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RESEARCH PAPER

The Birth of *Aus* Agriculture in the South-eastern Highlands of India – an Exploratory Synthesis

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Away from the Ganges valley, the south-eastern highlands of India is recognized as the region of origin of upland or *aus* rice. In this narrative, we attempt to reconstruct its origin synthesizing inklings from genetics, prehistory, and anthropology, and to find out the putative paleo-ecological, environmental, and cultural context that provided the necessary impetus to it.

Genetically, we uncover a highly diverse phenotypic base with unique alleles hinting at an independent origin of *aus* perhaps from *Oryza nivara*. Post-LGM paleo-niche portrays more widely distributed *O. nivara* as opposed to *O. rufipogon*; relatively abundant *O. nivara* could have enabled its preferential exploitation. While a dearth of archaeological study does not illuminate much on this aspect; the agricultural attributes of the ethnic inhabitants of the area, e.g., dry rice cultivation with the hoe and the axe, reveal a striking similarity with *aus* or upland rice cultivation. Furthermore, comparative analyses with other historical anecdotes suggest that upland rice seems to be born as an adaptive landscape management by pre-agriculturist society. It was developed through a broader plant-people-landscape interaction, where rice or its ancestors were grown for subsistence with other crops as a Neolithic proto-agricultural package; in this case along the hill slopes. Summarizing, the current study casts light on some of the understudied aspects of upland rice agriculture, but it also brings out many open questions inviting future examination.

Introduction

The Initiation of agriculture was a giant leap in the history of humanity. Domestication of Asian cultivated rice is a much-debated topic and hovers over two contrasting hypotheses, single and multiple (Molina et al. 2009; Huang et al. 2012; Civan et al. 2015; Choi et al. 2017). Archaeological records portray a parallel culture in India yet younger to China but emphasize the glory of past innovations. A plethora of sites uncovered across the upper Gangetic plains resonates with exuberant rice agricultural tradition (Fuller 2011; Tewari et al. 2006, 2009). Apart from the primary centers of domestication, independent local foci have been crucial in their contribution to agricultural involution (Rindos 1989). They have been largely overlooked and hence were relatively less explored. One such region, vital in terms of pre-historic rice agriculture, is the north-eastern Deccan plateau enveloping a part of Eastern Ghats. This is an extensive area comprising undivided Koraput district (Odisha), Jagdalpur (Andhra Pradesh), Bastar (Chhatisgarh), and southern Jharkhand state. The core area has earned its name as Jeypore tract often historically annotated with the earliest rice agrarian activities by many scholars (Mishra 2009; Sharma et al. 1998; Senapati and Sahoo 1966). More specifically, the birth of upland or dry rice, used interchangeably with *aus*, presumably had happened around this region.

Unlike wet rice, upland cultivation exercised mostly with rainfed water, without external water input, along the hill slopes. The significance of *aus* or upland rice lies in its wider acceptance in many highlands of south and south-east Asia where rice agriculture has been carried out by small-landholders with minimal extrinsic resources (Sharma et al. 1998). Although phenotypically closer to *indica* group recent genetic studies have explicitly segregated *aus* from other subpopulations, i.e., *indica* and *japonica*, by attesting to a divergent domestication history (Schatz et al. 2014). On a similar line, previous researchers have identified this region as a centre of diversity of rice mostly dwelling on a high phenotypic diversity of the cultivated landraces (Ramaih and Ghose, 1951; Ramaih 1953; Govindswamy and Krishnamurty 1959; Oka and Chang 1962; Sharma et al. 1998). Therefore, prefatory records taken together, the area appears as a cradle of upland rice agriculture; but rudimentary nature of the existing proof does not inculcate confidence, and demands a fuller consideration adhering to insights from various disciplines.

In this narrative, armed with inklings from genetics, prehistory, and anthropology, we attempted to examine the current state of knowledge on the origin of upland, or '*aus*' rice agriculture in the south-eastern highlands of India. In addition, we have also integrated information from paleo-distribution of wild ancestors with an aim to understand whether their relative availability had created an opportunity for exploitation in the past. Towards the end, we have reconstructed the putative environmental

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and cultural context that set this in motion to propose a plausible hypothesis.

