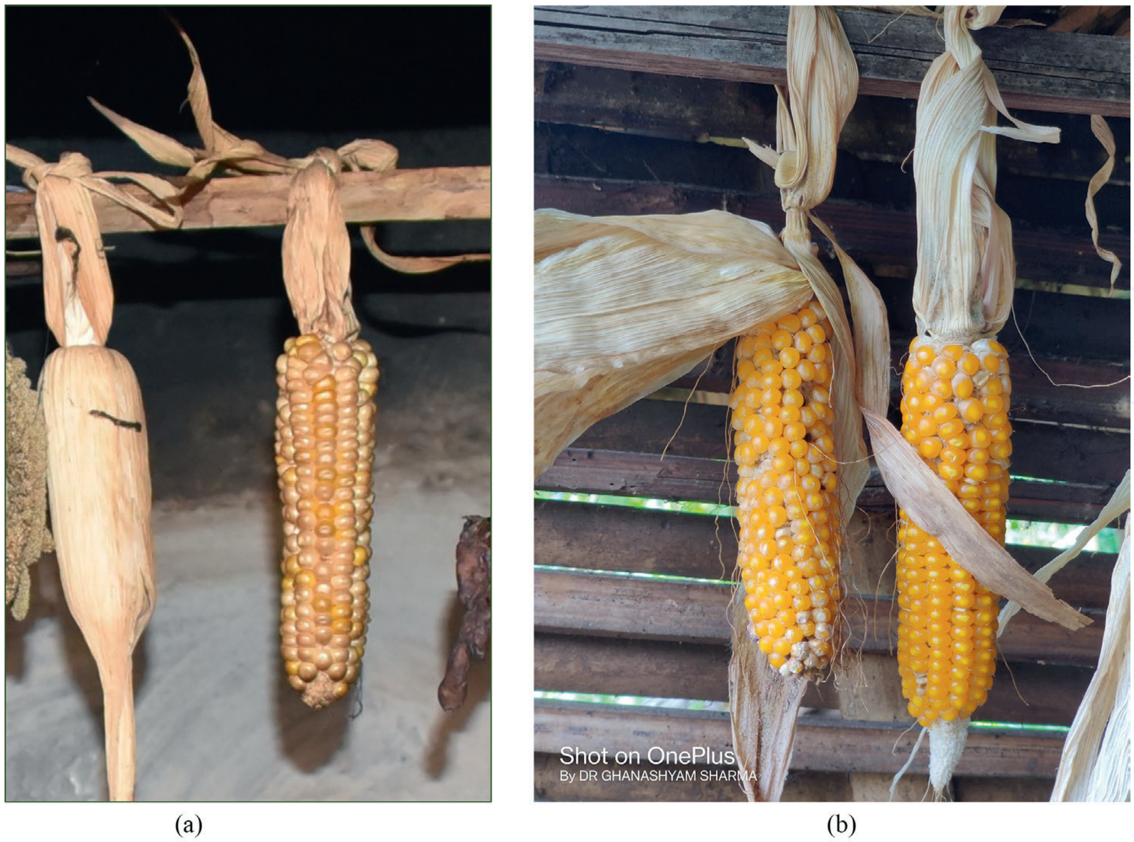

Figure 9.
Murali makai (a) Tinvong, Dzong North Sikkim, and (b) Amba, East Sikkim.

comprises several races of popcorn, including *Poorvi Botapa*, *Tirap Nag-Sahypung*, *Arun Tepi*, and *Alok Sapa*, which are distributed in the Eastern Himalayas, including Sikkim, at elevations ranging from 600 to 2000 m. The most primitive race, *Poorvi Botapa*, exists in pure form in North Sikkim, where it is known as *murali makai*. Two forms of *murali makai* are present, with different kernel colors (purple and yellow kernel maize), and designated as Sikkim Primitive-1 (purple kernel type) and Sikkim Primitive-2 (yellow kernel type). Notable varietal characteristics of *murali makai* include its prolific ear-bearing ability (with 3–5 cobs per plant, a rare trait in commercial maize), the presence of style remnants on the mature kernel, small cob size (8 cm long and 6 cm girth), and approximately 100 small kernels per cob. Despite the small kernel size, the popping efficiency is high, with a 100 kernel weight of 9.5 g (**Figures 10** and **11**).

Sikkim Primitive maize strains, namely Sikkim Primitive-1 (purple colored), and Sikkim Primitive-2 (yellow colored), were found to differ from the primitive Mexican races [5, 10]. Some of the local varieties, such as *Seti* and *Pahenli*, exhibit a thick husk coverage and an oblong cob orientation, which provide resistance against ear rot during the rainy season. Extra-earliness, a rare trait in mid and high-altitude maize, is observed in the high-altitude maize variety called *Tempo Ringing*, which reaches maturity in 85–90 days in mid-hills, outpacing other maize cultivars in silking completion. Fascinating local germplasm with promising traits, such as *Murli*, *Tempo Ringing*, and *Seti*, are currently being utilized in an ongoing breeding program at the ICAR, Sikkim Centre, Tadong (**Figure 12**) [22].

