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Germination and Taxonomy of the Coconut

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ABSTRACT

The time taken from reaping coconut seednuts to the appearance of the sprout through the husk distinguishes late germinating Niu kafa types from early germinating Niu vai types. Results from previously unrelated germination studies, carried out independently in Jamaica, Sri Lanka, Tanzania and Ivory Coast, show that the common tall varieties in those countries, and also in Benin and Mozambique, are Niu kafa types, whilst in peninsular Malaysia and on the Pacific coast of Panama the common tall varieties are Niu vai types. These findings agree with others based on different aspects of the palm and its ecology.

The relationship between germination and the degree of water absorption, particularly sea water, at the time the ripe fruit falls from the palm may account for the genetic stability of the wild Niu kafa type despite island conditions which would appear to favour genetic drift.

Key words: *Cocos nucifera* L., coconut palm, seed germination, dormancy, taxonomy.

INTRODUCTION

The link between the germination rate of the coconut, *Cocos nucifera* L., and its long distance dissemination by floating was realized and experimentally tested by Edmondson (1941). The possibility that the speed of germination might be a characteristic of taxonomic significance was suspected by Whitehead (1965). These ideas were unified in a comprehensive theory of coconut evolution (Harries, 1978) in which contrasting varietal differences, including germination rates, are related to natural selection, pre-agricultural domestication and introgressive hybridization. The Niu kafa–Niu vai-Introgression method of variety identification, in which the widest possible range of characteristics are examined, is described elsewhere (Harries, 1981). This study, which is intended to show how apparently disparate germination data can be resolved by the theory, also gives an unanticipated insight into the possible reason why, despite its pan-tropical distribution, only a single species, *C. nucifera*, is recognized by taxonomists.

MATERIALS AND METHODS

Four independently organized germination studies carried out in different countries, by different workers, using different coconut varieties and different germination methods are re-examined here. The following details have been taken from the published reports and include all the information that is relevant to the present analysis.

Jamaica (Whitehead, 1965)

The Jamaica Tall (JT) seednuts came from plantations selected for production of commercial planting material and 45947 seednuts were set in 12 regular monthly batches of at least 1000 each. Immediately after reaping the seednuts were sown in beds of coir fibre (dust) with only a small part of the husk exposed to sun and rain. No

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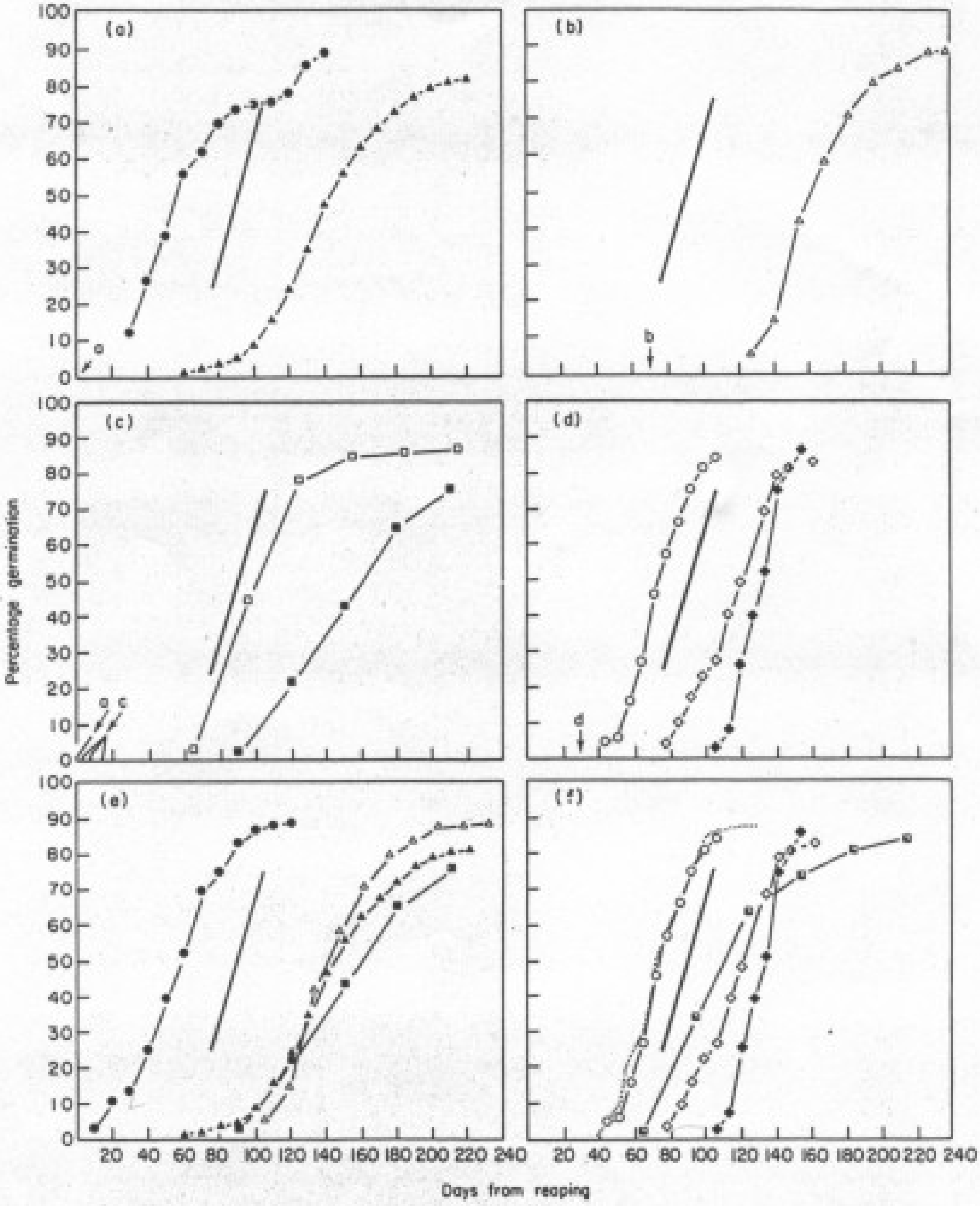

