Title: Diversification and cultural construction of a crop: the case of glutinous rice and waxy cereals in the food cultures of eastern Asia.

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Diversification and cultural construction of a crop: the case of glutinous rice and waxy cereals in the food cultures of eastern Asia.

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Abstract
While rice is one of the world's most important and productive staple foods, it is highly diversified in uses and varieties, including East and Southeast Asian sticky (or glutinous) forms. While stickiness to some degree can be achieved by cooking methods, true sticky (or waxy) rice is the result of a genetic mutation that causes a loss of amylose starch in favour of high amylopectin content. These mutations are unknown in wild populations but have become important only amongst cultivars in East and Southeast Asia, but not in other rice growing regions, such as South Asia or West Africa. In addition, other cereals (mainly millets, but also maize, barley and in recent times wheat) have evolved parallel mutations that confer stickiness when cooked and high amylopectin content within the same region of East Asia. The parallel evolution of this trait in a geographically circumscribed region points to a strong role for cultural history and food preparation traditions in the genetic selection and breeding of Asian cereal varieties. The importance of sticky rice in various ritual foods and alcoholic beverage production in East and Southeast Asia also points to the entanglement of crop varieties and culturally inherited food traditions and ritual symbolism.

Introduction

Rice has been a central food staple of Asian civilizations. The agricultural landscapes from much of Asia are characterized by rice cultivation, from lowlands gridded by embanked paddy fields to hill slopes carved into terraces. Today rice is consumed not just amongst urban and lowland populations in areas where rice productivity is high, but it is also a symbolically important and sought after food in tropical hill-forest regions where rice productivity itself is quite low (see discussion in Hayden 2011; Barton 2012). James Scott (2009) has characterized the political and economic history of southeastern Asia over the past thousand years as a cyclical process of state expansion through the control and taxation of productive lowland rice farming, and the marginalisation or active flight of shifting cultivators in the hills to evade state controls. On a longer time scale, some archaeologists and historical linguists argue that rice agriculture provided the motor of demographic growth which drove the expansion of grain agriculture and the migration of farmers from the Yangtze basin southwards to Southeast Asia (e.g. Bellwood 2011; Sagart 2011; see also, Castillo and Fuller 2010; Fuller 2011). However, rice has not remained static, but has undergone diversification such as local adaptations to varied ecologies, cultural practices and food repertoires. Narratives on the origin and spread of rice and models of rice production in more recent highland-lowland dynamics, have tended to overlook the diversification of rice varieties and their role in both promoting and reinforcing cultural variation in rice consumption and understandings of rice. The aim of the present essay is to review the great diversity of rice crops in relation to cultural preferences and tradition. We focus on the sticky and semi-sticky rices. These rices are key components in a family of related culinary traditions with deep cultural roots connected to an awareness of the relationship between ingestion and human bodily substance as well as links to ancestors. Within the sticky rice zone we also explore the selection of this textural trait paralleled in millets and other crops. This commonality indicates that cultural food preferences have had a strong hand in selecting for genetic change in crop diversification.

Past research on rice diversification and rice in cultural traditions

Much past scholarship on the origins of rice has focused on the simple binary division into *indica* and *japonica* subspecies. As was long postulated by Chang (2000), it is plausible that shortly after rice domestication the crop underwent divergence into two subspecies types, *indica* and *japonica*. Indeed, older

Chinese archaeological work often concluded that early rice finds included intermediate populations or a mixture of *indica* and *japonica* types. However, a critical review of the evidence argues against the existence of such a division in the early rice cultivated in China, due both to problematic reliance on grain morphometrics and the genetic evidence for significant differences between *indica* and *japonica* rices, especially the maternal ancestors of the chloroplast genome (Fuller et al. 2008; 2010; He et al. 2011). At the same time an archaeological case could be made for a separate trajectory to rice cultivation in India (Fuller 2006). While this has been complicated by evidence that fully-domesticated *indica* rice required hybridisation between wild-type proto-*indica* ancestors and *japonica* cultivars (Fuller et al. 2010; cf Molina et al. 2011), it remains the case that at least two distinct rice growing traditions can be traced, which differed also in terms of cultivation ecology: wet in early China and initially dry in India (Fuller et al. 2011). The spread of rice from China to Southeast Asia appears to have involved a separate development of dry rice cultivation (Castillo 2011; Castillo and Fuller 2010). Post-domestication scholarship has tended to focus on the dispersal of rice, often associated with postulated farmer migrations (e.g. Glover and Higham 1996; Bellwood 2011), but with little consideration of the diversification of rice, either in terms of the varied ecologies in South and Southeast Asia, or in terms of rice varieties and their culinary character.

At the same time, much ethnographic interest in rice has focused on its symbolism and ritual importance (e.g. Hamilton 2003a). But the variation in rice types and the extent to which these varieties have symbolic significance has not been properly explored. This is illustrated with the Yao (Hmong) people of northern Thailand, whose cosmology and ritual connections of rice are well-described by Hubert (1997), but that ritual dishes are normally glutinous rice must be inferred from descriptions of ritual foods amongst southern Chinese Yao (Sakamoto 1996), and the fact that they are located in the heart of the “glutinous rice zone” (Watabe 1967). It is often claimed that rice is somehow special, always invested with a spirit and ritual significance. This may reflect the banal observation that staple foods tend to take on symbolic salience; wheat and bread in west Eurasia (see Toussaint-Samat 2009), or maize amongst native American cultures (e.g. Ford 1994). Though there is potentially something more significant in terms of a relationship between crop diversification and cultural traditions of belief, ritual practice and cooking of food as an ingested substance. We explore the latter, building on the important ethnobotanical research of Sakamoto (1996), and the hypothesis that deep traditions of food technologies are linked to cosmological understandings of ingestion and bodily substance (Fuller and Rowlands 2011).