Figure 10.
Sikkim Primitive 1, grown in Dzongu, North Sikkim; Sikkim Primitive 2, grown in Dzongu, North Sikkim.

Figure 11.
Murali makai (Sikkim Primitive 2) grown in Sikkim.

5.1 Sikkim Primitive: a distinct maize landrace

In a study conducted by Sharma et al. [23], a diverse set of 48 maize landraces/locals sourced from various agroecologies across India were selected for analysis. Among these, 8 accessions were identified as "Sikkim Primitives", which were collected from

Figure 12.
Tempo rinzing maize variety of Lachung, North Sikkim (photo courtesy: Hishey Lachungpa).

different villages in Sikkim in November 2005. The remaining 40 accessions comprised 21 landraces from Northeastern Hill (NEH) regions (excluding Sikkim Primitives), 4 from non-NEH tribal hill regions, and 15 from the plains of India. This diverse set of landraces provided an opportunity to understand the genetic and phenotypic diversity present in maize germplasm in India. This study aimed to characterize maize landraces in India using both intensive phenotypic and molecular analyses. Through multilocation analyses of selected accessions, the study identified several promising landrace accessions that could be potentially useful in breeding programs. The utilization of SSR markers analyzed through DNA Sequencer technology by Sharma et al. [23] enabled an effective differentiation of accessions. Additionally, the Sikkim Primitives landrace accessions were found to be distinct at both the phenotypic and molecular levels when compared to other landrace accessions in India. These findings highlight the importance of conducting detailed characterization of germplasm collections to fully exploit their genetic potential.

5.2 Novel quantitative trait loci of '*murali makai*'

The maize landrace 'Sikkim Primitive' is known for its high productivity, producing five to nine ears per plant. However, the genes responsible for this trait had not been identified. Prakash et al. [24] conducted a study on 'Sikkim Primitive' maize landraces. They found a prolific inbred line called 'MGUSP101' which was developed and crossed with two non-prolific inbred lines, HKI1128 and UMI1200. Two F2:3 populations were evaluated across three locations. The number of ears per plant varied from 1.35 to 5.38 in the MGUSP101 × HKI1128 population. Using bulked-segregant analysis and targeted QTL mapping, a major QTL (bin: 8.05) that explained 31.7% of phenotypic variation was identified among 145 F2:3 individuals. The QTL was validated in 138 F2:3 individuals of MGUSP101 × UMI1200, and it explained 29.2% of phenotypic variance at the same interval. The novel QTL was designated as 'qProl-SP-8.05', and six candidate genes responsible for prolificacy were identified. This finding provides an opportunity to use marker-assisted selection to introgress the novel QTL for prolificacy in elite maize, and it represents the first report of the identification of the locus governing prolificacy in 'Sikkim Primitive' (**Figure 13**).

The local maize variety called *murali makai* in Sikkim, also known as Sikkim Primitive maize, possesses exceptional prolificacy and popping efficiency, making it a significant genetic resource. However, its population has suffered a severe decline, and its conservation has been overlooked, putting it at risk of extinction. To initiate the conservation and revival of this variety, Kapoor et al. [25] conducted a study that involved a characterization and documentation process. This involved assessing 31 morphological traits at different growth stages and conducting molecular characterization using simple-sequence repeat (SSR) markers.

5.3 Morphological and molecular characterization of Sikkim maize

'Sikkim Primitive' is a unique landrace discovered in the North-Eastern Himalayan region of India, particularly in the province of 'Sikkim' [24]. This landrace stands out due to its distinct ear and fruiting morphology, which closely resembles that of maize, setting it apart from teosinte where grains are enclosed in a hard fruit case or 'cupule' [21]. Detailed morphological studies conducted by Sachan and Sarkar [13] confirmed the close relationship of 'Sikkim Primitive' with maize. The designation of this landrace as 'primitive' is justified by its remarkable traits, including high prolificacy, sensitivity to photoperiod, small popcorn-like kernels, and the ability to produce abundant pollen. The unique characteristics exhibited by 'Sikkim Primitive' make it an exceptional variety deserving of further investigation and conservation efforts [24].

The plants of the Sikkim Primitive maize, locally known as *murali makai*, were observed to display remarkable prolificacy with each plant bearing 5–6 cobs. They also exhibited excellent popping capacity and several other distinctive traits. The plants

Figure 13.
Murali makai stored over the fireplace at Tinvong, Dzongu, North Sikkim.

were tall, and their stems were thin with loose drooping tassels. The base of the glumes and brace roots displayed anthocyanin colouration. The cobs were medium-sized and carried small seeds with low test weight, weighing 87.90 g [25].