Ancestral distribution in the LGM and the Holocene

Asian rice owes its origin to two sister species, *Oryza rufipogon* (henceforth *rufipogon*), and *Oryza nivara* (henceforth *nivara). Nivara*, a recently speciated form of perennial *rufipogon*, is putatively recognized as the progenitor of *aus* (Liu et al. 2015). *Nivara*, an annual species, grows along the seasonal ditches in vast swaths of the Indian subcontinent (Sharma and Shastry 1965; Sharma et al. 2000). The preference of *nivara* as a potential candidate for manipulation over *rufipogon* could be for a number of reasons, i.e., synchronous flowering, bolder grains, and relatively easy collectability which spurred their exploitation. Moreover, the preferred habitat of *rufipogon* was swamps, deep water near the deltas of big rivers that were not easy-accessible; whereas the habitat of *nivara*, i.e., rain-fed water bodies and shallow ditches which were easily reachable (Morishima et al. 1984). In addition, we also surmise that an abundance of the *nivara* during post-LGM period had outnumbered the *rufipogon* and won the preference of ancient people, despite having an overlapping distribution. In order to compare the LGM and the Holocene distribution of both the species, ecological niche modeling (ENM) was conducted with present occurrence points employing standard method (material methods in supplementary information -S1).

The potential distribution of *nivara* shows high probability areas across the coastal regions of Odisha and western peninsular India (**Figure 1c**). Apart from the coastal zone, medium to high probability regions also extend to interior of Odisha, Jharkhand, West Bengal, and Chhattisgarh even up to the Himalayan foothills. The medium probability regions encompass north-east India, mostly Assam. Apart from India, a vast section of coastal Bangladesh and Myanmar falls under medium to high probability. The distribution pattern indicates species preference towards zones with moderate to high rainfall and benign temperature. The images also depict a conspicuous spatial expansion of distribution area from relatively depauperate vegetation in LGM to gradual enrichment in the Holocene, especially in medium probability regions (**Figure 1a–b**). The steady increment in distribution zones along the eastern Deccan peninsula, and the Himalayan foothills are very prominent during the Holocene and current time period. One possible reason could be a rise in temperature after LGM made both the eastern Deccan and the Himalayan foothills amenable for species niche expansion. The temperature related variables, i.e., annual mean temperature (BIO1), mean diurnal range (BIO2), and maximum temperature of the warmest month (BIO5) contributed most in model development. On the contrary, the paleo-distribution of *rufipogon* mirrored the overall pattern portrayed by *nivara*, i.e., the gradual expansion from the LGM to the Holocene but demonstrated relatively sparser distribution compared to *nivara* (**Figure 2a–c**).

In light of the paleo-distribution during the LGM and the Holocene, it seems probable that relatively abundant *nivara* offered easily available and exploitable cereal grain source than did *rufipogon*; which could be one of the drivers underlying the choice.

Phenotypic diversity, unique alleles, and genetic origin of *aus*

In crops, the principal tenet of centre of origin is built on the diversity of landraces found in a region. In the same way, the claim of indigeneity of *aus* group around Jeypore tract, Odisha also draws support from a large number of landraces explored in the early fifties (Ramaih and Ghose, 1951; Ramaih 1953; Govindswamy and Krishnamurty 1959; Sharma et al. 1998). More than two thousand unique landraces have been grown across a vast region of the highlands for several decades (Govindswamy and Krishnamurty 1959). A few characters, e.g., i) black, or brown husk, ii) reddish kernel, iii) presence of awn, iv) photoperiod insensitivity, v) relatively fast maturing, vi) lower yield, v) low tillering, distinguished *aus* group from other subpopulations (Mishra 2009). Many of these landraces have not yet shed their ancestral features that implied they could be at the intermediate stages of domestication (Oka and Chang 1962).

Preliminary investigations on the origin of Asian cultivated rice have mostly dwelled on two major groups, namely *indica* and *japonica*, which largely ignored *aus* (Molina et al. 2011; Huang et al. 2012; Choi et al. 2017). Genetically, *aus* was recognized as a distinct subpopulation within *indica* varietal group (Garris et al. 2005; Huang et al. 2012). However, a suite of recent studies has evinced that *aus* possesses distinct genetic space despite being relatively closer to *indica* than *japonica* (Schatz et al. 2014). The inference is firmly based on the discovery of several important genes, e.g., the *Rc* locus, conferring reddish pericarp, the *Snorkel* locus underlying deep water viability, or the *Sub1* locus conferring submergence tolerance are all unique features of *aus* subpopulation (Schatz et al. 2014). The resurrected interest has unveiled a wealth of

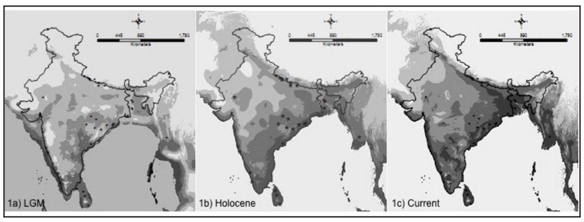

Figure 1: Potential distribution of *Oryza nivara* during **(a)** the Last Glacial Maxima (LGM), **(b)** the Holocene, and **(c)** the current time.