FIG. 1. Coconut germination cumulative frequency ogives. (a) Jamaica, from Whitehead (1965), ●, Panama Tall (PT); ▲, Jamaica Tall (JT); a = reaped and set promptly. (b) Sri Lanka, from de Silva *et al.* (1977), △, Sri Lanka Tall (SLT); b = set after 10 weeks storage. (c) Tanzania, from Thomas (1974), ■, Tanzanian Tall a (TZTa); □, Tanzanian Tall c (TZTc); a = reaped and set promptly, c = set after 2, 7 or 14 days soaking. (d) Ivory Coast, from de Nucé *et al.* (1979), ○, Malayan Tall (MLT); ◆, West African Tall (WAT); ◇, Mozambique Tall (MZT); d = set after 4 weeks storage. (e) PT adjusted for germination on the palm. JT compared to TZTa, without soaking, and SLT adjusted for bunch maturity. (f)... MLTf and MLT are related progenies showing similar germination rates in two different countries. ◪, TZTa:c (mean of all data) compared to WAT and MZT to show effect of partial soaking. In all figures, Niu kafa types to right of diagonal line, Niu vai types to the left.

treatments, such as storage or slicing away part of the husk, were applied before setting and no watering was done afterwards. The Panama Tall (PT)* was similarly set to germinate but, being less common, a total of 246 seednuts only were available in a 13 month period.

Sri Lanka (de Silva and Atputharajah, 1977)

A uniform stand of Sri Lanka Tall (SLT) coconuts at Bandirippuwa Estate, Lunuwila provided 240 seednuts, graded and selected according to size and weight. They were taken from the second bunch, making them approximately a month younger than the most mature bunch, and they were stored for 10 weeks after picking. At the end of this time each seednut was injected in the proximal end of the husk with 100 ml of dilute aqueous nutrient solutions. They were then laid in nursery beds and watered regularly according to requirements (sic).

Tanzania (Thomas, 1974)

The Tanzanian Tall (TZT) was used to study the effects of physical and chemical treatments on coconut germination. There were four replications of eight treatments with 20 seednuts of uniform size and maturity in each plot. The control treatment consisted of sowing in the usual way (sic), the second treatment consisted of chopping about 25 mm of husk from the apical and basal ends of the seednut before sowing and the other six treatments involved soaking seednuts in one of four aqueous solutions for 48 h or in water for 1 or 2 weeks before sowing.