An overview of rice diversity

Rice is arguably the world’s most diversified crop: it is cultivated from highly managed and irrigated paddyfields in temperate northeast Asia (approaching 40 degrees of latitude) to metres deep water in tropical river deltas; it is cultivated from sea-level to more than 2000 metres in parts of the Himalayas (in Nepal and Yunnan). Across this ecological and geographical variation rice has a wide range of local ecotypes (Table 1), with various growth season lengths, differences in photoperiodism, and variation in growth habit—from 3 metre culms in deepwater rices to 40 cms. tall dwarf rices. In the present essay, we do not explore the spectrum of rice ecologies (see discussion in Fuller et al. 2011), but instead focus on culinary diversity and the cultural importance of rice largely independent of ecological diversification. Rice is the basis of light flat breads and pancakes in the cuisine of Dravidian south India (e.g. v*elapum* in Kerala, a*kki roti* in Karnataka; mixed rice and pulse flours of *idli* and *dosa* throughout South India), noodles in southern China (Chinese *mi fan*), East Asian sticky flour based balls (Chinese *tangyuan*, Japanese *mochi*), and seaweed wrapped balls of sushi. Rice does not have the colour range found in maize or potatoes though there is still significant variation associated with preferences, from wild-type red in Sri Lanka (Chang 2000) and similarly highly valued, healthy red *raktashāli* rice of early historic northern India (Achaya 1994: 82), to selection for black/dark purple rices in the hills of Southeast Asia, found westwards to Assam (Appa Rao et al. 2006; on the causal mutation: Wang and Shu 2007), and the more widespread light brown and white grains. It may be fragrant or not (Kovach et al. 2009) and with varying degrees of stickiness. The conventional division into just two subspecies does a disservice to the cultural and biological diversity in rice, and to the different pathways of cultural history through which regional variations have evolved.

In approaching the cultural history of rice, it is useful to map some of the broad patterns in domesticated rice variation (Figure 1). The key division is between sticky (or waxy) and non-sticky rice though other divisions run from north to south, from low to high altitude or latitude, and others have regional foci. Grain size and shape is also highly variable but generally shorter grained rices, most often of the temperate *japonica* varieties, occur with higher prevalence to the north, i.e. high latitudes (Kitano et al. 1993) and at high altitudes in the mountains (Nitsuma 1993). In terms of fragrance, there has been less interest in fragrant rice in northeast Asia, whereas fragrant rice (created by various *BADH 2* mutations: Kovach et al. 2009) has more importance towards Southeast Asia, India and westwards to Iran. This is despite the fact that the most common fragrant mutation may have derived initially from a temperate *japonica* rice lineage. Fragrant varieties have long been highly valued in northern India, as indicated by medieval written sources, such as Chinese traveller Xuang Zang who described the royal fragrant *mahāshāli* rice (Achaya 1994: 150), and some earlier sources (Sattar et al. 2010).

A weakness in many of the more simplified models on the history of rice has been an oversimplification of rice diversity into a single story or just an *indica/japonica* story. We would like to remedy this by considering the particular structuring of diversity in rice and other crops via the principle of stickiness.

Sticky rice: recognizing a spectrum

To some extent rice can be made sticky by cooking methods, especially steaming, though genetic traits that increase the amylopectin are key. In the stickiest of rices, a well-known *waxy (wx)* mutation to the *GBSS1* [granule bound starch synthase] or Waxy gene knocks out the production of amylose starches (Yamanaka et al. 2004). But there are as many as 17 other genes that affect starch synthesis and starch gelatinisation on a smaller scale (e.g. Sun et al 2011), as well as other mutations affecting the *Waxy* gene. Thus while the *waxy* mutation is widespread in East and southeast Asian *japonica* rice, the range of sticky textures within this group is wide. While stickier rices are often regarded as more palatable and digestible, and mechanical tests developed in East Asian research (for example, the Toyo taste meter) take this as a given (cf. Sun et al. 2011), sticky rices are not favoured in traditional Indian cooking, either for plain rice or rice flour preparations. Thus mechanical tests of palatability may well be culturally biased. The western-most cultivation of traditional glutinous varieties is associated with Assam (Sharma et al. 1971).

Stickiness in rice shows a spectrum (Chang 2000; Fitzgerald et al. 2011). Typical *indica* varieties are the least sticky with the lowest amylopectin levels, tropical *japonica* also tends to be dry, temperate *japonica* are quite sticky, and true glutinous rices are a mainly *japonica* genetic group that are the most sticky (Table 2). The underlying genetics of this is increasingly understood, with the *wx* mutation apparently restricted to the most sticky "glutinous" rices and derived from primitive *japonica*, with rare introgression into *indica* varieties in Southeast Asia (Yamanaka et al. 2004; Mikami et al. 2008). Additional localised alternative mutations for low amylose continue to be reported, such as one in a Yunnan landrace (Liu et al 2009). This all points towards multiple pathways for this trait after domestication, maintained by cultural selection for this trait within East and Southeast Asia. Rare opaque landraces with low amylose (~10%) from India are also reported, but these are atypical.

