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Early Agriculture in Sri Lanka: New Archaeobotanical Analyses and Radiocarbon Dates from the Early Historic Sites of Kirinda and Kantharodai

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Abstract

Archaeobotanical evidence from two Early Historic sites in Sri Lanka, Kantharodai and Kirinda, is reported, providing significant evidence for agricultural diversity beyond the cultivation of rice. These data highlight the potential of systematic archaeobotanical sampling for macro-remains in tropical environments to contribute to the understanding of subsistence history in the tropics. Direct AMS radiocarbon dating confirms both the antiquity of crops and refines site chronologies. Both sites have *Oryza sativa* subsp. *indica* rice and evidence of rice crop-processing and millet farming. In addition, phytolith data provide complementary evidence on the nature of early rice cultivation in Sri Lanka. Both Kantharodai and Kirinda possess rice agriculture

and a diverse range of cultivated millets (*Brachiaria ramosa*, *Echinochloa frumentacea*, *Panicum sumatrense*, and *Setaria verticillata*). Pulses of Indian origin were also cultivated, especially *Vigna radiata* and *Macrotyloma uniflorum*. Cotton (*Gossypium* sp.) cultivation is evident from Kirinda. Both sites, but in particular Kirinda, provide evidence for use of the seeds of *Alpinia* sp., in the cardamom/ginger family (Zingiberaceae), a plausible wild spice, while coconuts (*Cocos nucifera*) were also found at Kirinda.

Keywords: Sri Lanka, Rice, Millet, Cotton, Agriculture, Archaeobotany, Phytoliths

1. Introduction

Sri Lanka possesses an archaeological and historical trajectory that, in many ways, diverges from that of the Indian peninsula, despite sharing many environmental and socio-cultural characteristics with the subcontinent (Coningham and Young 2015; Coningham and Strickland 2008, 791; Coningham and Allchin 1995, 152). Sri Lanka has been connected at various points in time and with varying intensity to broader Indian Ocean maritime trade networks, acting as an *entrepôt* for trade with South Asia and Southeast Asia, and interacting with both the Eastern and Mediterranean worlds (Thapar et al. 1996, 92; Fuller et al. 2011; Coningham, Manuel and Davis 2015; Crowther et al. 2016a; Prickett 1990; Prickett-Fernando 1994; 2003; Bopearachchi 1990; 2006; Perera 1952). Archaeological evidence testifies to an increase in maritime trade by the first millennium BC (Prickett-Fernando 1994, 2003; Bopearachchi 1995; 1996; 1998; Morrison 2016, 17; Muthucumarana et al. 2014, 56), as well as the emergence by this date of urban settlements and internal trade networks. To date, little archaeobotanical research has been undertaken in Sri Lanka, preventing a clear understanding of both the ecological context and subsistence strategies in which increasing urbanisation and trade was enmeshed (Kajale 1989; 1990; 2013; Premathilake et al. 1999; Premathilake 2006; Premathilake and Seneviratne 2015; Adikari 2009). To address this gap, this study adopts a multi-proxy environmental approach involving the examination of both the archaeobotanical seed and phytolith assemblages from the recent excavations of two early historic sites, Kirinda and Kantharodai.

1.1. Current Environment

The environment of modern day Sri Lanka is characterised by rainforests in the Wet Zone of the southwest of the island and drier variants in the Dry Zone in the rest of the country (Deraniyagala 1992, ix; Dassanayake and Fosberg 1983). The terrain of the island is low with the exception of the mountains located in the south-central interior; river systems radiate in multiple directions from this region to the coasts. Modern Sri Lanka is under the influence of a monsoonal climate regime modified by the effects of the mountains in the centre of the island (Gilliland et al. 2013, 1013), with the north-east monsoon lasting from October to March, with its regular rains ending in January and the southwest monsoon lasting from April to September with rain ceasing in June (Parker 1981, 347). Rainfall levels can

Figure 1: Map of Sri Lanka with labelled archaeological sites including Kirinda and Kantharodai. The hashed area represents the Wet Zone with the rest of the Island covered by the Dry Zone (Map created using QGIS 2.12.3-Lyon 2015)

show significant intra- and inter-annual variability depending on the relative strength of the monsoon (Bauer and Morrison 2014, 2208; Premathilake and Risberg 2003; Kulatilake 2016).

1.2. Mesolithic and Early Historic Period: Transitions and Trade

Sri Lanka possesses a different and less well understood trajectory to agriculture than that seen in the neighbouring Indian subcontinent. Archaeologists working in the region have documented no parallel phase with that of the various Neolithic-Chalcolithic cultures of India (Coningham and Allchin 1995, 153; Morrison 2016, 18). Instead, current understanding suggests that hunting/gathering/fishing economies dominated the island until essentially the Late Holocene (Deraniyagala 1992; 2004; Simpson et al. 2008). With no evidence of an intervening Neolithic or Chalcolithic period in Sri Lanka, it would appear that the Stone Age was followed directly by the early Iron Age in the first millennium BC (Deraniyagala 2004; Bandaranayake 1988; Samarathunga 2007, 191). The late Iron Age, which partly overlaps with the Early Historic period, acted as a formative period in Sri Lankan prehistory, with recognizable technologies and institutional structures emerging, including the use of metal, the adoption of new agricultural regimes such as rice and paddy field cultivation, introduction of different varieties of domesticated plants and animals and the appearance of sedentary village settlement, craft production of metal objects, beads and pottery, the construction and

expansion of sophisticated systems of water control and the appearance of increasing social inequality (Seneviratne 1984; Karunaratne 2010; Coningham and Allchin 1995, 153; Coningham and Strickland 2008, 791; Morrison 2016, 14; Samarathunga 2007, 191). In general, this trajectory in Sri Lanka appears broadly similar to that seen in parts of the far south of India, including areas of modern Tamil Nadu, where Mesolithic foraging transitioned directly into Iron Age agriculture, crop production and polity formation (see Fuller 2006, 53-55; Fuller 2008a). Along with the introduction of rice agriculture, a diversity of millets were adopted in the historic period, likely from Southern India, as dry farming, transforming the regional landscapes by the end of the First Millennium BC (Bauer and Morrison 2014, 2209-2210; Morrison et al. 2016; Morrison 2015, 11).

2. Kantharodai

Kantharodai, also known as Kadiramalai, is located in the arid zone of the Tropical thorn forest (also called Thorn Forest) ecozone (or ecozone-F by Deraniyagala (2004, Map 1, Figure 2.8)); similar ecozones exist in the Southern thorn forest, in Chittoor and Salem area of Tamil Nadu (Puri 1960; Asouti and Fuller 2008, 18), and the Thorn woodland of Burma (Richards 1964). The dominant physiognomy is shrub, normally comprised of stunted, twisted and gnarled trees with some ground flora. The arid zone temperatures range between 32-36 degrees Celsius. The annual rainfall in this region averages around 1000 mm (Deraniyagala 2004, 2) and the altitude is less than 300 metres (Perera 1975, 192).

Kantharodai is possibly the best-known archaeological site on the Jaffna peninsula (Deraniyagala 2004; 1992, x-xi; Ragupathy 1987; 2006, 57, 169), and was the first site the Archaeology Department in Sri Lanka excavated. In 1917, Sir Paul E. Pieris undertook a small-scale exploratory, horizontal excavation of the Buddhist monastic complex (Perera 2013, 62; Ragupathy 2006, 57). In 1970, a joint excavation between the University of Pennsylvania and Sri Lankan Archaeological Department returned and dug three test pits now believed to date to the Early Historic period (Ragupathy 2006, 57). A joint team of archaeologists from the Sri Lankan Archaeological Department and the University of Jaffna worked together on the most recent excavations at Kantharodai in 2012. They attempted to address some of the shortcomings from the previous 1970 excavations, including resolving issues of chronology and a lack of post-excavation analyses (Perera 2013, 63-65). The present

94 excavations at Kantharodai place the archaeological material discussed in
95 this paper firmly within the Historic period (Bohingamuwa 2017; Perera
96 2013; Deraniyagala 2004).

