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REVIEW ARTICLE

Early history of crop presence/introduction into India: VII. American cereal, maize (*Zea mays* L.)

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Abstract

The crop diversity in India have been enriched with the introduction of exotic crops from times immemorial, including maize. Maize originated and is domesticated in south-central Mexico. The semi-domesticated maize from here traveled to Americas and other parts of the world. In different geographical regions the semi-domesticate maize parallelly evolved interacting and adapting with the local environment into new domesticated landraces, besides the completion of domestication at center of origin. This led to the development of several centers of diversity. Genomic evidence suggests that the South American landraces through reverse gene flow (breeding) have further evolved the maize grain types in Central America. Presence of primitive types of maize in Central, East, South-east and South Asia, including India in pre-Colombian ancient times has been evidenced by the archeological proof in form of botanical remains, carving of maize-cob on temple walls, ancient dating, reference in ancient literature and similar looking vernacular names. These evidences confirm the pre-Colombian presence, thereby introduction of maize into old world (Asia) much before the commonly cited introduction for cultivation of maize in 16th century into Asia and in 17th century into India by Portuguese, generating further diversity. During ancient times maize appears to have traveled: 1. via the Mediterranean and Central Asia to Southwest China and further; 2. via Timur, Indonesia in extreme South-east Asia to India, and 3. *via* South-east Asia following silk route to India. The present article discusses these facets in detail.

Keywords: Americas, diversity, *Zea mays*, pre-Columbian introductions, primitive types

Introduction

The rich indigenous crop diversity of the Indian Subcontinent (South Asia) has been further enriched with introduction of exotic crops since times immemorial. It has been reflected by the hard evidence such as, the botanical remains of many exotic crops found in the archeological sites, sculptures in various monuments, ancient dating and many references found in the ancient Indian writings dealing with agriculture, indicating the presence of the crops of American, African, and Central Asian origin (Singh 1917; Singh and Nigam 2017; Singh 2022). The diverse ecological conditions of Indian Subcontinent facilitated the acclimatization, adaptation, and establishment of these crops, generating vast genetic diversity. This has made the Indian Subcontinent one of the major centers of genetic diversity, to the extent that for several of these crops it has been considered as one of the centers of origin, whereas for others secondary or regional center of diversity. Maize (*Zea mays* ssp. *mays*) has American origin; it has been domesticated in Balsas River valley of Mexico from Teosinte, *Zea mays* ssp. *parviglumis* (Zahn 2018). Maize is one of such crops, which based on evidence from different lines of investigations, it appears to have been introduced/present in Indian Subcontinent during ancient times much before Portuguese introduced it for cultivation in the country. The studies on maize origin/domestication in south-central Mexico (Central America), its further spread and evolution led to parallel completion of domestication in several regions of South America and other parts of the world, including Indian Subcontinent presents some fascinating revelations. The present article revisits the evidence, and attempts to churn these facts further, for tracing various possibilities about the origin, possible routes of ancient spread, introduction, parallel differentiation, and evolution of maize in Indian Subcontinent.

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Center of origin and initial evolution

Based on evidence revealed by different lines of investigations, such as presence of ancestral plant species, primitive domesticates, genomic analysis, etc., various theories have been proposed, speculating three different regions for the origin of maize namely, Mexico (Wilkes 1989), Andean's highlands of Peru (Mangelsdorf and Reeves 1939; Mangelsdorf 1986), and Himalayan region (Anderson 1945). Of these, the Himalayan origin is negated because of the absence of wild relatives such as Tripsacum and Teosinte and the phylogenetic relationship of modern maize varieties (Mangelsdorf 1986), like the other regions proposed in theories. Based on genetic diversity in relation to various traits, such as cytological, morphological, and physiological in Central and South Americas, some studies have proposed the concept of polycentric origin (evolution) of maize (McClintock et al. 1981).