Cooking techniques tend to differ between sticky and non-sticky rice, and reinforce genetic cohesiveness or fluffiness. Non-sticky rice is often boiled whereas sticky rice is almost always steamed. It is telling that the 7th century Chinese traveller Xuan Zang commented on the absence of use of steamers in India (Achaya 1994). Ceramic vessel sets for steaming were well-developed and widespread in the Yellow River and Yangtze regions by ca. 5000 BC (Fuller and Rowlands 2011). Today, across Southeast Asia a variety of 'steamed packets' are consumed consisting of steamed sticky rice with different ingredients such as peanuts, sesame, red beans and coconut wrapped in banana leaves (Freeman 2008).

The cuisines of some parts of Southeast Asia (e.g. northern Thailand, Laos) are entirely focused on fully sticky rice and have been defined as the "glutinous rice zone" (Watabe 1967). For many ethnic groups, such as the Htin and Khamu in Thailand, the Lao Sung in Laos and the Ede, Tai, Gai Rai, Gie and Muong in Vietnam to name a few, sticky rice is the staple cereal consumed daily (Nguyen 2001). The Lamet in Vietnam cultivate several types of rice but out of the five most common rice varieties planted, four are glutinous (Izikowitz 2001).

In some cases, such as for the Tai, their preference for sticky rice is considered inextricably linked to ethnic identity together with linguistic heritage, their writing system and land management practices (Golomb 1976; Vi Van An & Crystal 2003). In Thailand for example, a regional division exists between the Thai-Lao of Isan who consider sticky rice and fermented fish as part of their ethnic group identity and the Central Thai who prefer boiled rice and fish sauce (Lefferts 2005). In fact sticky rice is seen as peasant food by the Central Thai (Anderson 1993; Lefferts 2005). On the other hand, in Laos, where no prejudice against sticky rice exists, sticky rice is preferred over non-sticky rice by both urban and rural dwellers (Roder et al. 1996). Thus, Avieli (2005) concludes that 'food is nationalism' as identity is embedded in iconic food whether inherited or constructed.

In other Southeast Asian countries where sticky rice is consumed, it appears to be eaten as a staple only by certain ethnic groups and not in the entire country, but sticky rices remain more widely important as festival foods, in key rituals, for sweet foods and in alcohol production. It has been noted that beyond the glutinous-eating horizon sticky rice seems to be used mostly for sweets and alcohol (Golomb 1976). Thorel in the 19th century observed that sticky rice was better than non-glutinous types for the production of alcohol (Thorel 2001). In fact, in many cases glutinous rice is grown exclusively to make rice wine (Hamilton 2003b), and such wines also feature widely in many Asian festivals and spiritual offerings (Sakamoto 1996; Hamilton 2003b). Rice wines are widespread across the region, such as *chouju* or *huang jiu* in China, *doburoku* or *saki* in Japan, *gamju* in Korea, *ruou* in Vietnam, or Thai *sato*, and often serve as the base for distilled liquors. Made from sticky rice, ancient Chinese *li*, has been used since at least the Eastern Zhou period (770-220 BC) as is noted in the Old Chinese *Book of Odes.* Due to the sweeter nature of amylopectins, waxy cereals are often preferred in the production of alcohol.

Sticky rice has also been used beyond food and drink. In Japan, the straw particularly of sticky rice was traditionally used to weave ropes, mats and shoes, as well as the decorative hangings (*shimekazari*) at the entrance of Shinto shrines (Sakamoto 1996). Glutinous rice straw is apparently softer than non-sticky rice straw. In China, sticky rice flour has been used as an important binding agent. It was used to make a glue for mounting and framing (*biao hu*) traditional paintings on silk. It is also architecturally important, mixed with mineral lime and sand as mortar (*nuo mi sha jiang*) in brick wall construction by at least the 4th century (Yang et al 2010).

Ritual and symbolism of sticky rice

The incorporation of sticky rice in festivals and rituals across Asia transcends the modern religious beliefs of different groups of people. They may be Catholic, Buddhist, Shintoist or Muslim but they all share the use of sticky rice which plays a major role in festivals. In many parts of Southeast and East Asia, rice is associated with fertility and the rice spirit or the Rice Goddess (Hamilton 2003a; Ahuja and Ahuja 2010). The Tai in Vietnam believe that human fertility is linked to rice fertility (Vi Van An & Crystal 2003). Many Southeast Asian festivals are celebrated with sticky rice. A possible explanation for the almost exclusive use of sticky rice in rituals and ceremonies may be the belief that sticky rice rather than non-sticky rice embodies the 'rice spirit' (Nguyen 2001). Many festivals involve or revolve around food and eating. In Vietnam, glutinous rice is made into cakes called *Banh chung* (boiled cake) and *Banh giay* (elastic cake) for the *Tet Nguyen Dan* festival, the Vietnamese Lunar New Year (Hamilton 2003b; Nguyen 2001). These two cakes define the *Tet* event and are served as offerings to ancestors (Nguyen 2001). *Tet Nguyen Dan* like many other *Tet* celebrated by the Vietnamese occurs during a transition period linked to farming seasons (Avieli 2005). Sticky rice for the Vietnamese is important throughout a person's life. At birth a specialty called *xoi* is offered when the newborn is registered. Sticky rice is also present during important events such as graduations, weddings and banquets. And just as in birth, death is celebrated with *xoi* (Nguyen 2001). In Thailand, cakes made from sticky rice are given as offerings to ancestors by the Mien during Chinese New Year and the Lahu demonstrate their unity as a people through communal rice cake-making in preparation of their New Year (Anderson 1993). Rice plays a central role amongst the Akha and many of their ceremonies involve the use of sticky rice (Anderson 1993).