97 Kantharodai is an inland site with an adjacent ancient sea port called
98 Jambukolapatthana (Figure 1). Kantharodai was an early religious and agri-
99 cultural settlement situated in the centre of the Jaffna peninsula, and was
100 likely founded in the Proto-historic Early Iron Age and certainly by the be-
101 ginning of the Early Historic Period (*circa* 450-500 BC), coinciding with the
102 emergence in Sri Lanka of urbanization, literacy and long distance trade,
103 as well as the arrival of Buddhism (Coningham and Strickland 2008, 791).
104 Kantharodai, together with Anuradhapura, and Tissamaharamai, is amongst
105 the largest early historic urban and religious centres in Sri Lanka dating from
106 the Early Historic period. The ancient settlement mound is spread over 25
107 hectares, making it the largest early archaeological site on the Jaffna Penin-
108 sula (Coningham and Allchin 1995, 171; Perera 2013, 62; Ragupathy 2006,
109 57, 148, 169; Strickland 2017). Indeed, Kantharodai appears to be the only
110 early urbanised central place in Jaffna, with satellite settlements and *en-*
111 *trepôts* located throughout the Peninsula.

112 Unsurprisingly, given its proximity to the sea, Jaffna actively participated
113 in both early trans-oceanic trade and the regional trade between south India
114 and Sri Lanka, as evidenced, for example, by the presence of foreign trade
115 items such as coins and pottery dating to Indo-Roman times (Ragupathy
116 2006, 61, 151, 169). This maritime trade decreased with the decline of the
117 Roman Empire around the 5th century AD (Ragupathy 2006, 61). The later
118 Arab-Chinese trans-oceanic trade focused upon the port site of Mantai, 100
119 km southwest of Jaffna in the Mannar district of Sri Lanka (Figure 1) (Car-
120 swell 2013; Ragupathy 2006, 61, 174; Kingwell-Banham 2015; Bohingamuwa
121 2017).

122 Recent pollen work on archaeological grave fills of the Early Historic pe-
123 riod (ca. 420 cal BC- cal AD 20) at Galsohon-Kanatta, an Iron Age cemetery
124 in Yapahuwa, north-western Sri Lanka have suggested long-distance trade in
125 plant products, such as perishable flowers (Premathilake and Seneviratne
126 2015). Amongst the reported pollen identifications are temperate conifers
127 (e.g. *Pinus* sp., *Tsuga* sp.) and floating aquatics, waterlilies and lotus (i.e.
128 *Nymphaea* spp., *Nelumbo* cf. *nucifera*). Based on insecure identifications
129 to northern Eurasian (*Nymphaea* cf. *tertagona*) and Mediterranean (*N.* cf.
130 *alba*, *N.* cf. *lotus*) taxa, Premathilake and Seneviratne (2015) have argued
131 that this indicates trade in cut flowers from Early Egypt to Sri Lanka. How-

132 ever, given the likelihood of indigenous South Asian *Nymphaea* spp. and
 133 *Nelumbo*, the claim for maritime trade is probably overstated. Nevertheless,
 134 these aquatic taxa may be indicators of increased anthropogenic water en-
 135 vironments, such as irrigation tanks that would have been associated with
 136 early rice cultivation throughout the dry zone of Sri Lanka.

137 The importance of artificial irrigation for the Jaffna peninsula is clear.
 138 The peninsula possesses no major rivers or lakes and fresh water availability
 139 depends on two months of rainfall from the returning monsoon (Ragupathy
 140 2006, 135). This highlights the need for irrigation channels and water storage
 141 tanks for flooding for rice cultivation. Kantharodai's location has the most
 142 potential for settlement on the peninsula, with its tanks, drainage and paddy
 143 field belt. Thus, its advantageous location possesses the capacity to support
 144 the necessities of a central place in a region like Jaffna (Ragupathy 2006,
 145 169). However, with the movement towards a hydraulic-based agricultural
 146 system, it is likely that Jaffna, with less irrigated land and water resources,
 147 was unable to compete with Anuradhapura (Ragupathy 2006, 184). With the
 148 shift in power to Anuradhapura, based upon the archaeological evidence to
 149 date, it would appear that the settlements in Jaffna during this phase were
 150 impoverished compared to the richer settlements in the Dry Zone to the
 151 south. It is likely that during this phase, Jaffna came under the hegemony
 152 of Anuradhapura and that afterwards the site was abandoned (Ragupathy
 153 2006, 174).

154 *Table 1: Test pit No. 1 and No. 2 stratigraphy based upon radiocarbon dating,*
 155 *ceramic evidence and archaeological strata from Kantharodai. *See Table 9*
 156 *for complete AMS dating information*

	Test Pit 1	Test Pit 2	Phase	*Lab Number
	VIII & IX	VI, VII, VIII	Disturbed Strata	399421
	VIII	IV	ca. 170 BC	
157	VI	V	ca. 200 BC	399420
	VII	III	ca. 350-219 BC	399419
	IV	II	ca. 400 BC	
	II		Sterile	
158	I	I	Miocene Limestone Bedrock	

159 The most recent excavation information from Kantharodai is confined to

160 a brief report by the excavator (Perera 2013:63-65) and site stratigraphic
161 details are still unpublished. Trench KTD1 was excavated to a depth of
162 5.80m from the surface and seven phases have been identified by the excava-
163 tor. These phases include a lowermost phase, mostly comprised of Miocene
164 bedrock (Phase I) and a succeeding sterile layer (Phase II). KTD 2, the sec-
165 ond trench, was excavated to a depth of 6.00m from the surface. Eight phases
166 have been excavated by Perera (Table 1).

167 Bohingamuwa (2017, 89; Table 2.5; Catalogue 7.1.1.1 and 7.1.1.2), argued
168 that the trenches belong to the same chronological period, based on the strik-
169 ing similarities of the material culture recovered from both trenches, and drew
170 on this to construct continuous site phasing for Kantharodai. The majority
171 of the material remains recovered from both trenches were ceramics (11,011
172 ceramic sherds, representing 27 different types of wares), followed by beads.
173 Eighty-eight percent (88%) of the ceramics recovered were local wares. Of
174 the imported ceramics, 99% were Indian wares, including Fine Grey Wares
175 and Red Polished Wares. The small proportion (1%) of imported wares,
176 were largely undiagnostic, though some are suspected to be Southeast Asian.
177 The ceramic assemblage does not contain any diagnostic wares that could
178 be identified as being imports from the Middle East or China. Overall, the
179 ceramic assemblage clearly indicates that Kantharodais external interactions
180 were largely focused on India, though possibly with some limited interac-
181 tions with Southeast Asia (Bohingamuwa 2017). Nearly 84% of the bead
182 assemblage was also local, and the only imported beads were of Indian ori-
183 gin, confirming the above pattern in the ceramic assemblage (Bohingamuwa
184 2017: 396; Catalogue 7; Table C7.1.12.10).

185 3. Kirinda

186 Located in the Dry/Arid Zone (the Eco-zone F in Deraniyagala's classifica-
187 tion (1992; 2004:487), the main features of the southern and south-eastern
188 arid lowlands are the lagoons, marshes and sand dunes. The annual rain-
189 fall in this region averages between 100-1000mm (Wickramatilleke 1963: 31).
190 Kirinda is in the tropical lowland seasonal rain forest ecozone, which is similar
191 to the Tropical dry evergreen forest, along the Carnatic coast from Tenneval-
192 ley to Nellore, in Tamil Nadu, India (Puri 1960; Perera 1975, 192; Asouti
193 and Fuller 2008, 52-57). Evergreen trees are usually more abundant, and so
194 the forest retains its overall evergreen character at all times (Perera 1975,
195 197).