Ivory Coast (de Nucé de Lamothe and Wuidart, 1979)

The West African Tall (WAT) from Ivory Coast and Benin, the Mozambique Tall (MZT) and the Malayan Tall (MLT) seednuts came from palms growing in the IRHO coconut germ plasm collection at Port Bouet, Ivory Coast. The seednuts were harvested at stage 1, when turning brown, and were stored for 1 month before sowing. In a personal communication, de Nucé confirmed that the seednuts each had a slice of husk removed from the proximal end before being set and that they were watered each day by an overhead irrigation sprinkler at a predetermined rate of about 8 mm day^{-1}. He added that the germination data were obtained from one seed bed (i.e. from a single sowing of a large number of seednuts) for each type. He considered the results to be quite significant and similar to those got for the same types in previous years.

RESULTS

The results are presented as cumulative frequency ogives in Fig. 1 (a), (b), (c) and (d). The Jamaica Tall data [Fig. 1 (a)] show normal distribution and the curve is very regular because of the large number of seednuts involved. The Panama Tall [Fig. 1 (a)] germinates more quickly. The diagonal line arbitrarily separating Jamaica Tall from Panama Tall is repeated in each figure and its purpose will be explained in the Variety Recognition section of the Discussion. The letter **a** at the origin of the abscissa indicates that all seednuts were set in the nursery soon after reaping. The actual time between reaping and setting, especially when prolonged by specific treatments, must not be ignored.

The various treatments applied to the Sri Lanka Tall did not produce significant

* The Panama Tall coconut was called San Blas in the 1965 paper because of a misunderstanding about its introduction to Jamaica from the Pacific coast of Panama (Harries, 1980).

differences in the rate of germination and the results are combined [Fig. 1(b)]. The 10 week period of storage after reaping is included in the overall time to germinate and the time to setting in the nursery is indicated by the letter **b** on the abscissa.

For the Tanzanian Tall, the germination rate of the treatment which involved cutting away some of the husk was not significantly different from that of the control and the two sets of data are combined [TZTa in Fig. 1(c)]. The letter **a** again indicates setting soon after reaping. The six treatments that involved soaking gave results that were significantly different from the control but not from one another. The marginal superiority claimed for the two plain water treatments disappears when the actual time for treatment prior to setting in the nursery is added to the time spent in the nursery. The data from the six treatments are combined [TZTc in Fig. 1(c)] and the three different setting times are grouped under the letter **c** on the abscissa.

The data for West African Tall, Mozambique Tall and Malayan Tall [Fig. 1(d)] include the 4 weeks storage period. The time of setting in the nursery is indicated by the letter **d**.

DISCUSSION

Variety recognition

When Whitehead (1965) found that speed of germination was particularly useful (in addition to fruit composition) for distinguishing between the two tall coconut varieties in Jamaica [Fig. 1(a)] he hoped also to demonstrate the taxonomic significance of this characteristic by describing coconuts in other areas. However, germination data for a collection of 1766 seednuts from various Pacific islands were not published separately, as intended (Whitehead, 1966, p. 44), and after a further collection of 1700 seednuts, mainly from Asia he was forced to the conclusion that data from germination studies should be considered in only a very general way (Whitehead, 1968, p. 9).

It was from just such a general consideration that an evolutionary explanation was found for the contrast in many varietal characteristics (Harries, 1978). The main differences are related either to the natural selection of the Niu kafa type or to the pre-agricultural domestication of the Niu vai type. Where cultivation has brought the two types together intermediate forms have arisen by introgressive hybridization (introgression). Present day coconut varieties can be regarded as samples from a discontinuously variable range of forms between the extreme Niu kafa and Niu vai types. The names Niu kafa and Niu vai are taken from two Polynesian varieties, one with long, angular, thick-husked fruit and the other with spherical, thin-husked fruit. Other characteristics besides fruit composition are associated with the two basic types and are used in the Niu kafa–Niu vai–Introgression method of variety identification (Harries, 1981).