The recent review of the intense studies on the origin and evolution of maize has revealed that maize originated from a single domestication event began in a single large gene pool in southern Mexico about 9,000 years ago (Hake and Ross-Ibarra 2015). However, the semi-domesticated grains were carried to different regions of South America, where the domestication process continued, under a long and convoluted process for the final stages of its domestication and cultivation. It occurred more than once, at more than one place (Hake and Ross-Ibarra 2015), resulting in the evolution of different races of maize in different geographical regions of the Americas.

Kistler and associates' DNA studies suggested that the domestication of teosinte did indeed begin in Mexico, whereas the studies on mapping of genetic connection between modern maize varieties and ancient plants revealed several distinct lineages, each with their own unique relationship to teosinte. Most significantly, the results revealed that although maize domestication began with a single large gene pool in Mexico, the grain was carried elsewhere before the domestication process was complete (Kistler et al. 2018). Kistler et al. (2018) state "We found in the genomes evidence that South American maize actually originated within one of these semi-domestic lineages" and "You had these parallel evolutions happening in different parts of the Americas, with different groups of people".

According to these studies, a major wave of "proto corn" movement from Mexico to South America occurred. The partially domesticated maize seems to have landed in the southwest Amazon. Probably, maize in the South America locations evolved more quickly than maize in Mexico, which would explain why the 5,000-year-old cobs from the cave in Mexico appear to be in an intermediary phase of domestication at a time when maize was already being cultivated in the South America (Katz Brigit 2018). Few more studies also highlight that South American maize has undergone considerable adaptation somewhat independently from the partially domesticated maize of Mexico. For these reasons, it has been hypothesized that the backflow of South American genetic material might have contributed to the further genetic enhancement, leading to the development of a more productive staple maize type, *i.e.,* the staple grain of today (Katz Brigit 2018; Kistler et al. 2020).

Further spread within and outside Americas

The data on further diffusion routes of maize within the Americas, Latin America, the Caribbean region, South America (Kistler et al. 2020) and the USA and Canada, and to different parts of the world has been conflicting, complex, and confusing (Mir et al. 2013). South America served as a secondary center of improvement where the domestication syndrome became fixed and new lineages emerged in parallel with similar processes in Mesoamerica. The second wave of maize brought into South America hybridized with long-established landraces from the first wave resulting in newly admixed lineages, then were reintroduced to Central America. This led Kistler et al. (2020) to hypothesize that the influx of maize from South America into Central America may have been an important source of genetic diversity as maize was becoming a staple grain in Central and Mesoamerica, thereby suggesting that by the time the cobs ended up on the floor of the ancient cave in Mexico, maize had already travelled far beyond Mexico through human intervention to South America by at least 7,000 cal BP as a partial domesticates and had been cultivated in the southwest Amazon for around 1,500 years (Kistler et al. 2020).

The discovery of primitive types of maize in other parts of the world, particularly the Himalayan Mountains, like Sikkim, has led to the hypothesis that this region will be another center of origin or where further evolution took place. It is possible that ancient spread of primitive forms of maize may include the old-world, including East Asia, the Himalayan Mountains, and the Indian Subcontinent (Marszewski 1975-1978). Probably primitive maize spread or introduction across ocean took place during ancient times through early voyages or traders, including those working on silk route, which further evolved it into local landraces, supporting the proposition of polycentric origin/evolution of maize (Randolf 1959; McClintock et al. 1981).

Presence of maize in Asia and Indian Sub-continent during ancient times

Asia and Indian Subcontinent present a significant amount of diversity in maize. The waxy varieties of maize found in South-east Asia, starting from Myanmar (Burma) across China to the Korean peninsula (East Asia), mostly away from coastal areas [the region commonly believed, where 16th century Iberian (south-western Europe) sailors are supposed to have first introduced maize] are not known to be found in the

Americas. Therefore, appear to suggest the possible distinct geographical origin/evolution, though some unusual traits exhibited in these Asian maize's do have close matches to maize archaeologically known type from Peru (Towle 1961), or that is still being grown by native groups in Colombia, Peru, Chile, Bolivia, and Argentina (Anderson 1945; Sarkar et al. 1974). The discovery of these differentially developed genotypes/varieties in interior East Asia (Anderson 1945) indicates that there were probably separate introductions of 'primitive' maize into Asia, including the Himalayan region (Marszeewski 1975-1978).