Molecular characterization using 22 SSR markers demonstrated the amplification of unique amplicons, ranging from 100 to 800 bp. Of these markers, bnlg1083, umc1353, umc1128, bnlg1017, bnlg2077, umc2298, and umc2373 displayed distinct amplification patterns. The characterization of these traits and the molecular markers will be beneficial in utilizing Sikkim Primitive maize for genetic improvement and maintaining genetic purity [25].

6. Maize-based farming and its significance

In the region encompassing Sikkim and the Darjeeling Himalayas, maize cultivation is of paramount agricultural significance. This area has emerged as an optimal location for maize farming due to its favorable climatic conditions and suitable soil characteristics. Farmers in this region dedicate substantial land to maize cultivation, making a significant contribution to the overall agricultural output. The agroclimatic conditions within an elevation range of 200 to 2700 meters are particularly suitable for cultivating a diverse range of maize varieties. This includes as many as 26 traditional maize landraces and approximately 15 different hybrid and certified maize varieties, showcasing the rich agricultural diversity of the region.

Farmers in Sikkim and the Darjeeling Himalayas employ a blend of traditional and modern farming techniques to cultivate maize. They adhere to best agricultural practices, encompassing appropriate land preparation, meticulous seed selection, precise planting methods, and effective pest management strategies. These practices are implemented to maximize yield and maintain the overall health of the crop.

The maize production, productivity and area under cultivation in Sikkim from 2017 to 2018 to 2021-2022 is given in **Figure 14**. The area dedicated to maize cultivation in this region during 2021–2022 in Sikkim was 38,458 ± 580 hectares. This substantial figure underscores the significant role of maize farming in the regional agricultural landscape. Additionally, the region boasts an average annual maize production of around 67,692 ± 1243 tonnes [27]. This considerable output highlights the success and potential of maize cultivation in meeting the food requirements of the local population and beyond (**Figure 15**).

Between the years 1981 and 1990, there was a notable increase in maize cultivation in Sikkim, with a 27.6% expansion in acreage. During this period, there was a substantial increase of 174% in total production and 111% in yield per unit. These advancements were primarily attributed to the introduction of high-yielding varieties (HYVs) in Sikkim. However, the subsequent decade from 1991 to 2001 saw a decline in the growth rate, with only a 31.7% increase in total production and a 22.3% increase in yield per unit recorded. Interestingly, despite having more choices of HYVs available during the latter period, the sustained growth seen in the previous decade could not be maintained [28]. However, according to reports from the Agriculture Department of the Government of Sikkim, there has been a significant decrease in the cultivated area from 2012 to 2022, with a reduction of 1892 hectares. While productivity and production levels have remained relatively stable during this period.

Maize cultivation in the region encompasses contributions beyond economic and food security aspects and assumes a pivotal role in supporting the livelihoods of farming communities. Its practice generates employment opportunities, facilitates

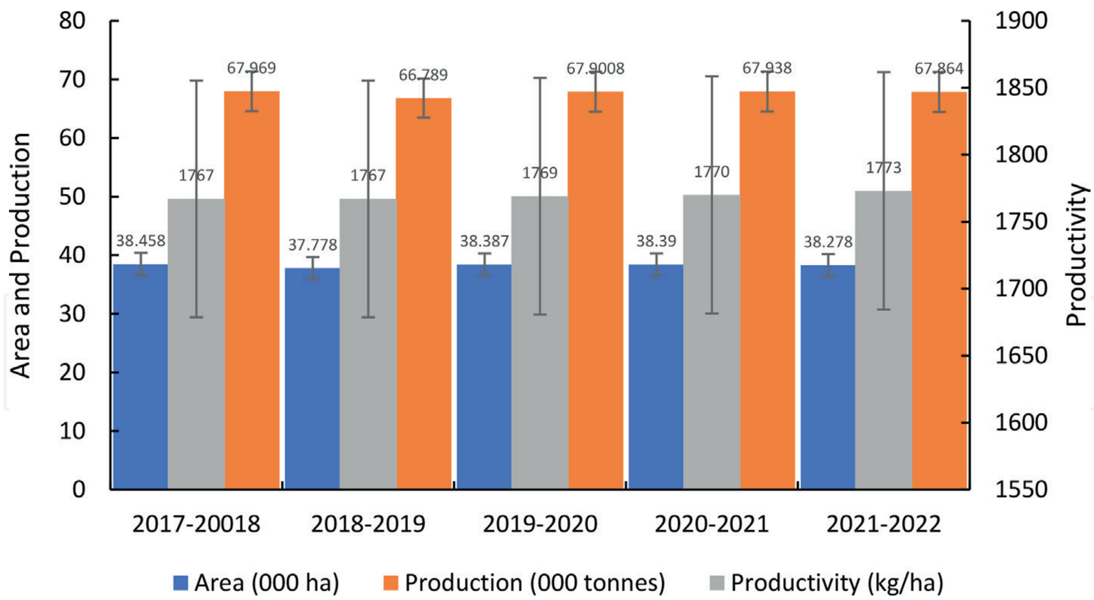

Figure 14.
Area, production and productivity of maize in Sikkim, India from 2017 to 2022 (data compiled from [16, 26, 27]).