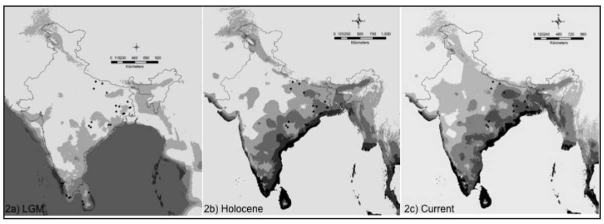

Figure 2: Potential distribution of *Oryza rufipogon* during: **(a)** the Last Glacial Maxima (LGM) **(b)** the Holocene and **(c)** the current time.

genetic information on *aus*; which suggests its far greater contribution to genetic base of Asian rice than previously imagined (Schatz et al. 2014). It may be largely due to its independent genetic as well as cultural trajectory, *aus* landraces have accumulated unique and rare alleles during the course of domestication and post-domestication improvement phase. Subsequently, artificial selection for various cultural and economic reasons over centuries led to the fixation of alleles. In many remote regions of south Asia, heirloom landraces are still isolated and cultivated marginally preventing genetic intermixing that tends to conserve the novel variants. Another likely reason of this genetic uniqueness is the diversity of its putative progenitor, *nivara* which differs from its sister species *rufipogon* in a number of key traits (Sharma and Shastry 1965; Xu et al. 2012).

Relying on the fragmentary genetic evidence, we propose a putative model to elucidate the pathway of *aus* origin and evolution; and in doing so, we divide it into three major phases, pre-origin, origin, and lastly domestication and diversification (**Figure 3**): i) pre-origin was the phase of ancestral differentiation, i.e., speciation of *nivara* from its sister species *rufipogon* which had happened in early Quaternary period (2–4 Ma and later) in the south and south-east Asia. However, the expansion and diversification of population would have continued till the retreat of glaciers, perhaps until post-LGM (Liu et al. 2015); ii) origin phase: an expansion of ancestral population during the LGM and the Holocene, had proffered the early cultural groups to capitalize on the existing plant resources. An abundance in highly productive eco-systems which possibly augmented the preferential exploitation of this wild annual leading to the formation of founder population of semi-domesticated *proto-aus* (c.a 4000–7000 years); a dearth of genetic evidence instigates us to hypothesize the derivation of a few *aus*-specific alleles (e.g., *Snorkel1*, *Rc* etc) from *nivara* during this phase or arrived as *de-novo* mutation in landraces later (Sweeney et al. 2007); iii) domestication and diversification phase: a step forward towards further differentiation of *aus* group from other, with or without major contribution from *japonica* and *indica* as late as 2000 BC or later (Huang et al. 2012; Choi et al. 2017). It followed a phase of geographic spread of *aus* culture and gradual amalgamation into the society leading to the origin and evolution of various landraces unique to the many cultural groups contingent on *aus* rice.

Cultural attributes of the highlanders

Once continuous forested landscapes of south-eastern Deccan plateau harbored a diverse array of flora and fauna, and tucked away in the hills used to live various tribal groups called the highlanders (Elwin 1950). Although we have only anecdotes of early farmers around north-eastern Deccan plateau, a closer scrutiny of the existing literature distinguishes a few major ethnic tribes. They belong to the Munda-speaking Austro-Asiatic groups namely *Saura*, *Gadava*, *Bondo* who bear the legacy of early farming (Mishra 2009; Chaubey et al. 2011; van Driem 2012). A few simple yet highly creative technological innovations portray their ways to engineer their habitat, e.g., shifting agriculture on hilly slopes, mixed cropping, basic manipulation of the land with simple technology, bunded water management practice (Elwin 1950; Senapati and Sahoo 1966). Historical account by previous researchers noted a prevalence of three different types of rice cultivation, i) wet cultivation in the irrigated and ploughed fields across the valleys, ii) nicely terraced cultivation with prolific water storage and distribution systems along the hills, and iii) dry rice cultivation with the hand-axes along the steep slopes of the hills (Elwin 1950). The agricultural heritage of *Saora* and *Bondo* people has been regally associated with remarkable terrace cultivation which is a type of wet cultivation. They used to efficiently manipulate water by creating bunds to hold water in the rice field. On the other hand, dry or upland rice cultivation by clearing and burning forests along the hilly slopes was also profusely performed by them (Elwin 1950). It is a relatively simple form of agriculture where the various crops, e.g.,