The 'First Plowing Ritual' which takes place in Isan (northeast Thailand) includes sticky rice sweet treats, boiled chicken, loincloths, gold and silver coins made from rice flour that are arranged in seven small banana-leaf cones (Smutkupt and Kitiarsa 2003). In another modern festival in Isan, *Bun Khaaw Jii Yak*, festivities include a lump of sticky rice so large a truck is needed to transport it. The survival of young rice shoots in Isan is celebrated with 'rice packets' called *hoo khaww* containing glutinous rice, fish, meat and fruits traditionally wrapped in banana leaves, but today wrapped in plastic bags (Smutkupt and Kitiarsa 2003). The *jaja* rice cookies of Bali used in rituals are likewise wrapped in banana leaves and boiled though they can also be deep-fried (Brinkgreve 2003). Plantain leaves are also used in some stages of rice liquor preparation in Thailand by wrapping the steamed rice in them together with ginger and spices, letting it sit for a day until the liquor oozes out (Adams 1977).

In the Philippines, many religious festivals and fiestas feature rice cakes made from sticky rice such as *bibingka, suman* and *biko* as part of the festivities (Aguilar 2005). In Japan, *kagami-mochi* or mirror rice cakes made from sticky rice are thought to embody the spirits of rice and are altar offerings given on New Year (Hamilton 2003b). In Bali, special cookies made from glutinous rice called *jaja* take on many shapes, colours and tastes and are given as offerings that range from small to big family rituals (Brinkgreve 2003). The Eastern Javanese continue to cultivate black glutinous rice, *ketan ireng,* for use in purifying rituals even though it is officially prohibited in favour of modern high-yield rices (Heringa 2003).

The *niao gao* is the Chinese cake eaten in the Lunar New Year festival and made of pounded steamed sticky rice sweetened with sugar cane. This cake is found across Southeast Asia brought with the Chinese and called *banh bia*, *tai long et* and *banh to* in Vietnam, *tikoy* in the Philippines and *kue randjang* in Indonesia. This is part of a tradition brought by a distinctive group of people which involves an essential ingredient, sticky rice, but presented in different ways in the new locality. Glutinous rice cakes are widely made across southern Chinese ethnic groups, for example for ritual use by the Yao (Sakamoto 1996). In some regions, food and drink made from sticky millets are used instead of rice, such as amongst Formosan groups in the hills of Taiwan, and traditionally in the mountain areas of Japan (Sakamoto 1996).

Beyond rice: other sticky cereals and correlated food patterns.

Despite the temptation to correlate highest frequency of stickiest rices (the glutinous rice zone) with a region of origin for the waxy rice mutations (e.g. Olsen and Purugganan 2002), this may not be the case. Instead the processes of cultural transmission involved in the dispersal of crops and cooking technology must be taken into account. Just as crop dispersal may lead to genetic bottlenecks and adaptation to new ecologies the spread of a crop variety and food stuff may undergo reinterpretation and gain new emphasis through the cultural selection process. Thus the ‘glutinous rice zone’ may represent cultural re-interpretation and emphasis on a crop variety that became favourably established, but which had previously been a festive food, and one variety amongst many. By considering the wider context of sticky cereals and development of cooking methods, we develop an argument for the origins of sticky cereals further north in China.

The preference for stickiness is not limited to rice but cuts across a whole range of cereals and pseudo-cereals. In reviewing waxy mutations in cereals more than four decades ago, Erikson (1969), noted that “the cultivation of waxy strains not only of maize but of barley and sorghum seems to be confined to the far east to a great extent.” Indeed subsequent research clarifies that millets, broomcorn and foxtail (*Panicum miliaceum* and *Setaria italica*), sorghum, barley, maize, amaranth all have sticky varieties found in what the ethnobotanist Sakamoto (1996) defined as a “glutinous endosperm starch” culture area (Figure 2). It is only in an overlapping region where sticky millets are cultivated, or where sticky maize, barley and sorghum have evolved. Ancient written sources differentiate two kinds of *Setaria* and *Panicum* already in the Shang Dynasty (>1200 BC), with many commentators inferring these to be glutinous and non-glutinous forms (Bray 1984). Genetic evidence suggests two alternative mutations conferring the waxy (low amylose) form on *Panicum miliaceum* (Hunt et al 2010; Araki et al 2011). Foxtail millet, which has been more extensively studied, has at least four distinct waxy mutations, and two low amylose origins (Kawase et al 2005).

The case of maize points towards strong selection exerted by cultural preferences of taste in particular regions. New world crops, such as maize only entered China from the 1550s (Ho 1955), and waxy forms evolved between then and 19th century scientific observations. As reported by Eriksson (1969) spontaneous mutation rates in waxy genes may be somewhat lower than across other parts of the genome. It is also worth noting that the sticky mutant forms have been occasionally reported in twentieth century agricultural studies in the Americas but sticky landrace varieties have never become established or favoured, once again pointing towards the importance of cultural selection in eastern Asia. Nevertheless, waxy forms of grain amaranths, including *A. hypochondriacus, A. cruentus* and *A. caudatus* are widespread in native Neotropical cultivars, suggesting that in this case sticky forms evolved early in their domestication in the new world and were introduced to Asia as sticky varieties (cf. Park et al 2011). Barley was introduced to China from central Asia by perhaps 2000 BC (Flad et al 2010) and sorghum by at least the early centuries AD. Although not yet well constrained archaeologically (cf. Bray 1984), waxy forms are not reported from regions where these crops originated (Near East, Africa) or occurred prior to their arrival in China (Central Asia, India). A single widespread genetic deletion appears responsible for East Asian waxy barley (Ma et al 2010). It can be hypothesized that the adoption of hexaploid breadwheat but not tetraploids like emmer or durum that are important in South Asia and known in west Asia, might yet again reflect a preference for a cereal, in which higher levels of gluten protein (rather than waxy starch) made for more cohesive foods (Fuller and Rowlands 2011).