In the Himalayan region, farmers grow primitive popcorn types with seven to nine ears per stalk, all concentrated in the upper 20% of the stalk in the regions, such as Trashigang, or Tashigang in Bhutan and Ilam in Nepal. Dhawan (1964), Thapa (1966) and Sachan et al. (1982, 1986a and 1986b) recorded the presence of primitive popcorn types in Sikkim and north-eastern India. These types have distinctive arrangements of leaves and their tassels droop in a form atypical for American maize. Winter flint maize with short conical ears with a somewhat fattish or pregnant, shape was found in eastern Bhutan. Conical ear shape used to be considered a trait of ancient specialization of maize in Mexico, Central America, and in highland of Peru. The extensive collection, characterization and evaluation of maize germplasm, primarily from the northeast Himalayan Mountain region by Singh (1977) led to descriptions of several primitive types, derived types, recent introductions, and hybrid races. Anderson impressed by such diversity found in the north-eastern Himalayan Mountain region, led to his proposition of Asiatic origin of maize (Anderson 1945), and/or an early trans-Pacific migration to South America. Stonor and Anderson (1949), Suto and Yoshida (1956) and others also showed the presence of maize with primitive characteristics (popcorn and prolificacy) in the Himalayan Mountain region. These have been described as Sikkim Primitive 1 and 2, from Sikkim (Dhawan 1964; Gupta and Jain 1973) and has astonishing resemblance to the progenitor of maize reconstructed by Mangelsdorf, then any other primitive races known or found in Mexico (Central America) (Nal-Tel {Yucatan 7}, Palomero-Toluqueño, Chapalote) or Colombian (Pollo Segregaciones) races, considered previously to be the most primitive types known (Marszeewski 1975-1978). These observations also led Zeven and de Wet (1982) to consider the Himalayan region a secondary center of origin and diversity of maize. Sikkim Primitive has similarity with the maize progenitor teosinte in bearing multiple ears per plant. However, the nature of prolificacy in teosinte and Sikkim Primitive is quite different. In teosinte, each of the primary branches terminates into tassel, and 30–50 ears are developed in place of secondary branches. While in Sikkim Primitive each of the primary branches leads to formation of an ear and there is no secondary branching. Furthermore, ear development in Sikkim Primitive starts from topmost node just below the tassel, thereby producing multiple ears of similar size, especially on upper half of plant, compared to the formation of single ear in the middle of the stem in other maize genotypes (Prasanna 2012). It may be an intermediary, evolved from teosinte. Prakash et al. (2019) have suggested that a major gene/QTLs may be responsible for prolificacy in Sikkim Primitive.

The report of maize ears to be taken out of a tomb excavated in Sichuan Province of China, which is said to date back to about 2000 BP = 51 BC (Han Dynasty). Archeological evidence with botanical remains from sites at the Timor Island, Indonesia in extreme Southeast Asia, dating back to 3rd millennium BC (3000 through 2001 BC) has demonstrated the presence of maize in Asia during pre-Columbian times.

Sculptures of maize ears found in the ancient Hindu and Jain temples, which might have been observed long back, but were probably confused with exotic fruits. Johannessen and Parker (1989) and Johannessen and Wang (1998) were the first to document these sculptures of ears of maize on temple walls of 11th to 13th centuries in Karnataka State (Fig. 1). At least one maize representation dates from the 1st century AD were found in Cave Temple III, Badami, Bagalkot, Karnataka (Sorenson and Johannessen 2004). Gupta (1996), an expert on temple art, identifies/reported around 70 plants in Hindu, Jain, and Buddhist temples of India, independently confirmed maize sculptures at the Lakshmi

Fig. 1. Wall sculpture from a temple at Somnathpur, Karnataka, India, is dated to AD 1268 Source: Sorenson and. Johannessen (2004)