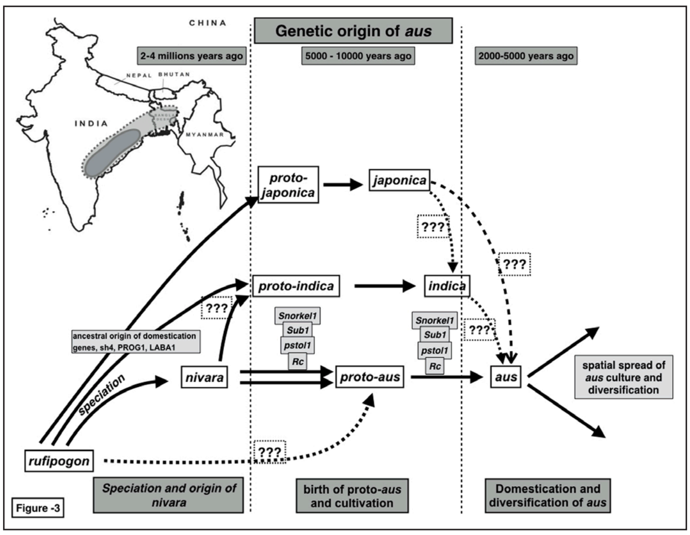

Figure 3: A model to elucidate the genetic origin and subsequent evolution of *aus* or upland rice of south Asia (*Oryza nivara* = *nivara*, *Oryza rufipogon* = *rufipogon*). The inset map of India shows the region of putative *aus* origin and domestication in grey with border, darker grey = the core area, lighter grey = the extended area.

millets, maize, oil-producing *Guizotia abyssinica*, Sago palm (*Caryota urens*), *Bassia latifolia*, legumes are grown together with rice in a mixed cropping pattern. Rainwater does not stagnate in the undulating landscape and entire cultivation process is devoid of any animal assistance or major tools except the hoe or the hand-axe. The shifting cultivation is highly accepted subsistence strategies among the other tribes of the adjacent areas, e.g., *Konda Reddis*, *Bison-Horn Marias*, *Didayi*, *Juang*, *Paroja*, *Kondhs* (von Fürer-Haimendorf 1909; Patnaik, 2005).

An understanding of ethnic tribal groups is often sought to explain the Neolithic culture. However, with the anecdotal information in hand, it is daunting to trace the antiquity, the origin of this agricultural exercise, and its subsequent geographic dissemination. We only have the implicit keys that unravel similarities with their subsistence agriculture, but, it also calls for further studies in terms of the timing of diversification of ethnic tribal groups, their language, their adoption of specific cultural practice, and other attributes of rice agriculture.

Archaeological records

Although there is no dearth of archaeological sites across the region, the south-east highlands lack explicit evidence to support our claim on antiquity of upland cultivation. However, archaeologists have unearthed two geographically divergent streams of culture, one settled on eastern coastal lowland whereas the other around tribal dominated foothills and uplands. They proposed different cultural trajectories, where eastern lowland denoted a settled agricultural life while the other resorted to shifting cultivation with seasonal movements across highlands (Harvey et al. 2006). It will be futile to predict an initiation of upland rice cultivation from these prefatory records; nevertheless, we discover a faint connection with the elements of agrarian activities. Rice (presumably wet) along with various pulses were grown across this lowland landscape whereas there is not much convincing evidence of the same around the upland. An absence of pottery in the upland sites may indicate less sedentary life-style with a food base mostly involving tuber crops rather than seeds. The authors relate their findings with that of shifting cultivation in the *Rajmahal* Hills discerned by Pratap (2000). It is an ethno-archaeological account of shifting cultivation around the highlands of *Santhal Parganas* of Bihar; however, the cultivation practice was mostly millet or maize-centric instead of rice. A relatively older narrative by Roy (1989) described a traditional slash and burn agriculture with the help of the hoe and the axe in Garo Hills, Meghalaya. Although the prehistoric connection was not well-deciphered the author found out the similarity in material culture between the past and the present. He inferred that the rice was cultivated as a major crop along with several others, e.g., millets, maize, vegetables. Prehistoric investigations on shifting cultivation are also available from the same region (Sharma 1990). Although an absence of studies obstructs further interpretation of cultural milieu of upland cultivation, a general trend becomes apparent comparing various highlands of India; a simple mode of plant tending cropped up in response to local ecology and environment, a central tenet that we briefly expand in our hypothesis.