Thus a collection of crops from many different geographical origins (Africa, Southwest Asia, the Americas) took on stickiness after arriving in eastern Asia, but sticky varieties evolved in this region have not dispersed outwards. This is most striking in the case of the Chinese millets, *Setaria italica* and *Panicum miliaceum*, since it seems likely that sticky varieties existed in North China by the Longshan period (ca. 2500-2000 BC), which is the period with good evidence for the diffusion of these crops westwards towards Central Asia, South Asia and beyond (see Fuller and Boivin 2009; Frachetti et al 2010). This suggests a cultural selection process which filtered out glutinous varieties in the diffusion out of China, but favoured the promotion of sticky mutants in cereals introduced into cultivation in this zone. Some of the sticky varieties have evolved in parallel more than once: as noted above this is the case with rice, but also with foxtail millet, in which four different mutational pathways into sticky forms have been identified (Kawase et al 2005), and in broomcorn millet with two (Hunt et al 2010; Araki et al 2011). In general waxy mutations tend to be recessive, and as such have evolved more easily in species with two sets of chromosomes, i.e. diploid rather than polyploid species (Sakamoto 1996), although *Panicum miliaceum* is a tetraploid requiring mutations in both chromosomes (Hunt et al 2010; Araki et al 2011). It is only in the late 20th century AD, that Chinese and Japanese wheat breeders succeeded in creating waxy forms of hexaploid bread wheat (Nakamura et al 1995), efforts indicative of the continued functioning of the sticky starch food culture area.

What is most striking in the distribution of sticky rices is the lack of a strong ecological barrier: India shares the same monsoon seasonality and tropical to sub-tropical climates as Southeast Asia and southern China, so at first glance it would seem obvious that crops ought to be shared. However, the rice, millets and barley of India differ in the lack of sticky varieties. This suggests that cultural geography trumps ecology: there are related cultural factors that condition the affiliation with sticky rices (both true waxy and more cohesive *japonica*) in East and Southeast Asia. Fuller and Rowlands (2011) have also noted that the sticky cereal zone coincides with the non-milking zone of eastern Asia (Simoons 1970). By contrast there is widespread consumption of fermented fish products, such as fish pastes and pickles, within the sticky cereal zone which has been suggested to particularly characterise Southeast Asian cuisine (Lefferts 2005; Freeman 2008), although similar traditions are found north to the Yellow River, South Korea and Japan. A fermented fish condiment called *hai*, made of fish meat, salt, wine and a mould ferment starter is recorded from the Eastern Zhou period (ca. 500 BC), with plausibly more ancient origins (Huang 2000: 380).

A working hypothesis of pre-agricultural continuities in bodily and ritual substance.

This preference for sticky rice has been suggested to have deeper, late Palaeolithic roots in a persistent east Eurasian cultural zone (Fuller and Rowlands 2011), which is defined by cooking technologies focused on boiling, steaming and cohesive foods, facilitated by the early development of ceramics (in China, Korea, Japan, Siberia), and multi-vessel steaming technologies. It may also be the case that there are commonalities in understanding kinship, ancestors and sacrifice in the sticky rice zone making ethnographic traditions distinct from those of West or South Asia. In particular there is a widespread emphasis on ancestor worship and beliefs that see key foods, such as rice, act to nourish and transmit substance. Food consumption, often of communal side dishes, eaten with one's rice or millet, serves to reinforce commensality and kinship. Methods of cooking with emphasis on boiling and steaming to soften and accentuate cohesiveness provide metaphorical reinforcement. Even fermentation can be regarded as a process that softens while it concentrates the essence (Adams 1977). Chinese rites have long focused on 'feasting to create ancestors' (Nelson 2003), for which offerings of simmered foods and wines together with staples like rice have served to keep ancestral spirits close, and to maintain lineage fertility (e.g. Dawson 1978; Thompson 1988). Archaeological evidence from tombs and associated banqueting vessels imply the persistence of this tradition from the Neolithic, from at least 6000 years ago (Rawson 1980; Nelson 2003). Related traditions can be traced through most of East and Southeast Asia, with grains, often rice in glutinous forms and grain wines, as well as meat used to serve ancestors (e.g. Adams 1977; Hubert 1997). The stickiness of glutinous rice has sometimes been interpreted to symbolise togetherness (Avieli 2005). Sticky-rice cakes eaten in Vietnamese festivals represent social cohesion and unity. Newlyweds in the Philippines are meant to eat sticky rice before walking into the household in order to acquire the quality of stickiness (Aguilar 2005). Hubert (1997) describes Yao cosmology as seeing a netherworld of ancestors covering and sustaining a living world that in turn must provide rice (usually glutinous), meat and alcohol to nourish the ancestors. As already noted, in many of these traditions the rice crop itself is anthropomorphised as a goddess that is central to fertility (Hamilton 2003c; Ahuja and Ahuja 2010).