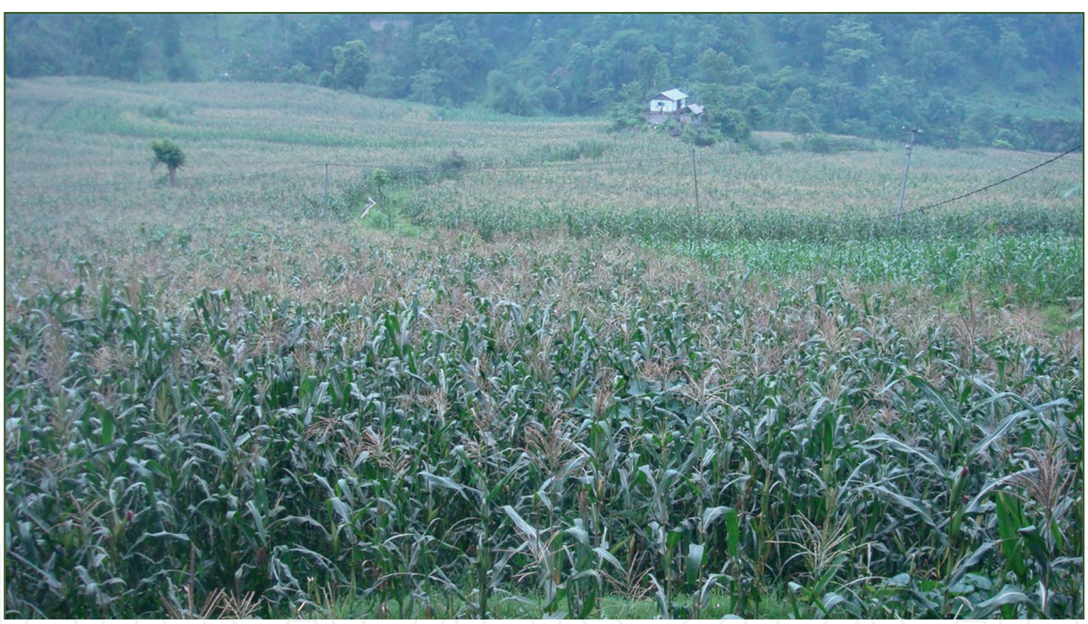

Figure 15.
A maize production farm at Martam, near Gangtok.

rural development, and strengthens the overall resilience of the agricultural sector. Since 2012, a total of 17 high-yielding varieties (HYVs) and hybrid varieties have been introduced in Sikkim. Alongside these introductions, hybrid and certified maize seeds obtained from external sources, such as Pusa Vivek (QPM 9 (Improved), NAC-6004 composite, 33 M66, 66 K99, JKMH-1701, have also been adopted in Sikkim [27]. Based on the experiences shared by farmers in various regions of Sikkim, it has been observed that nine prominent pests have infested the high-yielding varieties (HYVs) and hybrid maize varieties. These pests are the stem borer (*Chilo partellus*), cutworms (*Agrotis ipsilon*), armyworms (*Mythimna separata*), semi-loopers (*Plusia signata*), and cob borers (*Stenchroia elongella*). It is noteworthy that the indigenous landraces of maize exhibit tolerance to many of these pests [29].

A very high intensity of post-harvest infestations have been recorded by insects such as the maize weevil (*Sitophilus zeamais* Mostsch.) and grain moth (*Sitotroga cerealella* Oliv.) in the HYVs and hybrid maize varieties, which have been identified as major storage insect pests. While pest infestation in the indigenous varieties was significantly 80% less as compared to improved varieties.

Continuous efforts are underway to enhance maize production in Sikkim and Darjeeling Himalayas. These initiatives encompass the promotion of improved farming practices, the introduction of high-yielding maize varieties, and the implementation of sustainable agricultural techniques. These endeavors aim to ensure long-term food security, augment farmers' income, and foster comprehensive agricultural development in the region. The maize cultivation in Sikkim has proven to be a vital agricultural activity, contributing to food security, bolstering economic growth, and enhancing the well-being of local communities (**Figure 16**).

6.1 Maize inter-cropping

The study compared the productivity of intensified cropping systems to traditional maize-fallow systems in the rainfed region of Sikkim Himalayas. The results showed that intensified cropping systems, such as maize (green cobs)–urd bean–buckwheat and maize–rajmah, had significantly higher maize grain equivalent yield and system production efficiency compared to the maize-fallow system. The maize (green cobs)–urd bean–buckwheat system demonstrated the highest relative production efficiency and land use efficiency due to its longer crop duration, while the maize-fallow system had the lowest land use efficiency. These findings highlight the potential of intensified cropping systems to increase agricultural productivity and land use efficiency in the region. The study suggests that promoting the adoption of appropriate intensified cropping systems could contribute to enhancing food security and farm productivity in the rainfed areas of Sikkim Himalayas.