Germination is an important characteristic because slow germination is favourable to the wild Niu kafa type which is disseminated long distances by sea currents. Early germination, which would be unsatisfactory in that situation, is desirable for the domestic, cultivated Niu vai type which must compete for seedling establishment with other food crops. For the purpose of distinguishing the two types the diagonal line marked in Fig. 1(a), (b), (c), (d), (e) and (f) arbitrarily separates Niu kafa (on the right) from Niu vai (on the left). A convenient rule-of-thumb may be that coconut varieties which show less than 25 per cent germination in 75 days, 50 per cent in 90 days and 75 per cent in 105 days can be considered as predominantly Niu kafa types whereas higher germination values within the given periods indicates predominantly Niu vai types. Intermediate values are obtained from introgressed varieties, such as Tahiti Tall (Harries, 1981) and

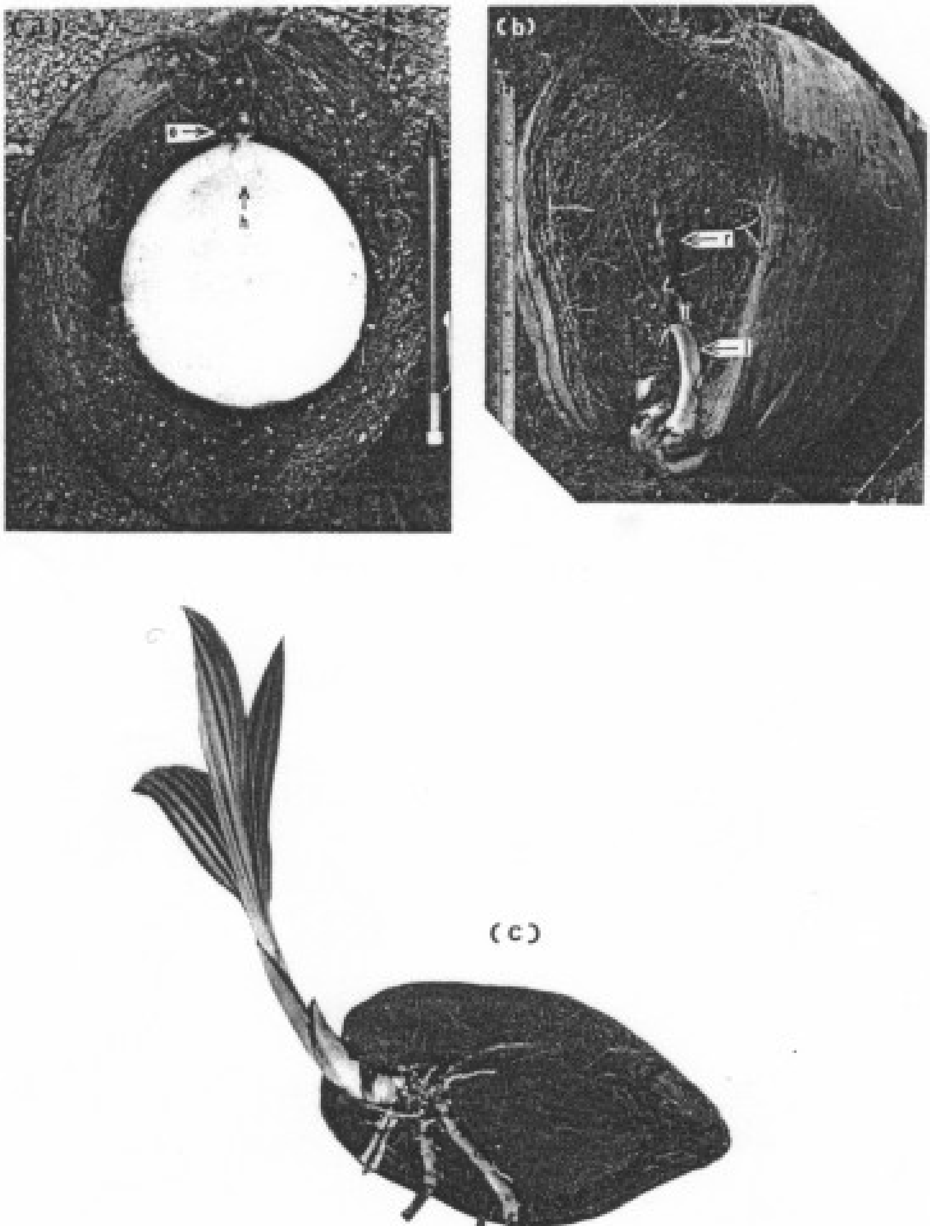

FIG. 2. Germinating coconut seednuts. (a) Niu vai type (vertical half section ×0·3), beginning to germinate when reaped. e, embryo; h, haustorium. Contrast spherical fruit and nut shapes with Fig. 2(c). (b) Niu vai type (seen from above ×0·3), in nursery bed. Husk partly removed to reveal young leaflet (l) adjacent to young root (r) caused by setting upside down after germination had begun. (c) Niu kafa type (side view ×0·2) with husk partly removed. This picture taken 103 days after the unsprouted seednut had been found amongst flotsam on a beach and removed to a nursery. Contrast long fruit and ovoid nut with Fig. 2(a).

also for dwarf varieties (Whitehead, 1965) but, for simplicity, these are not included in the present analysis. Due allowance must be made for different germination methods and, for experimental work at least, a standardized germination method is desirable (see Appendix A).