Beyond these many examples from Southeast Asia, it is striking that Indian traditions are so different. While rice may often serve as a sacrificial offering, it is primarily as a food and produce that is offered to deities, like the Goddes Lakshmi, who can ensure future wealth and fertility of land (Ahuja and Ahuja 2010). There is no sense of maintaining ties to ancestors and assuring fertility of the family line through rice offerings. Concepts of *karma*, reincarnation, ritual purity/pollution, and sacrifices that propitiate distant and sometimes dangerous deities (e.g. Elmore 1913; Khare 1976; Jamison and Witzel 2003), associated with variants of South Asian ritual appear quite different. This is in keeping with the interpretation of East Asia versus South Asia as zones of distinct, ancient food, technology and ritual worlds despite their shared monsoonal environmental conditions (Fuller and Rowlands 2011). In East and Southeast Asia, despite the parallel emphasis on kingroup/lineage unity cohesive foods and food offerings, there remains much overlying cultural diversity. In Chinese tradition the emphasis lies on patrilineage and filial piety (Dawson 1978; Feuchtwang 2009) whereas parts of Southeast Asia emphasise matrilineage and a rice mother goddess.

Integrating archaeobotany, genetics and history in the origins of sticky rice and millets

The origins and early history of sticky rices and millets remain obscure but we can outline here plausible deductions. Until ancient DNA methods have successfully targeted the waxy gene across ancient rices in many times and places, we must rely on other clues, including temperate *japonica* morphotypes, early Chinese written sources, and modern genetic distributions. The earliest written evidence for differentiation in rice comes from Chinese sources dating to the First Century AD, which distinguished between a stickier (*keng*) and non-sticky (*xing*) form of rice (Bray 1984), although these were perhaps equivalent to temperate and tropical *japonica* at that time, especially as *xing* appears to be a loan into early Chinese from a proto-Thai language (Sagart 2011). In all likelihood the process for evolving stickiness in rice began by a shift along the spectrum of amylopectin towards semi-stickiness, which characterises most temperate *japonica* rices. Other traits of these rices are that they tend to have short, plump grains and they are adapted to cultivation under temperate conditions, at higher latitudes with cooler winters and they show strong photoperiodicity (seasonality controlled by day length). The earliest rice of the Yangtze was presumably an undifferentiated ancestral *japonica* closer to tropical japonica (wx^b to wx^{in}). Temperate *japonica* (probably wx^b) can be inferred from the establishment of rice in more northwesterly parts of China, north of the Qinling Mountains, in areas where wild rice and tropical varieties are precluded (such as northern Henan, Shanxi, Shaanxi, eastern Gansu). It so happens that the first rices in these areas are also short-grained, markedly so compared to contemporary Yangtze populations. At the site of Nanjiaokou such rice appeared in small quantities by the end of the Early Yangshao phase (4500-3800 BC), with direct AMS-radiocarbon dates of ca. 3900-3800 BC, with more evidence from the Middle Yangshao (3800-3000 BC) at this site and several other sites in the region (Fuller e al 2010). Further north at Xishanping in Gansu and in the Sushui river of Shanxi rice finds date to the Yangshao period by ca. 3000 BC, and occur beyond the reach of modern rice cultivation, allowed by the somewhat warmer and wetter conditions of that time (Li et al 2007; Song 2011).

Agriculture in this region, however, was dominated by millet cultivation, predominantly by foxtail millet (*Setaria italica*) and secondarily broomcorn (*Panicum miliaceum*). Both of these species have glutinous varieties, and the genetic studies of Kawase et al. (2005) point to this area as one of the regions in which waxy foxtail millet has closely related non-waxy wild populations (haplogroup IV). Both sticky genotypes of broomcorn are common here (Araki et al 2011). However, the fact that different sticky mutations are focused in different regions suggests that the initial dispersal of foxtail millet took place before the evolution or widespread adoption of sticky forms in the millet nuclear region. In other words, it can be inferred that the initial southward dispersal of foxtail millet towards Taiwan in the east, by 3000-2500 BC (Hsieh et al 2011) or to Sichuan and Yunnan in the west, before 3000 BC (Guedes 2011) involved non-sticky *Setaria*. Then, independently, preferences for stickiness favoured the selection of local glutinous millets. While we cannot be sure whether true glutinous rices preceded sticky millets, it seems clear that low amylose forms of temperate *japonica* probably did, and ancient cooking and food traditions of central China (from the Yellow River to the Yangtze) favoured the selection of glutinous mutants when they arose. It seems plausible that semi-sticky temperate *japonica* rice arose in the middle Yellow River region, and that glutinous millets may have followed; in which case true glutinous rice probably evolved during or after the early southwards dispersal of rices from China towards Southeast Asia, 5000 to 4000 years ago. It appears that by the time we get written evidence, even Shang era oracle bones (ca. 1500 BC), glutinous forms of both millets are likely to have been known in northern China (Bray 1984).

The challenge of tracing a food tradition

Rice variation is both a product of, and an important constituent of, the cultural histories of Asia. Reconstructing this history, however, is an interdisciplinary challenge; our essay is a first attempt to sketch some of the problems and potential synthesis of current evidence and inferences, drawing on ethnography, genetics, written sources, historical linguistics, and archaeobotanical evidence. Conventional archaeobotanical methods, focused on carbonized remains that normally occur archaeologically are at present unable to distinguish rice of glutinous varieties, nor fragrant or coloured rices, but ancient DNA holds some promise. The linkages we have proposed with cooking traditions and ritual food offerings may provide additional lines of evidence with artefactual correlates that can enhance our incomplete patchwork history of rice, a crop which has been inseparable from much of the diversity of Asian civilizations.