196 Kirinda is a historic coastal site situated in the Hambantota district of the
197 Southern Province, on the southern coast of Sri Lanka (Figure 1). Kirinda
198 sits within the Lower Kirindioya basin. It is located about 10 km southeast
199 of Tissamaharama, the capital of the ancient Ruhuna kingdom, founded in
200 the 3rd century BC according to both historical sources and archaeological
201 remains (Weisshaar et al. 2001, 61). The modern day Kirinda fisheries
202 harbour is located adjacent to the ancient Kirinda Vihara, dating to the 2nd
203 century BC based upon inscriptions.

204 Previous research at Kirinda surveyed and excavated a habitation mound
205 (referred to as KR01) (Bohingamuwa 2017; Somadeva 2006). Previous dat-
206 ing attempts have been problematic with significant reversals in the strati-
207 graphic sequence between the uppermost deposit (dated to 1410-1700AD)
208 and an overlying horizon (dating to 260-30BC). This is one of the reasons that
209 the authors decided to analyze samples from disturbed contexts. However,
210 the majority of dates from the site correspond to the Historic period *circa*
211 550-900AD. Nevertheless, the site has been interpreted as having long-term
212 occupation from 260BC to 1400AD, overlapping with early urban activity
213 across the Lower Kirindioya basin (Somadeva 2006; cf. Bohingamuwa 2017).

214 The renewed study of Kirinda in 2013 was undertaken as part of a col-
215 laborative project between the Central Cultural Fund of Sri Lanka, the Post
216 Graduate Institute of Archaeology of Colombo, and the Universities of Ox-
217 ford, Bristol, Institute of Archaeology, UCL and Ruhuna. In addition to the
218 recovery of samples for archaeobotanical investigation, these excavations were
219 conducted to resolve problems surrounding the dating of the archaeological
220 sequence at Kirinda (see Tables 2 & 3, & S4). Excavations were conducted in
221 two locations, both of which reached culturally sterile beach deposits. The
222 first trench (KR02) was excavated as four adjacent 1m quadrants at the edge
223 of modern beach deposits. A shallow sequence of occupation horizons in-
224 cluding minor cut and fill activity was identified and formed eight discrete
225 horizons (Table 2). Phases 1, 3 and 5 were identified as discrete occupation
226 horizons that likely reflect small-scale domestic activity at the site (Table 2).

227

228 *Table 2: Description of stratigraphic phases identified in excavations of Trench*
229 *2, Kirinda (KR02). Note that the number of the phases begins at the low-*
230 *est phase. Additional soil descriptions provided in Supplementary S4. * See*
231 *Table 9 for full AMS radiocarbon dating data.*

	Phase	Description	AMS Lab No*
	Phase 8	Modern topsoil	
	Phase 7	Recent occupation deposits	
	Phase 6	Mixed occupation deposits	
	Phase 5	Occupation horizon	
232	Phase 4	Low intensity occupation deposits, small circular pit present	376484 376483
	Phase 3	Occupation horizon rich in artefacts	
	Phase 2	Lack clear occupation characteristics	376485
233	Phase 1	Oval pit cut including post-hole	

234
235 A second larger trench (KR03) was excavated as a single 4m x 2m trench
236 into habitation mound deposits. Twelve distinct phases of activity were iden-
237 tified in the 2m deep sediment sequence (Table 3). Initial cultural activity at
238 the site was evident in the form of hearth refuse deposits and a collection of
239 small postholes in Phase 1, sealed by a mixed ashy loam in Phase 2, sugges-
240 tive of small-scale habitation. More significant structural activity is evident
241 in Phase 3a, with a linear alignment of large postholes spanning the length
242 of the trench, and likely extending beyond. Phase 3b marks the end of the
243 life of the structure, with large pits cut around the post holes, potentially to
244 aid robbing large posts for use elsewhere. The overlying deposits predomi-
245 nately comprise numerous discrete or mixed dump deposits, with little clear
246 indication of occupation within the bounds of the trench spanning Phases
247 4-12.

248 *Table 3: Description of stratigraphic phases identified in excavations of Trench*
249 *3, Kirinda (KR03). Note that the number of the phases begins at the low-*
250 *est phase. Additional soil descriptions provided in Supplementary S4. *See*
251 *Table 9 for full AMS radiocarbon dating data.*

Phase	Description	AMS Lab code No*
Phase 12	Disturbed topsoil	
Phase 11	Pale grey ashy, silty sands	
Phase 10	Broken ceramics present, potentially a discrete dump	
Phase 9	Mixed occupation dump deposits	
Phase 8	Mottled horizon comprising shell rich dump horizons	
Phase 7	Shell rich dump horizons	
252 Phase 6	Discrete dump horizons	
Phase 5	Thick deposit with sparse charcoal inclusions	
Phase 4	Distinct clayey horizon, potentially stabilise ground surface	
Phase 3a	Linear alignment of large post-holes	
Phase 3b	Robbing post-holes and cutting of large pits	
Phase 2	Ashy mottled silty sands	378859
Phase 1	Initial occupation with small scale structural activity	399418 (S401556 & S402885), 376487

253
254 The overall sequence represented at Kirinda, based upon the radiocarbon
255 dates and limited quantity of Chinese and Middle Eastern ceramic wares as
256 well as datable local wares, appears to date from ca. late 3rd/4th century
257 AD to the early/mid-8th or 9th century AD (Bohingamuwa 2017; 98; Ta-
258 ble 2.6). The material culture recovered from the two trenches at Kirinda
259 is strikingly similar, with assemblages dominated by ceramics, with beads
260 constituting the next most common class of material culture recovered. The

paucity of imported materials highlights the role of Kirinda as a regional fisheries harbour that only occasionally participated in external trade. Of the ceramics recovered from KR3, for example, 93% appear to be local wares while 1.5% are classed as India-Sri Lanka wares, non-diagnostic coarse wares that could have originated from either India or Sri Lanka. Very limited quantities of ceramics from India, South-east Asia, China and the Middle East were identified (Bohingamuwa 2017, 478 and Table 7.2.1.2). The bead assemblage recovered from Kirinda also confirms this pattern. Ninety-three percent (93%) of the 447 beads recovered from KR3 were locally made (Bohingamuwa 2017; 478-488 and Table 7.2.2.11), while only a small quantity of imported beads, produced in India, the Mediterranean and South-east Asia, were recovered. Some or all of these imported artefacts may have arrived in Kirinda via Tissamaharama, the main urban centre in the region (Figure 1) (Bohingamuwa 2017).

4. Materials and Methods

Flotation samples of bulk sediment were collected during excavation at Kirinda and processed near the site by means of washover method bucket flotation (Pearsall 2000, 84). This method has proved reliable over a wide range of field conditions in the tropics (e.g., Fuller et al. 2004; Castillo et al. 2016a,b; Crowther et al. 2016b). Flots were captured in bags with 250 μ mesh, which is sufficiently small to assure good recovery of rice chaff (spikelet bases) and small weed seeds, notably of aquatics such as *Cyperus* or *Typha*. All archaeological stratigraphic layers, i.e. fills, as well as those associated with recognizable cultural features were targeted. At the site of Kirinda, flotation was supervised by Charlene Murphy (CM) and H. Horton; the majority of flotation samples measured 40 litres (Table 4, S2). Heavy fractions were sorted in the field for other categories of archaeological evidence. At the site of Kantharodai, 20 litre archaeobotanical samples were taken and floated by Wijerathne Bohingamuwa (WB) and colleagues (Table 4, S2). All additional environmental remains recovered from heavy fractions, such as artefacts, faunal remains, and snails and other shells were sorted, labeled and catalogued.