Figure 16.
Maize varieties stored under the roof.

6.2 Economics of maize inter-cropping

In an economic analysis conducted by Sing et al. [30], it was found that the maize (green cobs)–urd bean-buckwheat cropping system had the highest net return of 303,000 INR per hectare and a benefit-cost ratio of 2:6, which was significantly better than the maize–rajmah system. Conversely, the lowest return and benefit-cost ratio were observed in the maize–fallow cropping system. In terms of relative economic efficiency (REE), which is a comparative measure of economic gains over the existing system, all the intensified systems had higher economic gains than the maize-fallow system. Moreover, the maize (green cobs)-urd bean-buckwheat cropping system had the highest system profitability of 831 INR per hectare per day, while the maize–fallow system had the lowest system profitability of 238 INR per hectare per day (**Figure 17**).

Employment generation is a key indicator when assessing the sustainability of cropping systems. The data showed that the intensified systems added to the employment generation and generated more employment than the maize-fallow cropping system, which only generated 106 man-days per hectare to harvest the final produce. The relative system employment generation efficiency (REGE), which measures the additional man-days required for a diversified system compared to the existing system, revealed that all the intensified systems had higher employment generation ability than the prevailing system in the region [30]. Among the cropping sequences, the cultivation of maize (green cobs)-urd bean-buckwheat resulted in the maximum REGE of 168%, followed by the maize-rajmah system.

6.3 Post-harvest storage management

Once the corn cobs are harvested and sun-dried, a traditional method of preservation is employed in the mountains of Sikkim Himalaya. To accomplish this, four to six cobs are carefully selected and their husks are tied together. In preparation, the outer rough and aged husks are removed, while some of the inner husks are torn

Figure 17.
Maize intercropping with a variety of other crops.

without completely separating them from the shank, forming what is known as a husk tail. These husk tails are then used to tie together a minimum of four cobs, creating a bundle known as "*Jhutta*." This bundling technique helps to keep the cobs secure and protected from external elements, ensuring their quality and freshness during storage.

Maize farmers in Sikkim employ organic cultivation methods and employ effective post-harvest storage techniques, abstaining from the use of chemical pesticides and adopting improved seed bins. This sets them apart from farmers in other states of India who rely on chemical interventions. Pest management in these regions follows a meticulous decision-making process aimed at controlling pests in a cost-effective manner.

Sun drying has traditionally been the primary method employed for pest management practices in this region. Additionally, several bio-rational plant products have shown superior efficacy in controlling maize weevils. These include Sweet flag (*Acorus calamus*), Neem oil (*Azadirachta indica*), Neem seed powder, Timur (*Zanthoxylum armatum*), and Titepati (*Artimesia vulgaris*). These bio-rational plant products have proven to be effective alternatives to synthetic pesticides. Furthermore, approximately 10% of farmers utilize barriers such as leaves of *Pinus roxburghii*, *dalle kuro* (*Urena lobata*), *babio* (*Eulaliopsis binata*), as well as red and white soil, to prevent rat invasions. These preventive measures contribute to pest control and minimize crop damage. By employing organic methods, utilizing bio-rational plant products, and implementing physical barriers, maize farmers in Sikkim demonstrate their commitment to sustainable pest management practices. These approaches not only ensure the production of high-quality maize but also contribute to the preservation of the environment and the health of consumers (**Figure 18**).

Following the tying of the corn cobs, the next step in the storage process is finding suitable locations in the house. One common method is to store them on "*Thangro*," which is a structure made of a vertical pole topped with a rooftop. Another option is to hang the tied cobs under the eaves in a structure known as *Bardali*. These storage practices ensure that the cobs are kept off the ground,

Figure 18.
Storing Pahenli makai in a Thangra.

preventing moisture absorption and minimizing the risk of pests and rodents. By employing the *Kunyo* or *makaiko-haar*, the communities in this region can maintain the quality and availability of their corn supply throughout the year. These storage arrangements provide safe and elevated spaces for the corn cobs, protecting them from moisture, pests, and rodents that can compromise their quality. By employing these storage methods, the communities ensure that the stored maize remains preserved and readily available for consumption throughout the year (**Figures 19** and **20**).

Figure 19.
Storing maize in a Thngra.

Figure 20.
Storing maize in a rope alongside of a house.

7. Soil fertility and crop management

Soil fertility has been identified as a significant constraint affecting maize production throughout all districts of Sikkim. The availability and quality of manure/compost have been recognized as crucial inputs for sustaining and improving soil fertility. Farmers have expressed concerns regarding limited access to an adequate supply of manure/compost, primarily due to the scarcity of high-quality fodder for their livestock. The quality of compost has shown considerable variation, indicating that many farmers have not yet adopted improved compost management practices.