In Fig. 1 (a) the Jamaica Tall and Panama Tall are seen to be, respectively, Niu kafa and Niu vai types in agreement with previous identification (Harries, 1978). For the Jamaica Tall, total germination might have been greater if the observations had continued longer. This would be a disadvantage in a commercial nursery but is highly desirable for natural dissemination of the wild Niu kafa type. For Panama Tall it is worth commenting that, on p. 370 of Whitehead's 1965 paper a footnote mentions that a small sample of Niu vai coconuts introduced to Jamaica from Wallis Island in the Pacific had a similar germination pattern. In Jamaica and in some Pacific islands early germinating varieties may germinate on the palm if left (Whitehead, 1965, 1966) and the lack of a tail at the bottom of the Panama Tall curve suggests that some seednuts already contained a sprout within the husk at the time of reaping [Fig. 2(a)], resulting in a flush of germination within a month of setting. Indeed, the kink at the top of the curve may also be caused by pre-germination but with the continued growth of the sprout within the husk being delayed by the nut being set upside down in the nursery [see Fig. 2(b)]. If the late germination data are transposed and considered as early germination a typical sigmoid curve is obtained [Fig. 1(e)].

In Fig. 1 (b) the Sri Lanka Tall data have normal distribution but germination seems to be very late. However, the seednuts were immature when reaped. It is often casually assumed that coconut palms flower and their fruit bunches ripen at monthly intervals. According to Fernando (1976), the interval between the opening of successive inflorescences for the common tall in Sri Lanka is 18·3 days (male phase 19·5 + female phase 3·4 − intra spadix overlap 0·9 − inter spadix overlap 3·7). However, not every bunch sets fruit and Fernando also records that 11–17 bunches are reaped annually (giving 33 to 21 days between successive reapings). Since a first (i.e. mature) bunch must be present if a second, consecutive bunch is to be identified and reaped, the shorter period of 21 days may be taken as the difference in maturity. Deducting this amount from the Sri Lanka Tall data produces a curve which is very similar to that of the Jamaica Tall [Fig. 1(e)]. The common tall coconut in Sir Lanka is often called *typica* (viz. Fernando, 1976) but the use of this designation to describe all palms of tall habit was criticized by Whitehead (1965 p. 371) because of germination differences. It is suggested here that the Sri Lanka Tall represents the Niu kafa type. Less common tall varieties in Sri Lanka, such as the *kamandala*, which have thinner-husked, more spherical fruit suggesting introgression of Niu vai germplasm could now be investigated to see if they also show quicker germination.

In Fig. 1 (c) the Tanzanian Tall shows two quite distinct sets of results. The curve TZTa resembles both the Jamaica Tall and the Sri Lanka Tall curves [Fig. 1 (e)]. The Tanzanian Tall may therefore be regarded as a Niu kafa type. The more rapid germination shown in curve TZTc can be attributed entirely to the soaking treatment. A thorough soaking, perhaps to the point of saturation, would appear to encourage a flush of germination whereas coconuts set directly into the nursery must absorb moisture from rain or irrigation before germinating (see Appendix B). Under some conditions a dry husk could act like a dry mulch on the soil and actually prevent light showers and insufficient irrigation from penetrating. Coconuts stored for long periods can easily lose 20–30 per cent of their fresh weight and most of this loss is from the husk, especially in thick-husked varieties. Thus the 100 ml injections into the husks of the Sri Lanka Tall seednuts after 10 weeks storage probably did not replace a sufficient amount of the lost moisture which had then to be absorbed after setting in the nursery.