All light fraction flotation samples were run through 2, 1 and 0.5 mm geological sieves before sorting. Sorting for Kantharodai was carried out by Patrick Austin, a research assistant at UCL and CM; identifications were made by CM and Dorian Q Fuller (DF). Sorting for Kirinda was carried

out by CM and identifications were made by CM and DF. Dried flots from both sites were sorted in London under a low power binocular microscope for the separation of seeds and wood charcoal, with identification carried out with consultation of the UCL archaeobotanical reference collection, various seed atlases, and reference to previous experience with tropical Asian assemblages (e.g. Fuller 1999; Fuller et al. 2004; Castillo et al. 2016a). Discussion of some key identification criteria is included in the Discussion section. All radiocarbon dates were sent to Beta Analytic, UK and carried out on charred archaeobotanical remains using standard pre-treatment methods (acid/alkaline washes). (Table 9, S1).

Table 4: Kantharodai and Kirinda Flotation and Archaeobotany Summary

	Kantharodai		Kirinda	
	Trench 1	Trench 2	Trench 2	Trench 3
Average Flotation Sample Volume (L)	20	20	40	40
Total Flotation Volume (L)	380	520	1060	2785
No. of Light Fraction Samples	19	26	28	44
Total Volume of Light Fraction Samples (L)	1	3.2	1.5	9.2
Total Count of Archaeobotanical Remains	1614	974	1054	2484
Total Taxa	16	27	5	11

4.1. Phytoliths

Small sediment samples of up to approximately 5 grams of unprocessed soil were collected from each archaeological context at both sites for phytolith analysis. Fourteen phytolith samples in total were analysed. Five samples

from Kirinda and 9 samples from Kantharodai were analysed. Methods of phytolith extraction (removal of organics by loss on ignition in a furnace, removal of carbonates by HCL acid, and heavy liquid flotation with sodium polytungstate) followed established protocols in the UCL Archaeobotany Laboratory. Subsequent systematic analysis of slides by AW recorded at least 300 single cell morphotypes and 100 multi-celled silica skeletons, following, in the first instance, the international code for phytolith nomenclature (Madella et al. 2005) and beyond that utilising the phytolith reference collection at UCL and published references (Metcalf, 1960, Kealhofer and Piperno, 1988, Chen et al., 2013, Weisskopf, 2014, de Albuquerque et al., 2015) (S3).

5. Results

Preserved macrobotanical remains were recovered from both Kantarodai and Kirinda. Many of the seed remains recovered are taxa that have been found across numerous archaeological sites in South Asia and for which there are established identification criteria. The most ubiquitous crop on both sites was rice, including grains and rice spikelet bases; spikelet bases could be classified following the scheme of Fuller et al. (2009). Millets were also recovered, and identified following Fuller (1999; 2006), while pulse identification criteria follow Fuller and Harvey (2006). Cotton (*Gossypium* sp.) could be identified based on testa fragments and funicular caps (Fuller 2008b; Crowther et al. 2016b). Weedy taxa and other wild remains were assigned to the most probable family where known matches in reference material or seed atlases could not be made. Key criteria used for some challenging taxa are summarized here, including millets, *Spermacoce*, and *Alpinia*.

Table 5: List of Specimens Present in Trench 1 from Kantharodai by Phase

Taxa	ix	viii	vii	vi	v	iv	iii	ii	i
Rice		X	X	X	X	X			
Rice Spikelet bases	X	X	X	X	X	X	X		
Zingiberaceae		X			X				
Genus <i>Alpinia</i>									
Cotton	X	X	X						
Pulses	X	X	X						
Millets	X	X	X						
Weed Seeds	X	X	X						

Table 6: List of Specimens Present in Trench 2 from Kantharodai by Phase

Table 7: List of Specimens Present in Trench 2 from Kirinda by Phase

Taxa	vii	vi	v	iv	iii	ii
Rice	X		X	X	X	X
Rice Spikelet bases	X	X	X	X	X	X
Zingiberaceae						
Genus Alpinia		X			X	
Cotton			X		X	
Pulses	X	X	X	X	X	
Millet	X	X	X	X	X	
Weed Seeds	X			X		

Taxa	Tsunami	Post-hole Building Fill	Fill	Upper House	Fill	Lower House	Fill	Oval House	Natural
Rice			X	X	X	X	X	X	
Rice Spikelet bases			X			X		X	
Zingiberaceae	X	X	X	X	X	X	X	X	
Pulses			X	X		X		X	
Millet				X			X		
Portulaca			X	X			X	X	
Coconut				X			X		
Nutshell				X	X		X	X	
Weed Seeds					X	X			
Fruit Mesocarp				X					
Exocarp			X			X			

Table 8: List of Specimens Present in Trench 3 from Kirinda by Phase

Taxa	Phase i	Phase ii	Phase iii
Rice	X	X	X
Rice Spikelet bases	X	X	X
Zingiberaceae			X
Genus Alpinia			
Pulses	X	X	X
Millet	X	X	X
Portulaca	X	X	X
Coconut		X	X
Nutshell	X	X	X
Weed Seeds	X	X	X
Fruit Mesocarp	X		X
Exocarp	X		
Cotton	X	X	X

344

345 5.1. AMS Dates and Chronology

346 Table 9: List of Specimens Radiocarbon Dated from Kirinda and Kan-
347 tharodai. *All radiocarbon dates were sent to Beta Analytic, UK. Standard
348 pre-treatment methods were used (acid/alkaline washes). OxCal. v.4.3.2 and
349 IntCal14 Bayesian sequence model used.

350

351 6. Discussion

352 6.1. Archaeobotanical Assemblages

353 6.1.1. Kantharodai

354 The archaeobotanical assemblage from Kantharodai was composed pri-
355 marily of pulses, millets, rice and rice crop-processing waste (Table 5 & 6).
356 Figure 9 shows that each phase is dominated by rice spikelet bases which

Lab ID*	Sample ID	Site	Material	Delta ¹³ C age (BP)	Radiocarbon (95% confidence)	Calibration Date
378857 & Supplement 376483	KR02-31-5	Kirinda	Charred Rice (<i>Oryza sativa</i>)	-25.50/00	1430±30	AD 575 to 655
376484	KR02-35-4	Kirinda	Charred Rice (<i>Oryza sativa</i>)	-25.50/00	1490±30	AD 540 to 640
376485	KR02-48-6	Kirinda	Charred Rice (<i>Oryza sativa</i>)	-22.30/00	1620±30	AD 385 to 475 AD 485 to 535
399418 Supplements 401556 & 402885	KR03-64	Kirinda	Charred Rice (<i>Oryza sativa</i>)	NA	1420±20	AD 595 to 660
378859	KR03-36	Kirinda	Charred Rice (<i>Oryza sativa</i>)	-25.40/00	1210±30	AD 715 to 745 AD 765 to 890
376487	KR03-41D-1	Kirinda	Charred Rice (<i>Oryza sativa</i>)	-25.60/00	1290±30	AD 660 to 770
399419	KTD02-32	Kantharodia	Charred Kodo millet (<i>Paspalum scrobiculatum</i>)	NA	2140±30	350 to 305 BC 210 to 90 BC 65 to 60 BC
399420	KTD02-37	Kantharodai	Charred Rice (<i>Oryza sativa</i>)	-25.60/00	2220±30	BC 380 to 200
399421	KTD02-15	Kantharodai	Charred Kodo millet (<i>Paspalum scrobiculatum</i>) & Rice (<i>Oryza sativa</i>)	-18.30/00	2080±30	180 to 40 BC 5 BC to AD 0

357 decrease slightly through time. Very low numbers of rice caryopses, millet
358 and pulses were recovered from the rest of the assemblage. There is evidence
359 of *Alpinia* cf. *zerumbet* (Zingiberaceae), as at Kirinda, but in very low num-
360 bers (S2). Rice caryopses comprised a low percentage of the total assemblage,
361 1% of the total assemblage from Trench 1 and 4% from Trench 2; a typical
362 pattern seen with rice crop-processing at archaeological sites (S2). This do-
363 mesticated crop assemblage is complimented by the recent faunal analysis
364 which has identified food debris, comprised notably of domestic cattle, pigs,
365 and goats along with fish and wild pig remains suggesting that the inhab-
366 itants were using both domesticated and wild animals in their subsistence
367 strategy (Perera 2013, 62).