In relatively more accessible areas, farmers have resorted to supplementing manure/compost with organic fertilizers provided by the Department of Agriculture. However, the use of fertilizers has been predominantly limited, raising concerns about potential deficiencies in other essential nutrients, particularly phosphorus. The organic inputs commonly used by farmers have been found to be insufficient sources of phosphorus. Soil erosion has emerged as a significant challenge, resulting in substantial loss of productive topsoil, especially in fields with sloped terrain and experiencing intense monsoon rainfall.

Indigenous traditional knowledge and practices associated with soil fertility maintenance include *in situ* farm manuring, mulching, bio-composting, green manuring, livestock ranching, cultivation of nitrogen-fixing plants, land fallowing, and litter decomposition. These practices can contribute to the improvement and sustainability of soil fertility in maize cultivation.

8. Uses and culinary practices

Maize has a long-standing significance as a dietary staple in the hilly regions of Sikkim, where it is deeply ingrained in various traditional culinary practices. In these practices, the dried maize seeds are commonly utilized as the primary ingredient for the preparation of popcorn. The green cobs, carefully harvested at the milk stage, undergo a grinding process to produce a versatile food product known as *phyaplo*. Moreover, these green cobs are also employed in the creation of local bread varieties (**Figure 21**).

Another notable utilization of maize involves the light beating of maize to separate the husk and the kernel. The kernels are then soaked in hot water for 24 hours and is roasted lightly on fire and the hot kernels are beaten in wooden *oklhi—musli* to cup shape structure referred to as *chyadung/chadung*. This form adds diversity to the range of maize-based food items. Additionally, maize flour, obtained by grinding the maize kernels, is transformed into a dough-like consistency, which is then spread evenly onto banana leaves. The dough-laden banana leaves are then subjected to the radiant heat generated by burning wooden coal in a traditional fireplace called *Agenu*. This process, known as *Bhungrey-roti*, facilitates the roasting and cooking of the maize flour, yielding a unique and culturally significant culinary creation. In a traditional culinary practice, freshly harvested maize seeds are subjected to pounding using either a *Dhiki* (a wooden pounding tool) or an *Okhli-musli* (wooden mortar and pestle). This pounding process results in the production of beaten rice, which is a popular food item. The beaten rice is commonly consumed with hot milk, creating a nourishing and satisfying meal. This method of processing maize seeds into beaten rice demonstrates the resourcefulness and utilization of maize as a versatile food source in the region.

(a) (b)

Figure 21.
(a) Fermented Jarrnd preparation out of maize kernels by Mangar community of Karjee, West Sikkim and (b) boiled maize with Indian pumpkin curry, cheese pickle and buttermilk as dinner.

The utilization of maize in these scientific cooking techniques showcases the rich culinary heritage and cultural importance of maize in the hilly regions of Sikkim. In addition, young green cobs are often consumed after being roasted or boiled. Maize grains are partially ground, and a combination of rice with an equal ratio of *makkaiko chamal* (maize grains) and powdered maize grain starch is used to prepare *makkaiko pitho*, and *chyakhla* (coarse maize rice) or *saraulo* (fine maize rice). Roasted seeds are grinded to powder known as *'champa'* or *'Saatu'*. Sometimes, *champa* preparation includes a blend of wheat or barley. Maize seeds are boiled and a fermented product called *Makaiko-Jarnd* is prepared. Wines are also prepared using fermented maize products.

9. Conclusion

Primitive maize cultivars in the Northeastern Himalayas of India have generated interest among researchers for their high prolificacy (4 to 8 ears/plant) and their link to the origin and evolution of maize [31]. Sachan and Sarkar [14] concluded that Sikkim Primitive maize is equivalent to pre-Chapalote, pre-Nal-Tel, and prehistoric wild corn of Mangelsdorf. Besides being of interest for origin and evolution, Sikkim Primitives serve as a valuable source of prolificacy, pest resistance, and drought tolerance, given their resilience against natural challenges.

To enhance farm productivity and food security in the rainfed Eastern Himalayan region, it is necessary to intensify the existing maize-fallow system by incorporating more crops per unit area. This requires careful crop selection and increased productivity, especially in rainfed ecosystems. However, intensified production systems also demand higher energy and other inputs. Therefore, focusing on sequential cropping in mono-cropped areas and crop intensification is crucial for improved agricultural production. Vertical growth, by increasing productivity per unit of land, offers an alternative to expanding horizontally due to limited space.

Genetic characterization and improvement of local and indigenous maize cultivars are pivotal in addressing their limitations. In Sikkim, the rapid introduction of high-yielding and hybrid varieties has led to the decline of traditional landraces in agroecosystems. Thus, conserving these landraces in the National Bureau of Plant Genetic Resources (Indian Council of Agricultural Research) is imperative for future research, registration, and protection under the Protection of Plant Varieties and Farmers' Rights Act 2001.