Narasimha temple, Karnataka, "Nuggehalli. Gupta (1996) reports a set of maize sculpture from temples of west-central India that date to the 5th to 8th centuries earlier than those of Karnataka state. They have sculpted figures of male Hindu gods holding maize in their hands. Other temples that have possible maize effigies include Sravana Belagola, a Jain Temple complex of the 8th century AD; Bodhgaya Temple, 1st century BC; and a Kubera Temple in Rajasthan of the 8th century AD (Sorenson and Johannessen 2004). About the presence of these sculptures of maize-ears in many Hindu, Jain and Buddhist Temples, the common belief among Indian crop scientists is that maize originated in Mexico and came to Indian Subcontinent by the 11th-12th century. By the time these temples were constructed, maize would have become reasonably common in India. Pre-Columbian contacts between India and Mexico, have been postulated from varied evidence (Sorenson and Johannessen 2004).

The availability of Sanskrit names, such as *Sasyam*, *Stambakari*, *Sasyavisesha* (Watt George 1889) and *Yavanala* (Chopra et al. 1956; Torkelson 1999) in fifth century AD literature and references to maize fields found in the inscriptions of Assam (*kosthamakkhi-yana*), and the reference to maize in the ancient Chinese literature belonging to 13th century AD, further corroborates the presence of maize in Asia before Columbian exploration. Additionally, studies of names for maize in India and other parts of Asia find notable similarities with certain American vernacular names, particularly in connection of names used in Amazonian South America, namely *Choclo* with that of vernacular names used South India, such as, Tamil- *Makka-Cholum*; and *Malyali-Cholam* and others in parts of Asia. The similarity vernacular names are so much as if the people with common roots used them. This fact calls on to indicate that ancient introductions most probably took place from South America by people contacts. Also, maize is recorded in a Chinese medical encyclopedia of *ca*. AD 1448 giving detailed guidance on the curative use of corn (maize) silk and seeds (Sorenson and Johannessen 2004). This would not have been true for a recently acquired plant. Burkill (1966) reported that maize products are still used in Southeast Asia to treat renal problems.

Almost all agricultural scientists and botanists who have studied diversity of maize in detail in respect to their morphology, cytology, genetics, physiology and distribution are also inclined to admit their pre-Columbian occurrence at least in some parts of the above-mentioned regions (South China, South-east Asia, Himalayan Mountain range, and South Asia). For this reason, most author(s) repeat this viewpoint of Collins, Kuleshov, Anderson (for Atlantic/Iberian sailors), Suto and Yoshida, Gupta and Jain, Vishnu-Mittre, and Gupta, all of whom either favor or admit the pre-Columbian presence of maize.

Above facts reaffirm the presence of maize in Asia, South-east Asia, and Indian Subcontinent, as part of the agriculture much earlier than common belief. It was introduced into cultivation by the Portuguese during the 17th century into India and by Atlantic/Iberian sailors in 16th century from Central America in South-east Asia. Columbus did bring maize to Europe but was adopted for cultivation sparsely in Iberia for animal feed (Johannessen and Parker 1987).

Ancient presence in other parts of world

Different lines of investigations indicate the pre-Columbian presence/introduction of maize in other parts of the world. Historical record places the crop in the Middle East by AD 800 and that maize may also have reached Eastern Europe and Africa in pre-Columbian times (Jeffreys 1953; Sauer 1962). The immediate source of these introductions/ presence of maize in Middle East may be India, because of being the center of some of the oldest civilizations and having long trading relationships with these regions, though other possibilities for direct contact do exist.

Some maize-cob decorated potsherds have been found in West Africa (Stanton and Willett 1963), which are believed to date several centuries before Columbus landed in the New World in 1492. This archaeological evidence and another evidence point to the introduction of maize into Africa through Arab/African contacts with the Americas in the beginning of AD 900. Also, a specimen of maize was collected along the Euphrates River in Iraq in 1574 (stated by Sorenson and Johannessen 2004).

During post-Columbian times, maize was reintroduced and further spread to other parts of the world, facilitated by the voyages, and spread of colonial rule of European military and trading powers. This late medieval and colonial period of has been considered to be era of the introduction and spread of many crop species into other parts of the world bringing revolution in agriculture and agricultural biodiversity in other countries of both old and new world, including Indian Subcontinent.