368 6.1.2. Kirinda

369 The archaeobotanical assemblage from Trench 2 was dominated by *Alpinia*
370 cf. *zerumbet*, with fruits and nuts representing the next largest category.
371 *Alpinia* cf. *zerumbet* are present in most phases of Trench 2, raising the
372 possibility that it is more than a contaminant from the surface level/2005
373 Tsunami level. Also, as it is charred this would suggest anthropogenic use.
374 Low counts of rice, rice spikelet bases and pulses, millets and other weed
375 seeds were recovered (S2).

376
377 From Trench 3, rice is the largest component of the assemblage recovered.

378 The Zingeribeceae family is also present. Rice and rice spikelet bases, pulses
 379 and millets were recovered in slightly larger numbers, when compared with
 380 Trench 2, along with some cotton fragments (*Gossypium* cf. *arboreum*)(S2,
 381 Table 7). Looking at the results from Trench 3 by phase it is clear that rice
 382 dominated the assemblage in phases i and ii and there was a shift in phase
 383 iii with rice spikelet bases dominating the assemblage. Small amounts of
 384 coconut shell, fruit mesocarp, and vascular tissue were also recovered from
 385 all three phases along with cotton (*Gossypium* sp.) and a few different mil-
 386 lets including *Echinochloa* cf. *frumentacea* (millet) and *Brachiaria ramosa*
 387 (browntop millet) (S2, Table 3).

389 6.2. Millets

390 Small millet grains were recovered in limited quantities from both sites
 391 (4-21% of seeds in selected samples), including a diversity of morphotypes
 392 at Kantharodai (S1). Identifications of millets was done using criteria that
 393 had been developed from a fairly extensive reference collection at UCL and
 394 extensive experience with archaeological millets across South and East Asia
 395 (e.g. Fuller 2003; Fuller et al. 2004; Deng et al. 2015). Representative
 396 specimens are illustrated in Figures 2 and 3. Three of the millets types have
 397 long embryos, i.e. with embryo length of around 60% grain length or more,
 398 as characteristic of *Brachiaria*, *Echinochloa* and *Setaria*.

Figure 2: A. *Echinochloa* cf. *frumentacea*, from KTD Pit 2 Flot 37; B. *Paspalum* sp., from KTD Pit 2 Flot 32; C. *Brachiaria ramosa*, from KR03, Flot 44l D. *Panicum sumatrense*, two adhering grains, from KTD Pit 1, Flot 50; E. *Setaria* cf. *verticillata*, from KTD Pit 1 Flot 10 (Drawn by DQF).

399 Among these, *Echinochloa* (Figures 3A and 4E) is recognizable by hav-
 400 ing its maximum breadth displaced towards the embryo end while tapering
 401 towards its apex. Other millets have their maximum breadth towards the
 402 middle of the grain. *Echinochloa* also has a hilum that is wider than it is long

Figure 3: Millets recovered from Kirinda and Kantharodai a. *Paspalum* sp., b. *Setaria* cf. *verticillata* c. *Panicum sumatrense* d. *Brachiaria ramosa* e. *Echinochloa* cf. *frumentacea* f. *Digitaria* sp., Carbonised Cotton (*Gossypium*) from trench 3 from Kirinda g. KR03-41 h. KR03-33 i. KR03-15, j. & k. SEM image of Coconut shell fragment from Kirinda.

403 (hL/wW < 1). While it not strictly possible to distinguish *Echinochloa* to
 404 species, domesticated taxa (*E. utilis*, *E. frumentacea*) are closer to round (the
 405 L/W ratio in modern *E. frumentacea* averages 1.07), while wild taxa, such as
 406 *E. colonum* averages more than 1.2. This specimen, of *Echinochloa*, is most
 407 likely to be cultivated sawa millet of Indian origin (De Wet et al. 1983a),
 408 and is therefore assigned to *Echinochloa* cf. *frumentacea*. The prehistory of
 409 this crop is poorly known, although there is some evidence that it was cul-
 410 tivated in parts of the Harappan world as suggested by recent finds (Bates
 411 et al. 2016). *Echinochloa* recovered from South Indian Neolithic (Fuller et
 412 al. 2004) suggest it was an occasional crop from ca. 1500 BC onwards in
 413 southern India, and it is known from Iron Age/Early Historic contexts in
 414 Tamil Nadu (Cooke et al. 2005), from whence it likely came to Sri Lanka as
 415 reported here.

416 The other large long embryo millet is *Brachiaria ramosa*, which is similar
 417 in general to *Setaria italica*, but is generally more dorso-ventrally compressed
 418 (L/T around 0.5), with a somewhat larger hilum (hL/L averages 0.25 com-
 419 pared 0.2 in modern *S. italica*). *Brachiaria ramosa* was the staple millet of
 420 South India throughout the Neolithic (Fuller et al. 2004; Kingwell-Banham
 421 and Fuller 2014), and remained an important crop into the Early Historic
 422 era as indicated by evidence from Paithan in Maharashtra (Fuller, n.d.) and
 423 sites in Tamil Nadu (Cooke et al. 2005). In the Southern Neolithic, *Se-*
 424 *taria verticillata* was a recurrent companion species to *Brachiaria ramosa*,
 425 interpreted as a grain crop (Fuller et al. 2004), and thus the identification
 426 of a small *Setaria* cf. *verticillata* type from Kantharodai is perhaps to be

427 expected.

428 A shorter embryo millet is represented by *Panicum sumatrense*, with an
429 embryo length/length ratio of just under 0.5., which also has a characteristic
430 acute apex. This Indian little millet was an occasional crop in South India
431 during the Neolithic and Iron Age to Early Historic periods (see Cooke and
432 Fuller 2015), but was a much more prominent crop in Gujarat and elsewhere
433 in the Harappan world of northwestern India (Weber and Kashyap 2016;
434 Pokharia et al. 2014).

435 Much shorter embryo ratios are found in a few grasses, including the
436 rather round *Paspalum* sp. and the small, elongate *Digitaria* sp.. *Digi-*
437 *taria* spp. are widespread weeds, both of rice and millet cultivation (Chen
438 et al. 2017; Moody 1989). While kodo millet (*Paspalum scrobiculatum*)
439 was an important cultivar in Iron Age and Early Historic southern India
440 (Cooke and Fuller 2015). Domesticated kodo millet tends to have much
441 more circular (L/W= 1.0) and thicker grains. *Paspalum scrobiculatum* is
442 a widespread weed of rice cultivation (Moody 1989). Rice weed surveys in
443 Sri Lanka have found the closely related *P. commersonii* and *P. conjugatum*
444 are frequently encountered weeds (Chandrasena 1989), and these have
445 more elongated grains than *P. scrobiculatum*, although further comparative
446 work is needed to separate the charred grains of various wild *Paspalum* spp.
447 The only complete specimen recovered is fairly elongate (L/W: 1.5) and has
448 a compressed shape. This suggests that the *Paspalum* recovered here may
449 have been a wild form.