Diversification and intensification of maize-based systems, through traditional crop management practices, can enhance profitability and resource use efficiency in both irrigated and rainfed ecosystems of the Sikkim Himalayas. Diversifying mono-cropped maize areas improves the profitability and productivity of organic agriculture, sustaining the livelihood security of organic growers in Sikkim. This approach supports the development of a more sustainable agricultural system, contributing to food security and livelihood enhancement.

The Eastern Himalayan region of India is widely recognized as a significant secondary centre of maize diversity, housing a diverse array of genetic resources. Maize cultivation in this region spans altitudes from 300 to 2500 masl. A field investigation conducted between 2010 and 2022 employed a combination of traditional knowledge and scientific methods to characterize maize morphologically. A comprehensive literature review documented the diversity of maize cultivation in the Sikkim Himalaya since the 1960s. The primary objective was to assess the number of indigenous maize varieties cultivated in the Sikkim Himalayan region approximately 60 years ago until 2023.

Categorizing maize landraces provides valuable insights into the diversity and classification of maize varieties, contributing to our understanding of maize genetic resources. The study also involved the collection of *in situ* germplasm in farmers' fields to conserve cultivated plant diversity. Prioritization at the species level and in specific geographic regions was necessary due to the dynamic demand for germplasm. The primary objective was to assess the risk of extinction or erosion of specific maize germplasm, crucial for cultural and ecological preservation. The study aimed to safeguard valuable genetic resources, ensuring their availability for food security, livelihoods, climate resilience, and research. Furthermore, the study focused on improving landraces and increasing access to high-quality germplasm.

During the study, as many as 31 different landraces of maize were identified, highlighting the need for comprehensive research on the genetic characterization of each variety, which remains unexplored in the region. Notably, *Murali Makai, Seti Makai, Pahenli Makai, Rato Makai, Baiguney Makai, Gadbadey Makai, Tempo-Rinzing*, and *Lachung Makai* exhibited excellent adaptation to local environments ranging from 300 to 2500 m. These landraces displayed variations in agronomic and quality traits, as well as resistance to biotic and abiotic stresses. Their adaptability has resulted from natural and artificial selection. Conserving these landraces is crucial for future food security and sustainable agricultural practices.

Genetic research on Himalayan maize is critical for unraveling the genetic basis of unique traits, including agroclimatic adaptability, disease and pest resistance, and abiotic stress tolerance. This knowledge is essential for breeding superior maize varieties with enhanced productivity, nutritional value, and resilience. Additionally, studying the genetic diversity of Himalayan maize aids in conserving valuable landraces and heirloom varieties, which possess traits absent in commercial cultivars, thus ensuring long-term food security and farming community resilience. Genetic research facilitates the identification and utilization of genes and markers associated with desirable traits, enabling the development of molecular breeding techniques like marker-assisted selection and genetic engineering for targeted maize improvement. Furthermore, understanding the genetic diversity and population structure sheds light on maize's evolutionary history, migration patterns, and contributes to broader scientific knowledge of crop domestication and genetic dynamics. This research supports the formulation of sustainable agricultural policies and strategies by providing evidence-based data on crop improvement, seed systems, biodiversity conservation, and farmer rights. Ultimately, the genetic research on Himalayan maize is pivotal for advancing our understanding of unique traits, conserving genetic resources, enhancing breeding programs, and fostering sustainable agricultural practices, thereby promoting food security, resilience, and the well-being of farming communities.

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Conflict of interest

The authors declare no conflict of interest.

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References

[1] Prasanna BM, Cairns JE, Zaidi PH, Beyene Y, Makumbi D, Gowda M, et al. Beat the stress: Breeding for climate resilience in maize for the tropical rainfed environments. Theoretical and Applied Genetics. 2021;**134**:1729-1752

[2] Iltis HH, Doebely JF. Taxonomy of *Zea* (Gramineae) II. Subspecific categories in the *Zea mays* complex and generic synopsis. American Journal of Botany. 1980;**67**(6):994-1004

[3] Beadle GW. The ancestry of corn. Scientific American. 1980;**245**:112-119

[4] Doebley JF, Iltis HH. Taxonomy of *Zea*, I. A subgeneric classification with key to taxa. American Journal of Botany. 1980;**67**(6):982-993

[5] Mukherjee BK, Gupta NK, Singh SB, Singh NN. Meteroglyph analysis of Indian and exotic maize. Euphytica. 1971;**20**:113-118

[6] Manglesdorf PC. Corn: Its Origin, Evolution and Improvement. Cambridge, Massachusetts, USA: Harvard University Press; 1974

[7] Wilkes HG. Maize in India. Maize Genetics Cooperation Newsletter. 1981;**55**:13-15

[8] Dowswell CR, Paliwal RL, Cantrell RP. Maize in the Third World. Boulder, Colorado, USA: Estview Press; 1996