Possible explanation for presence/ route of introduction

The evidence presented above from various studies, corroborate the origin and domestication of maize in south-central Mexico and highlight further diffusion of semi-domesticates to South America in waves with parallel evolution, leading to polycentric completion of domestication in regions of South America (Fig. 2). The studies performed on South American maize have indicated that the maize on reaching South America has undergone a considerable amount of adaptation/acclimatization somewhat independently of the maize in Mexico. This is expected in a cross-pollinated crop and may be more so when plant is wind pollinated with pollen produced in abundance. Studies on genomic analysis has further indicated that there might have been backflow of South

Fig. 2. Hypothesized routes for the dispersal of semi-domesticated or primitive maize into other parts of the world.

American maize genetic material to Central American region (through human intervention) contributing to genetic enhancement and selection of more productive grain/staple types (Kistler et al. 2020).

The presence Sikkim primitive popcorn type maize in Himalayan Mountain region and unique waxy varieties in Asian region starting from Myanmar (Burma) across China to the Korean peninsula opened an entirely new angle on the origin, evolution, and dispersal of maize in this part of the world. It has been admitted that the presence of primitive races in Sikkim, Nepal, Bhutan, or Assam hills is extremely puzzling and cannot be explained on the assumption of introduction and spread of maize in the post-Columbian era, but only based on ancient pre-Columbian era introductions through cross-Ocean transfer/spread. Further research is obviously needed on these primitive forms and those of South-central, East, Southeast and South Asia and their possible phylogenetic relationships with American maize's.

The Asian primitive/diverse types exhibit a distinct constitutive hetero-chromatic phenomenon from that found in South American maize (Sachan et al. 1982). This reflects that some ancient ancestral primitive maize likely existed in Asia for a long time and differentiated into a different line. However, it is not clear how the differential characteristics noted relate to the complex of strange maize traits, including primitive popcorns and sticky starch maize of the Naga Hills and Assam reported by Stonor and Anderson (1949), evolved here after arrival of primitive types. These peculiar types of maize stretch from the Aegean (Greece) to the Asiatic Pacific, including Nepal, Sikkim, and North Assam. Nearest counterparts of such types occur in South America before the Incas (Peruvian highlands). Anderson and Brown (1952) consider it plausible that primitive maize was transferred both cross-Pacific and cross-Atlantic via Mediterranean Aegean Island to Asia. Kuleshov (1928) demonstrated that primitive maize like that in Naga region (of India) was widespread in Central Asia from Persia and Turkestan to Tibet and Siberia, probably because it travelled cross-Atlantic to the Mediterranean Aegean Island route. Therefore, Aegean Island and Central Asia is possibly one route for the introduction of maize into Southwest China (Fig. 2). This is corroborated by Maize ears reported from a tomb excavated in Sichuan Province of Southwest China. These might have been extended even to the Himalayan Mountain region. Although, a little evidence exists to support Laufer's (1929) theory of maize dispersal eastward from Spain. Further research is obviously needed on these primitive forms of maize found in Central and South Asia (Afghanistan and Himalayan Mountain in north to Indian Ocean in south east, to Arabian Sea and Pakistan in west and Bay of Bengal in east.) and possible relationships between them.

There is a widespread presence of waxy (sticky) starch maize in Asia, from Manchuria and Korea Peninsula, across China to Myanmar, but rare to non-existent in South America during ancient civilizations such as the Maya and Inca, which is another puzzle. However, some unusual traits of these Asian maize's do have close matches to maize known archaeologically from Peru (Towle 1961), or that is still being grown by native groups in Colombia, Peru, Bolivia, Chile and Argentina (Anderson 1945; Sarkar et al. 1974). It has been stated that waxy starched maize in China has a significantly distinctive isozyme distribution that is very different from New World maize's isozymes (cited by Sorenson and Johannessen 2004). How far are these isozyme patterns have not yet been thoroughly explored. Marszewski (1975–1978) hypothesizes that 'primitive' forms of maize could have been picked up from one or another sector of the Pacific coast of the northern South America or southern part of Central America at an as yet indefinite time of the pre-Columbian era. This could have been done by some aboriginal sailors coming from the northern part of South Vietnam shores and belonging perhaps to the Cham or other akin people. Thereby suggesting cross-Pacific Ocean introduction of primitive maize from Central and/or South America via South-east Asia up to South Asia (Indian Subcontinent) is possibly the second route (Fig. 2).