450 6.3. Zingiberaceae: *Alpinia* cf. *zerumbet* type

451 From the archaeobotanical assemblage from Kirinda, quite a few spec-
452 imens of an ovate-conical to slightly trigonous seed were recovered. These
453 have a strong resemblance to taxa in the Zingiberaceae family, and identi-
454 fication as such is favoured not only by overall shape, but by the presence
455 of an interior tubular embryo and an irregularly patterned or rippled surface
456 (Figure 4). Preservation of internal morphology was limited however, as in-
457 teriors were often highly porous in broken specimens, a taphonomic outcome
458 that might be expected with Zingiberaceae as a result of their endosperms
459 essential oil content. Zingiberaceae is a family of flowering plants made up
460 of more than 1,300 species of aromatic perennial herbs, which are divided
461 into approximately 52 genera found throughout tropical Africa, Asia, and
462 the Americas, with particularly high diversity found within tropical Asia.
463 The most diverse group is the tribe Alpinoideae, including the genus *Alpinia*

464 (Kress et al. 2005; Mabberley 2008). This family includes a larger number of
 465 economic species, cultivated and collected for either their seeds (various forms
 466 of cardamom, grains of paradise) and/or their rhizomes (gingers, turmeric,
 467 galangal). Published studies of seed morphology and anatomy are available
 468 (Liao and Wu 2000; Benedict et al. 2015), although none are comprehensive
 469 and no seeds were available as reference material in our collections. Neverthe-
 470 less, general seed shape and surface patterns resemble those illustrated from
 471 *Alpinia*. A few broken specimens preserve what appear to be two parallel
 472 embryo compartments about one third of the distance along the seed length
 473 (Figure 4b). This suggests a forked embryo, regarded as characteristic of the
 474 *Alpinia* ki clade in Benedict et al. (2015), which includes the shell ginger,
 475 *A. zerumbet*, known to be cultivated for its rhizomes in India and Sri Lanka
 476 (Ibrahim 2001). The large quantities of remains of this type in our material
 477 suggests the use of the seed, probably as a cardamom-like spice. Given that
 478 both of our sites lie in the dry zone of Sri Lanka, whereas *Alpinia* can be
 479 expected to grow mainly in the Sri Lanka wet zone, we infer that these were
 480 either traded to these sites as spices or were cultivated.

Figure 4: A. Selected schematic cross-sections on internal anatomy of *Alpinia* spp. and close relatives grouped into the clades (h, p, Ki, etc.) after Benedict et al. (2015) (drawings by DQF). B. Drawings of two examples of charred *Alpinia* seeds from Kirinda, a complete seed at left and a broken seed, at right, showing the cavities from split embryo like that in the ki clade (drawings by DQF). C. Carbonised *Alpinia* seeds from Kirinda D. SEM of carbonised *Alpinia* seed from Kirinda.

481 6.4. Weeds

482 Mericarp fruit segments, which appear to be from a Rubiaceae, *Sperma-*
 483 *cocce* (syn. *Borreria*), were identified in the Sri Lankan assemblages. These

Figure 5: Drawing of *Spermacoce* cf. *hispida* from Kirinda, Trench 3 (Drawings by DQF)

are semi-conical in shape with a round ridge or tongue running down the middle of the flat side (Figure 5). *Spermacoce* is a genus of many weeds found in arable fields throughout the tropics (Sivarajan et al. 1987). Amongst original species in the Old World are taxa that have apparently been human dispersed from Africa to Asia and from Asia to Africa (Fuller and Boivin 2009). The Sri Lankan material here has a pitted surface, which on closer inspection has a finely reticulate testae pattern, with five-sided, fairly equilateral, and straight (not sinuous), cell walls. The seed (mericarp) has a broadly ellipsoid shape. Based on a comparative study of ten species (Chaw and Sivarajan 1989), we found similarity with *S. alata* (usually considered as South American in origin), although now widespread in Sri Lankan rice (Moody 1989; Chandrasena 1989), and *S. hispida*, regarded as native to South Asia (Fuller and Boivin 2009), and frequent on rice field bunds in Sri Lanka (Chandrasena 1989). Its native habitat is sandy soils, and it is common in coastal regions (Panda 1996; Sivarajan et al. 1987); thus it could be native to the region around Kirinda, growing around rice fields or in millet fields. Previously, a *Spermacoce* sp. has been found in South Indian Neolithic sites as a probable weed of millets like *B. ramosa* (Fuller 1999), and these finds were also probably *S. hispida* type.

6.5. Coconuts

Fruits and nuts were recovered in relatively small quantities from both sites. Some of these could not be accurately identified. One recognisable taxon was coconut, preserved as fragments of shell (i.e., endocarp of *Cocos nucifera*). The SEM images show that coconut nutshell has a consistent thickness, with indented impressions of fibrous hairs often running through

509 the surface of the shell fragments (Figure 3i & 3j) (Walshaw 2010). Vascular
510 strands are also visible as hollows in the cross section.

511 Aside from the identification of a few coconut shells, there is limited
512 evidence of any sort of wild fruit and/or plant resource used at either Kirinda
513 or Kantharodai. Although quite a few fragments of the category vascular
514 tissue and probable exocarp tissue were recovered, these were not identifiable
515 to species level.

516 Coconut is an important traditional cultivar in Sri Lanka, especially in
517 coastal regions, as it is elsewhere in India and Southeast Asia. Recent genetic
518 research suggests two main groups of coconuts, one associated with the Indian
519 Ocean and one with Island Southeast Asia and the Pacific (Gunn et al. 2011),
520 although most earlier commentators have pointed to a single Malaysian origin
521 (e.g. Burkill 1966; Simoons 1991). Possible wild coconuts are suggested to be
522 found in the Seychelles, Sri Lanka and parts of coastal Southeast Asia, but the
523 early history of cultivation and translocation of these trees remains obscure,
524 although dispersal throughout the Pacific and westwards to mainland Africa
525 and Madagascar has been traced through a combination of linguistic and
526 archaeological evidence (Boivin et al. 2013; Crowther et al. 2016b; Gunn et
527 al. 2011). In South India, Dravidian linguistic reconstructions suggest that
528 coconuts were added to the plant repertoire at the Proto-South Dravidian
529 stage, at around the same time as Citrus fruits, cotton and iron metallurgy,
530 placed broadly in the first millennium BC or later second millennium BC
531 (Fuller 2007).

532 6.6. *Phytoliths from Kirinda and Kanthoradai*

533 Both sites produced phytoliths, Kirinda more than Kanthoradai, despite
534 fewer samples (5) being analysed, probably because despite being in the dry
535 zone, Kirinda is situated in a tropical lowland seasonal rainforest environment
536 where abundant evapotranspiration is to be expected, whereas Kanthoradai,
537 located in the arid zone, has less access to water outside the monsoon which
538 is reflected in both the composition of the samples and the production of
539 fewer phytoliths overall.

540 As can be seen from multivariate correspondence analysis (Figure 6), while
541 along axis 1 the samples from both sites all fall within the same range,
542 the sites separate along axis 2. This is because Kanthoradai has a greater
543 variation in morphotypes and greater variation in the proportions of mor-
544 photypes. The samples containing the millets are separate on the right side
545 of the chart. These samples contain higher proportions of Panicoids but also

546 some rice and phytoliths from hydrophilic plants, suggesting both millet and
547 rice crop-processing waste in the same sample.

548 Although there are bilobate single cells from Panicoids, there were no
549 millet or Panicoid multicells at Kirinda. One sample contained scant *Setaria*
550 type bilobate single cells (1.6%). At Kantharodai, however, five samples
551 contain either *Setaria* type bilobes, millet, Panicoid multicells which fits with
552 the macrobotanical results and the site's location in the arid zone. The
553 majority of phytoliths cannot be identified to species. Taphonomically, millet
554 husk phytoliths are less robust than rice phytoliths, in part because rice takes
555 up copious amounts of silica and the cells used to identify rice husk are hairs
556 (double peaked glumes) which are commonly very strong, while millet husks
557 are identified using long dendritic cells from the lemma and palea which are
558 generally thinner and more fragile. However, this alone does not account for
559 the paucity of millets at Kanthoradai. It would seem that even though rice
560 farming requires considerably more labour than millet, especially in the arid
561 zone where there are few natural water sources, it was considered the more
562 important crop.