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Table 1. An summary of Asian rice variation: Subspecies, ecotypes and culinary-cultural varieties of *Oryza sativa*

Clade/ taxon	Cultivar group/ ecotype	Geography	Water Conditions	Photoperiod PPD=sensitive *ppd=insensitive*	Comments
Subspecies *Indica*					
***indica* group**	*Aman*	Bengal/ Bangladesh	Deep water. Upland & irrigated, long seasons (Mar-Nov)	PPD, strong	
	Rayada group	Bengal/ Bangladesh. Similar types in Southeast Asia	Floating rices, deepwater	PPD, strong	Early Elongation Ability in intercalary meristems, controlled by one major gene from *rufipogon* (Hattori et al. 2007).
	Cereh / Tjereh	Indonesia	Lowland rainfed	PPD, strong	Usually red pericarp . Note some 'gundil varieties fall here (Oka 1988: 151)
	Typical *Indica* of Southeast Asia, "10th-month rice" of Vietnam	southeast Asian plains	lowland	PPD	Incl. rare Black-pericarp glutinous *indica* (in Laos & Thailand: Prathepha 2007)
	Chinese xian籼稻, some Japanese upland rice	China, Korea, Japan	Upland, shortseason,	*ppd* to weak PPD	Introduction events unknown, likely multiple
	1st cropped rice	Taiwan	Lowland. Sown winter and harvested by summer.	*ppd*	Related to above(?);
***aus* group**	*aus,* dry, short season (Mar-July)	Bengal to Assam, Bangladesh	Lowland, dry	*ppd*	Centre of diversity: Bangladesh
	Boro, irrigated, winter (Oct.-Jan.)	Bengal, Bangladesh	Lowland, dry	*ppd*	
	Deepwater *aus, Ashwina* group	Bangladesh, Bengal, Manipur	Deepwater rice, offseason. Grown in stagnant permanent water.	*ppd*	See Oka 1988: 151
	Champa rice; "fifth-month rice"	Vietnam, Thailand	Lowland, dry, rainfed, short season	*ppd*	introduced to China c. 1100 AD from S. Vietnam (Barker 2011)
	Some upland *indica* types of China, Taiwan, japan.	China, Taiwan, Japan	Dry/upland, shortseason	*ppd*	Heritage from Champa rices (above) (cf. Ishikawa et al. 2002). These are included in traditional Chinese xian籼稻
Subsp. *Japonica*					
Tropical *japonica* group (syn. *javanica*)	Basic "tropical japonica"		*Probably lowland, floodplains, rainfed*	*Originally* PPD ?	*Probably close the original rices of the Lower Yangtze.* Includes glutinous (*wx*) types that evolved secondarily
	bulu (=javanica)	Indonesia, Philippines	Lowland, dry (rainfed)	*ppd*	Awned (*bulu* means "hair")
	gundil (= javanica)	Indonesia	Lowland, dry (rainfed)	*ppd*	Awnless
	nuda	SW China	Dry, lowland or upland	*ppd*	Awnless
	American Long-grain	Mississippi basin	Lowland, irrigated	Mainly *ppd*	Awnless
	African upland	West Africa	Upland, rainfed	Mainly *ppd*	Awenless; distinct from African rice , *Oryza glabberima.*
	Black rice, Lao *khao kam*	Laos, Vietnam, Thailand	Upland rainfed	*ppd* [?]	Black-pericarp glutinous (*wx*)
Temperate *japonica* group (syn. sinica)	Chinese *jing*粳稻	China, Korea, Japan	Lowland, usually irrigated	PPD	Included many glutinous (*wx*) and some non-glutinous (*Wx).*
	Short-grained California rice	California	Lowland, irrigated	PPD	
	Risotto, paella rices	Mediterranean Europe	Lowland, irrigated	Mainly *ppd*	Italian *Arborio* is a glutinous (*wx)* type; Carnaloni is non-sticky (Wx). (cf. Cortois et al. 2011)
	Dian-Chi Lake deepwater rice	Yunnan	deepwater	PPD (?)	Recently extinct (Oka 1988: 217)
Aromatic group [=*frag*]	e.g. Indian *basmati,* Iran *sadri,* Thai jasmine, *hom* rices of Laos	SE Asia, South Asia, Iran	Mostly Lowland, irrigated	PPD or *ppd*	Mainly derived from temperate *japnonica BADH2* mutation group (Kovach et al 2009). Lao fragrant rices include waxy and non-waxy (Appa Rao et al. 2006a)

Table 2. The spectrum of stickiness in rice (after Chang 2000) with inferred genetic & taxonomic correlations (Yamanaka et al 2004; Mikami et al 2008).

Rice type	**Amylose**	**Amylopectin**	**Description**	**Waxy genotypes**
glutinous rice (“var. glutinosa”)	<2%	>98%	Grain opaque when fractured; Highly sticky when cooked, sweeter.	*wx* mutations mostly *japonica,* few *indica*
opaque-grained *indica*	~10%	~90%	Grain opaque when fractured; Cooked: soft, cohesive, aggregated	Wx^{op} rare: India, Nepal, Myanmar
typical *japonica* (temperate *japonica*)	10-15%	90-85%	Cooked: soft, cohesive, aggregated; “mushy if overcooked” (Grist 1975)	Wx^{b} or Wx^{in}
typical *javanica* (tropical *japonica*)	15-22%	65-78%	Tender, slightly cohesive	Wx^{in} (also in some aromatic *indica*)
typical *indica* (also *aus*)	22-30%	<78%	Dry & fluffy; “resistant to overcooking” (Grist 1975)	Wx^{a}
Oryza nivara annual wild rice	~25-30%	~70-75%	as *indica*	Wx^{a}
Oryza rufipogon perennial wild rice	~25-30%	~70-75%	as *indica*	Wx^{a}
O. glaberrima, African rice	~25%	~75%	Dry & fluffy. (Amylose %: Aluko et al. 2004)	Wx^{a}

Figure Captions

Figure 1. Map showing broad geographical divisions in variation in cultivated rices

Figure 2. Map of sticky rice and sticky cereals zones, together with foci of early cultivation of rice and Chinese millets. Dispersal pathways of rice or rice and millets indicated with approximate minimal ages indicated in grey. Inferred dominant starch compositions in early rice populations indicated.