The presence of botanical remains in archeological sites in the Timor Island, Indonesia, situated in extreme of South-east Asia indicates that this can be third possible route for early cross-Pacific Ocean introduction of maize into Asia (Fig. 2). It may include Northeast Himalayan Mountain region being close to this region and having similar mountainous ecology like the Andes Mountains (one of the regions involved in early evolution and spread of maize), facilitating introduction, acclimatization and establishment of maize. Thus, there appears to be three possible routes of ancient introduction of maize into Asia, including the Himalayas and Indian Subcontinent: 1. Cross-Atlantic via Mediterranean and Central Asia, 2. Cross-Pacific via South-east Asia, and 3. Cross-Pacific via extreme South-east Asia.

The study using SSR markers (Mir et al. 2013), including sets accessions from Americas, Europe, Africa, and Asia

was conducted to trace dispersal of maize from center of origin in Central America to other parts of the world. This study grouped the accessions from different continents into distinct clusters, revealed mean population diversity (Hk) higher in North America diminishing progressively eastwards with the smallest value in Asia and opposite trend for genetic differentiation among accessions (Gst), where values were higher in Asia and diminished westward toward the Americas, closeness of Tropical and Mexican accessions with those of Southern Asia, clear separation of Western Asian accessions with the existence of a genetic gradient eastward, separation of accessions from South-east Asia with a contribution toward the northeast and to a lesser extent toward the west, ancestry from the Mexican highlands cluster throughout Eastern Asia, especially along the coasts, suggesting maritime introduction(s) and tropical lowland ancestry in western Asia from Nepal to Afghanistan, making Asia the contact zone between these two diffusion routes (Pacific and Atlantic), highlighting that Tropical lowland and Mexican origins of Asian landraces and their contact zone, and that landraces from distinct American origins coexist. However, repeated introductions over times, local selection, and adaptation, involving a highly diverse gene pool, out-crossing nature, and global trade in maize has led to more confusion at molecular level creating difficulty in understanding exactly where the diversity of the local maize landraces originated. This is particularly true in Africa and Asia.

The Absence of ancestral wild species or progenitor teosinte rules out the possibility of origin of maize in Asia (Himalayas). However, the occurrence of diverse phylogenetically close primitive maize genotypes, cross-Atlantic and cross-Pacific Ocean in Central, East, South-east and South Asia, including Himalayan Mountain region supports the concept/idea of polycentric evolution of semi-domesticated/primitive types after cross-Ocean introduction/spread, to produce distinctive primitive types of maize. It may be same way as speculated for the spread and evolution of maize in to South America after origin and domestication south-central Mexico (Kistler et al. 2018, 2020). Postulation of ancient (pre-Columbian) contacts between India and Mexico suggest that maize in the Himalayan Mountains (India) was first introduced cross-Pacific via South-east Asia might have been repeated by traders travelling along the silk route (Dhawan et al. 1996) and got established in the region because of congenial ecology (Fig. 2), although, the precise date and route of introduction remains a mystery due to lack of authentic historical records to this effect. These hypotheses on route of introduction are researchable issues for lack of hard direct data support.

Therefore, the precise date of the first introduction of maize into Indian Subcontinent remains a mystery. However, in light of the above evidence, the belief commonly cited in the literature that the Portuguese's first introduction of maize into India in 17th century stands completely negated and is not tenable. There is no data on maize's subsequent spread and cultivation during ancient India. The use of Muslim terminology (Urdu) Makka ('Mecca') as vernacular names in India, does suggest that the popularization of maize first in northern India and later into peninsular India was facilitated by Arab/African forces, again corroborating presence/arrival of maize into India long before the Portuguese (Sorenson and Johannessen 2004).

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