563 Despite having different proportions of constituents in the samples overall,
564 as would be expected given the different environmental zones, rice phytoliths
565 are ubiquitous at both sites. At Kirinda, 100% of the samples produced
566 rice husk phytoliths (double peaked glumes or distinctive husk multi cells)
567 and silica bodies from rice leaves. While fewer rice phytoliths were found at
568 Kanthoradai they are still common with husk occurring in 56% of the sam-
569 ples and a higher proportion of phytoliths from leaves (67%) suggesting crop
570 processing was taking place at both sites. There are relatively large propor-
571 tions of phytoliths from hydrophilic plants, for example *Phragmites*, as well
572 as abundant *Cyperaceae*, both leaves and nutlets, at both sites. *Cyperaceae*
573 is a common wetland plant rice weed (Moody 1989). *Cyperaceae* also has
574 numerous economic uses such as weaving mats and basketry and some sub-
575 families include many edible species (Balick 1990; Johnson 1998). There are
576 large proportions at both sites. This would be a little unusual in an arid
577 zone such as Kanthoradai if the rice agricultural system was rainfed so the
578 presence of such high proportions points to irrigated rice. Both leaves and
579 nutlets could be part of the rice crop processing waste. Leaves could also be
580 from discarded woven goods or matting.

581 Rugulose spheroids from *Arecaceae* leaves are present in all samples at
582 Kanthoradai and all except two at Kirinda. Palms are a useful economic
583 plant. They can provide shelter, construction material, thatch, matting, and

584 food and drink. Zingiberaceae type phytoliths are also present at both sites,
 585 as well as possible Marantaceae leaves (Piperno, 2006), as are a very few
 586 folded spheres (found in some Anacardiaceae) and scalloped forms possibly
 587 from Curcubitaceae rind. There are numerous cultivated and wild cucurbits
 588 in South Asia (see e.g. Decker-Walters 1999; Dassanayake and Fosberg 1983).
 589 No banana phytoliths were in evidence at either site.

Figure 6: Correspondence analysis of Kirinda v Kantharodai on 14 samples with 59 variables. Kantharodai (KTD), Kirinda (KR)

Figure 7: Correspondence analysis of Kirinda v Kantharodai for Crop and Wild grasses on 14 samples with 33 variables. Kantharodai (KTD), Kirinda (KR)

590 6.7. Rice

591 Rice spikelet bases were examined and recovered from both sites. The
 592 rice spikelet bases were identified as either wild-type with a smooth scar, or

Figure 8: Frequency of rice spikelet bases from Kirinda and Kantharodai. The image in the top right-hand corner shows rice identifications from Kirinda a. Wild-type carbonised rice spikelet base b. Domesticated carbonised rice spikelet base

domesticated with a deep indentation and jagged, irregular scar based upon the criteria of rice spikelet bases established by Fuller et al. (2009) (Figure 8). Taken together, the presence of rice spikelet bases provides firm evidence of rice crop-processing taking place on site. Based upon recent genetic and morphometric work on South and Southeast Asian rice by Castillo et al. (2016a), a similar methodology was employed on rice grains from the sites of Kirinda and Kantharodai. Using the Length/Width ratio for rice the Sri Lankan sites were compared with the two South Asian sites and three Southeast Asian sites studied by Castillo et al. (2016a) to classify archaeological rice as either more likely to have been *Oryza* subspecies *japonica* or *Oryza* subspecies *indica*. The results are presented below and revealed a mixed population with the majority of rice ratios falling within the greater than 2 category for Kirinda and thus more than half were likely *O. sativa* subspecies *indica*. A similar pattern is seen at the site of Kantharodai [n=3] in which 2 of the rice ratios were greater than 2 and one was less than 2. Thus, two of the rice grains were probably *O. sativa* subspecies *indica* and one was *O. sativa* subspecies *japonica*.

Figure 8 shows that the majority of rice spikelet bases recovered from both sites over 50% at Kirinda and over 75% at Kantharodai were domesticated; these occur alongside a few wild and indeterminate rice spikelet bases. No immature types with protruding vascular strands were found. Wild

Figure 9: Percentage and Ratio of Sensitive versus Fixed phytolith types from Indian and Sri Lankan sites. Mahagara (MGR), Koldihwa (KDH), Gopalpur (GPR), Golbai Sassan (GBSN), Kantharodai (KTD), Kirinda (KR) (Weisskopf et al. 2014)

rice species such as *O. rhizomatis* and *O. rufipogon* are known in Sri Lanka (Vaughan 1990) and weedy varieties or crop-wild hybrids can be expected. Rice grain measurements were taken and analysed following morphometric work on South and Southeast Asian rice by Castillo et al. (2016a). The results suggest a mixed population, with both wild and domesticated rice spikelet bases, with somewhat greater dominance of *O. sativa* subsp. *indica*. It is possibly a mixed population in which some subspecies *indica* were also present, as were found at Early Historic sites in Gujarat and Maharashtra, India (Castillo et al. 2016a). A similar pattern is seen at the site of Kantharodai, with a very small sample size [n=3], in which 2 of the rice ratios were greater than 2 and one was less than 2. Thus, two of the rice grains were probably *O. sativa* subsp. *indica* and one was *O. sativa* subsp. *japonica*. There is no currently available comparable rice morphometric measurements recorded from other Sri Lankan sites. Environmental recovery was undertaken at the Early Historic site of Anuradhapura (Coningham and Gunawardhana 2013, 423) and rice grains and husk were recovered but it pre-dated the methodology employed here for improving the recovery and recognition of rice spikelet bases. There may have also been issues with the recovery of smaller seeds, i.e. millets, at Anuradhapura due to use of a coarse (1mm) mesh size.

Using the sensitive vs. fixed model (Madella et al. 2009, Jenkins et al. 2010, Weisskopf et al. 2015, Fuller et al. 2016) where sensitive represents wet rice agriculture and fixed dry or rainfed arable systems, Kanthorodai and Kirinda were compared to the phytoliths from sites in Uttar Pradesh and Odisha, India analysed by Harvey et al. (2006); Harvey and Fuller (2005). The Indian samples were collected from Koldihwa (Neolithic to Iron Age 1900-500 BC) and Mahagara (Neolithic 1700-1400BC) in the Belan Valley,

Uttar Pradesh and Golbai Sassan and Gopalpur, lowland settlement mounds on the coastal plain of Odisha. The samples analysed here characterise the agricultural economy at the transition from the Neolithic (Chalcolithic) to the Iron Age, 1300–1000BC at Golbai Sassan and 1400–1000BC at Gopalpur (Harvey et al. 2006). The chart shows a sharp contrast between the higher northern sites to those on the coastal plain and further south (Figure 9). The ratios of sensitive to fixed suggest rainfed rice in the higher and drier Belan Valley, while the lowland Odisha sites are clearly irrigated, as is Kanthoradai. Kirinda has a lower ratio. Kirinda is in the far southeast next to the beach so the sandy soils, easily draining, could have an effect. Thus, based upon both the macrobotanical and phytolith data presented in the present paper by ca. 300 BC, raising questions over whether a shift took place at the end of the Iron Age locally, or whether this represents the spread of already established wet rice traditions. The drier reconstructed at Kirinda, further indicates, variability in the degree of intensification of rice production across Sri Lanka over time.