Evolution of upland rice – an emerging hypothesis

Aus is mostly an upland or dry rice that is grown in rain-fed condition, as opposed to predominant wet rice cultivation where the plant matures with standing water at the base. We intend to emphasize that the dry rice cultivation seemingly has surfaced as an adaptive measure to engineer an undulating landscape of the highlands. It can be viewed as a set of cultural practices (i.e., clearing the forests, preparing the land, and seeding) in order to make use of the locally available resource for food production, a proposition which anchors our key tenets in the current geographic context (**Figure 4**).

Prior anthropological accounts suggested a kind of subsistence agriculture with multiple crops in the cleared forest lands along the hill slopes was the major element of upland cultivation, which is synonymous with slash and burn or swidden agriculture. A relatively basic form of

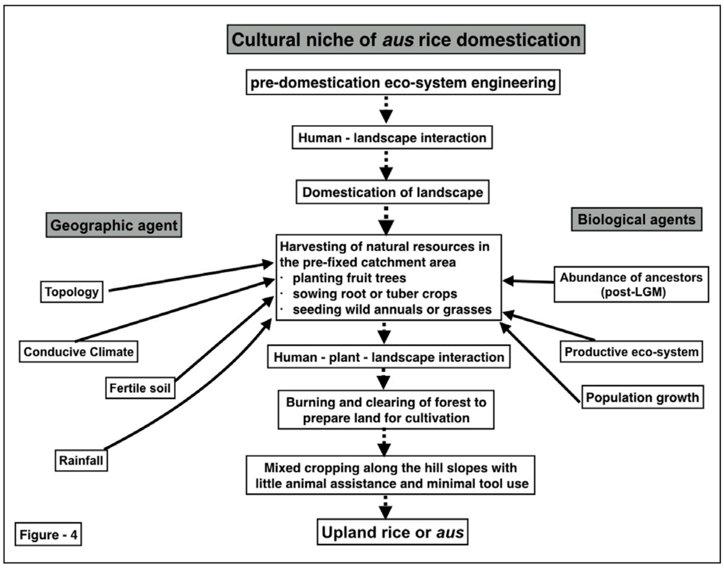

Figure 4: A proposed cultural niche of *aus* or upland rice domestication.

cultivation that had likely evolved to grow a package of crops together (not only limited to rice) without the aid of larger tools or animals (White 1995). Although studies are scarce, we can borrow from a few historical anecdotes to compare and situate our arguments on the evolution of upland rice cultivation system.

Geertz (1963) and Janzen (1975) have articulated their observations on the differences between dry and wet cultivation. They stated dry or upland rice cultivation was technologically simpler and did not demand any major assistance from tools or instruments, i.e., plough, or animals, yet only employing an axe or a hoe. It involved fewer steps (no bunding, nursery preparation, or transplanting etc), was less labor-hungry (minimal field and water management), and low in output comparable to subsistence agriculture. Characteristically, it is similar to polyculture emulating the dynamics of complex natural tropical ecosystems. In a historical account of the swidden cultivation in Philippines, Conklin (1957) has observed a large number of crops (in some cases the number reaching to fifty) growing in a three-acre plot. It exercised intercropping of many types of domesticated plants including legumes, roots and tubers, vines and tree crops, and cereals. A diverse spectra of living culture of multi-cropping is still predominant in the hilly tracts of south Asia, ranging from eastern, south-eastern to north-eastern India; where subsistence farmers used to rely on cultivation of legumes, oil seeds, cereal crops, spices, roots, and tubers in the same field to meet up their nutritional requirement, even though the number and the variety of crops vary with region (Juyal and Sati, 2010; Mishra 2009; Ramakrishnan 1984).