[9] Marszewski T. The problem of the introduction of primitive maize into Southeast Asia. Folia Orient. 1978;**19**:127-163

[10] Prasanna BM, Sharma L. The landraces of maize (*Zea mays* L.): Diversity and utility. Indian Journal of Plant Genetic Resources. 2005;**18**(2):155-168

[11] Anderson E. Maize in the New World. In: Wilson CM, editor. New Crops for the New World. New York, USA: Macmillan; 1945

[12] Dhawan NL. Sikkim primitive maize. MNL. 1964;**38**:69-70

[13] Sachan JKS, Sarkar KR. Plant type of 'Sikkim Primitives'. Maize Genetics Cooperation Newsletter. 1982;**56**:122-124

[14] Sachan JKS, Sarkar KR. Discovery of Sikkim primitive precursor in the Americas. Indian Journal of Genetics. 1986;**46**:153-161

[15] Tanksley SD, McCouch SR. Seed banks and molecular maps: Unlocking genetic potential from the wild. Science. 1997;**277**:1063-1066

[16] APR. Annual Progress Report 2021-2022. India: Government of Sikkim, Department of Agriculture; 2022

[17] Singh B. Races of Maise in India. New Delhi, India: Indian Agricultural Research Institute. Printed in India by V. Ananda Krishna Chettty, at Hoe and Co.; Madras and Published by SS Grewal, Under-Secretary to the Indian Council of Argiculture Research, New Delhi; 1977

[18] Mangelsdorf PC. Reconstructing the ancestor of corn. Science, USA. 1958;**128**:1313-1320

[19] Mangelsdorf PC, MacNeish RS, Galinat WC. Domestication of corn. 1964;**143**:538-545

[20] Bhat BK, Dhawan NL. Effect of cytoplasm on quantitative character of maize. Indian Journal of Genetic Plant Breeding. 1969;**29**:321-326

[21] Sharma L, Prasanna BM, Ramesh B. Analysis of phenotypic and microsatellite-based diversity of maize landraces in India, especially from the north east Himalayan region. Genetica. 2010;**138**:619-631

[22] Rahman H, Karuppaiyan R. Agrobiodiversity of Sikkim. In: Arrawatia ML, Tambe S, editors. Climate Change in Sikkim: Patern, Impact and Initiatives. Government of Sikkim, Gangtok: Department of Information and Public Relations; 2011. pp. 403-428

[23] Sharma L, Singh NK, Guleria SK, Ramesh JS. Molecular distinctness from other maize landraces in India. In: Asian Regional Maize Workshop, 10. Maize for Asia-Emerging Trends and; Technologies. Proceedings of The Asian Regional Maize Workshop; Makassar, Indonesia; 20-23 October, 2008 (p. 250). CIMMYT; 2008

[24] Prakash NR, Zunjare RU, Muthusamy V, Chand G, Kamboj MC, Bhat et al. Genetic analysis of prolificacy in "Sikkim Primitive"-A prolific maize (*Zea mays*) landrace of North-Eastern Himalaya. Plant Breeding. 2019;**138**(6):781-789. DOI: 10.1111/pbr.12736

[25] Kapoor C, Singh S, Awasthe RK, Shankar SM, Pattanayak A, Raj C, et al. Harnessing potential of maize (*Zea mays*) genetic review for exploring yield and yield-related traits under organic farming in hill region. Plant Genetic Resources: Characterization and Utilization. 2022;**20**:425-433

[26] APR. Annual Progress Report 2020-2021. India: Government of Sikkim, Department of Agriculture; 2021

[27] HBAS. Hand Book of Agriculture 2019-2020. Agriculture Department, Government of Sikkim, India: Agriculture Census and EARAS Unit; 2020. p. 84

[28] AR. Annual Report 2011-2012. Krishi Bhawan, Gangtok Sikkim, India: Department of Agriculture, Government of Sikkim; 2012

[29] Singh R, Kalita H, Kapoor C, Gopi R, Babu S, Das SK. Maize (*Zea mays* L.). In: Awasthe RK, Pradhan Y, Bhutia K, editors. Handbook of Organic Production in Sikkim. Jointly Published by Sikkim Organic Mission, Government of Sikkim, Gangtok Sikkim, and ICAR Comple for NEH Region. Sikkim Centre, Gangtok Sikkim India; 2014. p. 408

[30] Singh R, Babu S, Avasthe RK, Yadav GS. Crop Diversification and Intensification for Enhancing Livelihood Security in Sikkim. Tadong, Gangtok, Sikkim, India: Published by ICAR-National Organic Farming Research Institute; Ministry of Agriculture and Farmers Welfare, Government of India; 2018

[31] Mani VP, Jotshi HC, Koranne KD. Preliminary observations on drought tolerance in Sikkim primitive maize. Maize Genetics Cooperation Newsletter. 1987;**61**(2)