6.8. Cotton

Gossypium arboreum, commonly known as tree cotton, is a woody shrubby plant, native to India and Pakistan. Tree cotton possesses a natural distribution across tropical and subtropical warm regions. However, the current distribution may not represent the primary wild habitat, as feral varieties may have spread and introgressed with early cultivars (Fuller 2008b). Cotton was likely grown in ancient India as a perennial fruit crop, similar to grapes or tree fruits such as dates. Cotton has been documented as a cultivar in the Indus region dating to pre-Harappan times (Fuller and Madella 2001) and had spread to the South Deccan by the Early Iron Age (Fuller 2008b). Old World cotton, which includes tree cotton, is now considered a relic crop, having been replaced by New World cotton (Zohary, Hopf, Weiss 2012). New World cotton is now grown throughout much of India, aside from the eastern part of the country, due to the subcontinent's long rainy season (Fuller 2008b). The other Old World cotton, *G. herbaceum*, originated in Africa and is known to have been grown in northern Sudan from the early centuries AD (Clapham and Rowley-Conwy 2009; Fuller 2015). While this species became important in parts of northern India, it seems less likely to have been present in ancient Sri Lanka. Annual forms of tree cotton probably only became available in Sri Lanka and other parts of the world during Medieval times (from 9th or 10th c. AD), after which annual forms of tree cotton

spread to regions with cold winters like Central Asia and China (Hutchinson 1959); thus we expect that the cotton identified here was a perennial, tree cotton, managed in small groves, or hedges. Management of tree cotton in hedges is described from the rice growing areas of Southeast Asia in the 19th century (Thorel 1873). This was perhaps similar to the cotton found sites in Madagascar and East Africa from the 8th c. AD (Crowther et al. 2016b), which is inferred to be a perennial *G. aboreum* var. *indicum* based on colonial era distributions (Hutchinson and Ghose 1937; Hutchinson 1959).

6.9. Dating

6.9.1. Kantharodai

Settlement at Kantharodai has been dated to the 5th century BC, continuing to at least the 1st century BC, as surmised from excavations conducted in 1970 (Deraniyagala 1992, 730). Previous radiocarbon dates from Kantharodai fall in the range 500-100 BC (Ragupathy 2006, 57). The newest radiocarbon dates (Beta 399421, Beta 399420, and Beta 399419) on rice caryopses from Kantharodai shows a date range of roughly 300 BC to 200 AD; which fits with the historically accepted date and occupation of the site (S1).

6.9.2. Kirinda

We ran six radiocarbon dates on charred rice (*Oryza sativa*) grains from Kirinda, placing the start of trench 2 at c. AD 500 and the start of Trench 3, c. AD 600, both firmly within the Historic period (S1). These results support the bulk of dates previously reported from KR01 (Somadeva 2006).

6.10. Broader Picture

These new Sri Lankan archaeobotanical finds indicate the movements of native South Asian millets as well as rice southward through the subcontinent and into Sri Lanka. Although present in the North and South Deccan in the Iron Age, the native millets move into Tamil Nadu and Sri Lanka by the Early Historic period and are fully adopted along with a few African millets (Cooke, Fuller and Rajan 2005).

Similarly, South Asian native and African pulses are present at an earlier date in the North and South Deccan, move southwards to Tamil Nadu and Sri Lanka by the Early Historic period (Fuller et al. 2004). Few of the Near Eastern crops are present in Tamil Nadu and Sri Lanka until quite a bit later,

711 for example during the Medieval period at the port site of Mantai (Kingwell-
712 Banham 2015). As summer crops (kharif), pulses and millets, are often in-
713 tercropped and formed the core of peninsular Indian and Sri Lankan farmers
714 repertoires and staple foods of the majority of the inhabitants for over 3,000
715 years (Petrie and Bates 2017; Morrison 2015, 13). This form of dry cultiva-
716 tion was likely supported by rainfall and traditional water-harvesting facili-
717 ties such as runoff-fed reservoirs capturing seasonal rains from the monsoon
718 (Morrison 2015, 13-14). Both archaeobotanical assemblages from Kirinda
719 and Kantharodai show close similarities to sites in Southern India (Tamil
720 Nadu) with their consistent presence of rice, millets and pulses which domi-
721 nate the Southern India site assemblages. As in Southern India, hunting and
722 gathering likely co-existed with alternative subsistence strategies including
723 pastoralism, extensive and intensive agricultural practices, fishing and col-
724 lecting of marine resources, and trade on Sri Lanka. Thus, there was likely
725 a complex mosaic of interconnected communities and economic strategies in
726 Sri Lanka during the Early Historic period (Morrison 2016, 18).

727

728 Recent work by Morrison et al. (2016) has argued for a major agricul-
729 tural transition from a predominantly dry-farming agro-pastoral regime in
730 the Southern Neolithic and most of the Iron Age in Southern India to a more
731 complex and diversified productive landscape during the later periods. From
732 the later Iron Age and beginning of the Early Historic period irrigated rice
733 (wet rice or paddy) assumes a greater role and intensive farming in irrigated
734 zones, built in favourable areas (Kingwell-Banham 2015; Krishna and Mor-
735 rison 2009; Morrison et al. 2016; 1996). Bauer and Morrison (2014, 2210)
736 argue that the proliferation of larger reservoirs constructed for the purposes
737 of agricultural intensification in Sri Lanka was most concentrated during
738 the Early Middle Period/Early Historic Period (500-1300 AD) based upon
739 archaeological as well textual references and inscriptional evidence. Bauer
740 and Morrison (2014, 2213) posit that it was during the transition from the
741 Iron Age and Early Historic Period that a shift occurred from a reliance on
742 rainfed agriculture to reservoir irrigation which would have produced radical
743 changes to the landscape (Bauer and Morrison 2014, 2213). As well, Bauer
744 and Morrison (2014, 2213) argue that changes in irrigation infrastructure
745 were accompanied by the adoption of these new cultigens and the cultural
746 values associated with this new cuisine (cf. Fuller and Rowlands 2011).

747 7. Conclusions

748 This study offers new insights into Sri Lankas agrarian and ecological
749 past in the Early Historic period and attempts to situate these results within
750 the wider context of South Asian archaeology. Kantharodai, as one of Sri
751 Lanka's four most important historic sites, appears to have a similar, parallel
752 economic and urbanized development to other early south Indian and Sri
753 Lankan urban centres such as Anuradhapura and Magama at the end of the
754 Protohistoric period (Perera 2013, 53; Ragupathy 2006, 61, 169). During the
755 Early Historic period, Sri Lanka was connected with the wider Indian Ocean
756 with archaeological evidence of regular trade relations with the rest of South
757 Asia, Southeast Asia and the Mediterranean world. The archaeobotanical
758 assemblage recovered from Kirinda and Kantharodai does not demonstrate
759 specific trade organization but does suggest connectivity between Southern
760 India and Sri Lanka as they possess a similar crop package. The phytolith
761 evidence from Kantharodai suggests the presence of both millet and rice
762 crop-processing waste. Whereas Kirinda has evidence of rice and rice crop-
763 processing waste but no evidence of millets. The ratio of sensitive to fixed
764 phytolith morphotypes (as defined by Weisskopf et al. 2015, Weisskopf, 2017)
765 suggests that Kantharodai possessed irrigated rice while Kirinda may have
766 been rainfed. Phytoliths from palms were common at both sites and could
767 include those from coconut, as several charred fragments of coconut shell were
768 recovered from Kirinda from the macrobotanical assemblage. Thus, both
769 Kirinda and Kantharodai conform to our current, if patchy, understanding
770 of Early Historic sites in Sri Lanka and Southern India. The archaeobotanical
771 and phytolith assemblages from both sites, although located at opposite ends
772 of the island, possessed similar signatures which would suggest that irrigated
773 rice agriculture and millets were firmly established at both sites in the Early
774 Historic period. In Southern India and Sri Lanka during the Early Historic
775 period we see a trend towards greater diversification with a wide range of
776 millets and pulses adopted as cultigens along with evidence of rice, both
777 Kirinda and Kantharodai fit within this broader pattern. Thus, there is now
778 empirical environmental data to extend this trend to Sri Lanka for the first
779 time.

⁷⁸⁰ **Conflicts of Interest**

⁷⁸¹ Authors declare no conflicts of interest.

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824

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829 Development Team, QGIS 2.12.3-Lyon 2015. QGIS Geographic Information
830 System. Open Source Geospatial Foundation Project. <http://www.qgis.org/>)

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