White (1995) has proffered a succinct description of the origin of upland rice cultivation system in south-east Asia based on his long-term observation from Ban Chiang of the north-east Thailand. He found that aborigines cultivated rice that differed significantly in their maturation time; so did wild rice presumably governed by the photoperiod sensitivity. It perhaps demonstrated that the early manipulators may have exploited their knowledge of wild rice physiology for better harvest, and while doing so the preferential selection for seeds had occurred.

Building on above discussion, we have gained following insights that may infuse strength to our arguments: i) landscape manipulation employing polycultural exercise, ii) simple, without major tools or animal assistance, iii) a little landscape management, unlike systematic or industrial agriculture. Together, it implies a human cultural association with the landscape through minimal plant husbandry that likely evolved into a much complex system. Thus, upland rice agriculture could be an offshoot of much holistic human adaptive strategies to domesticate enveloping landscape.

Throughout human history, landscape has had a crucial role in shaping cultural attributes of human race and the reciprocating adaptation for survival had been remarkable (Sutton and Anderson 2004; but see Erickson 2008). Situating the similar premise in current spatial context, we can possibly reconstruct the cultural events. The undulating landscapes of extended south-east highlands perhaps posed a challenge to the prehistoric cultural groups to win over; the forested hills, low lying water-filled ditches full of wild grass like rice progenitors, and sufficient rainfall stimulated them to adapt and thereby extensively manipulate the surrounding catchment environment. In course, early peasants perhaps tucked in the forests of the hills heuristically initiated burning and clearing of the forests in the hill slopes, preparation of land followed by seeding of several useful plants in a simplistic manner with minor tools like hoe, hand axe, or a spear (**Figure 4**). The Neolithic plant package perhaps included a few kinds of wild grass, primarily *nivara* which was plentiful, or to a lesser extent *rufipogon* (**Figures 1** and **2**). Post-LGM, superfluous expansion of *nivara* outnumbered *rufipogon* that probably enhanced the opportunity of harvest.

Hence, the origin of upland rice should not be treated as an event in isolation; but it could make much sense if this can be conceived as a kind of human-landscape interaction. The interaction was not essentially limited to one specific crop but included a range of other co-occurring plants, i.e., the Neolithic package which foragers used to rely on as wild or semi-domesticates, especially during LGM and the Holocene when they were already living on low-level food production (Smith 2001). Some authors prefer to use the term 'domestication of landscapes' instead of domestication of a single crop (Terrell et al. 2003; Erickson 2006). It also invokes support from pre-history that is not depauperate of records of landscape effects on human cultural activities, e.g., in the Andean Highlands, where humans have tamed the extremely hostile landscape radically in order to suit their needs of food (Erickson 1992, 2006). Moreover, drawing on other accounts of landscape management revealed a perpetuating legacy of human-plant interaction mediated through landscape elements, and agriculture is sometimes acknowledged as an outgrowth of much broader entanglement between plant and the people (Harris 1989; Ellis et al. 2013; Erickson 2006).

Thus, amalgamating the insights from the nature of slash and burn cultivation and landscape management, the emergence of upland rice seems to unfold. We may consider it as one of the outcomes of upland cultivation along the hill slopes pertaining to a broader plant-people-landscape continuum, an exercise that prehistoric inhabitants had initiated prior to systematic agriculture. The rise of rice into prominence most probably was a result of preferential selection as a primary cereal that happened later driven by various other demographic, cultural, and socio-economic factors.

Conclusion

Although the current state of knowledge has provided useful insights, the recreation of history of upland rice agriculture appeared far from being complete. We have obtained insights from genetics, paleo-distribution, and the cultural attributes of the original inhabitants, a paucity of archeological records greatly constrained the interpretation.

Genetics and anthropology altogether seemed quite compelling to render the claim of independent origin of *aus* stronger. In light of which we propose that upland cultivation in the south-east Indian highlands emerged as an adaptive reciprocation, in a much larger context of plant-people-landscape interaction. Wherein, the ancestors of rice were cultivated along the hill slopes as the Neolithic proto-agricultural package for subsistence, equivalent to low-level food production. However, it must be admitted that the trajectory of upland rice is an extremely complex process; it has been entangled with spatio-temporal elements of human bio-cultural evolution, demographic and multiple socio-economic factors; and calls on for further interdisciplinary research to assemble all the fragmentary pieces.

Additional File

The additional file for this article can be found as follows:

- **Materials and Methods.** Ecological niche modeling. https://doi.org/10.5334/aa.146.s1

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Competing Interests

The authors have no competing interests to declare.

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