Fuller & Castillo, Glutinous Rice and waxy cereals. Illustrations

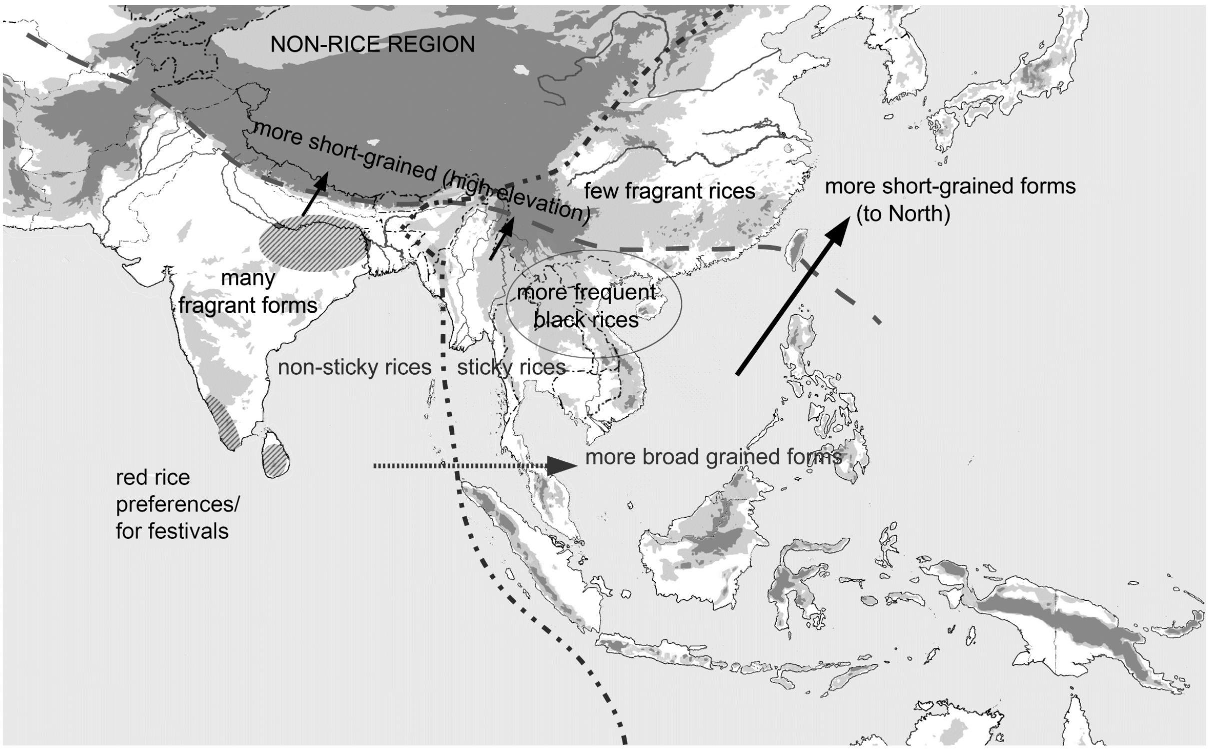
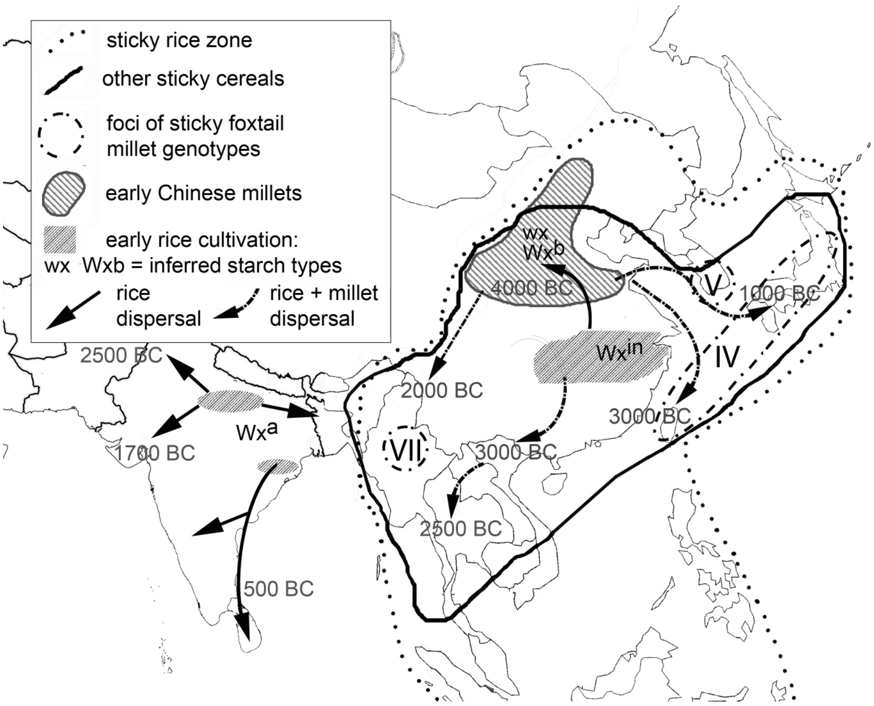


Figure 1. Map showing broad geographical divisions in variation in cultivated rices



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