In Fig. 1(d) the West African Tall and Mozambique Tall data appear to be intermediate between the range exhibited by the two Tanzanian curves. Indeed, if the data from all eight Tanzanian treatments are combined the new TZT curve is similar to those for WAT and MZT [Fig. 1(f)]. These types may also be considered as Niu kafa which agrees with previous identification (Harries, 1981). It is quite clear that the overhead sprinkler irrigation system used in the Port Bouet nursery is fairly efficient in re-wetting the husks of the seednuts that have been stored for 4 weeks. The Malayan Tall curve in Fig. 1(d) resembles the Panama Tall curve so that it can be regarded as a Niu vai type, also in accordance with previous findings (Harries, 1981). The Malayan Tall in the IRHO collection at Port Bouet, Ivory Coast came from selected palms on United Plantations Berhad estate at Teluk Anson, West Malaysia (de Nucé de Lamothe and Wuidart, 1979) and germination data from open pollinated progenies from Fields 8 and 28 of the same estate presented by Whitehead (1968, fig. 5 IV/S) are almost identical (Fig. 1(f), MLT and MLT/f]. Since the conditions under which the two sets of seednuts were collected and germinated were different it might be suggested that the similarity is coincidental. Conversely, and as Whitehead originally hoped to show, germination has a taxonomic significance that can find a general application.

Taxonomic status

Edmondson (1941) demonstrated that coconuts will sprout whilst floating freely on the surface of unagitated sea water. Seednuts which had recently fallen from the palm and which had not been stored or treated in any way were floated on a sea water reservoir and 9 out of 39 (23 per cent) had produced visible shoots, one up to 24 cm long, within 74 days. Controls set on beach sand nearby showed no visible sprouting whilst under observation for nearly 3 months. The floating coconuts absorbed 15–150 ml of water and Edmondson reasoned (p. 303) that because the upper half of the coconut has no contact with the water, evaporation of moisture from the husk may nearly equal the absorption of water by it. He tentatively suggested that germination may be hastened by such contact. In contrast, coconuts floated in the tidal waters of Pearl Harbour, Hawaii showed no visible signs of sprouting for periods of up to 110 days. They germinated normally when removed to a nursery and nine seednuts showed a range of 110–329 days to germinate when the floating and nursery periods are combined. These coconuts, which were exposed to wave action, absorbed more water, (from 300–3000 ml), and it would seem that immersion in sea water does not enhance coconut germination. In a recent coconut floating experiment, Ward and Allen (1980) reported that immersion in sea water does indeed retard germination. Unlike Edmondsons's experiment, their controls germinated in less than 3 months, allowing the tall variety that they used to be identified as a Niu vai type.

It is suggested that Edmondson observed adaptability in three ecological situations which correspond to the natural conditions encountered by coconut seednuts before germination. On the isolated coral atolls, where the coconut probably evolved and where, in some instances, it may still be possible to find the wild Niu kafa type, there are three places only where the ripe fruit may fall. They may drop directly on to the ground, more or less below the crown of the palm and possibly in its shade, where they will remain unless washed away by a higher than usual tide or by a tsunami. They may fall into the restricted and relatively calm waters of the lagoon and float a short distance before reaching another part of the same atoll. Or they may fall into the open and turbulent ocean and float thousands of kilometres before reaching another beach – even a beach where no coconuts have grown before.

The seednuts on the ground below the palm are in a situation equivalent to a nursery. Relying on rainfall, germination will tend to be slow, especially where heavy shade lowers the air temperature. In these circumstances slow germination gives the best chance that a seedling will be available to replace the adult palm if that should be destroyed by lightning strike, pest, disease or just old age at any time within 200 to 300 days, the best part of a year.

Quick germination of the seednuts floating in the lagoon gives these the best chance of becoming established as soon as possible after they have washed up a short distance away. This could well be where previously existing adult palms were recently lost to one of the causes mentioned above or, more particularly, where they have been uprooted by cyclonic windstorms and tsunamis which would also have battered seedlings to destruction and washed away unsprouted nuts.

The coconuts in the open sea are the classic example of dissemination by floating. A distance of about 3000 miles (5000 km), as estimated by Edmondson, would satisfy most of the inter-island distances in either the Pacific or the Indian Oceans. The greatest possible distance, about 8000 km from the Line Islands in mid-Pacific to the coast of Central America, may be disputed (computer simulations [Ward and Allen, 1980] and a free-floating experiment [Harries, unpublished] have been designed to test this possibility). In such an extreme case, slow germination may not answer and dormancy might need to be invoked. With species that do not show dormancy characteristics, Villiers (1975) has suggested that one method of preventing germination would be to keep the seeds imbibed in a non-toxic solution of high osmotic pressure (negative osmotic potential). Perhaps a natural example of this may be the freely floating coconuts with their husks saturated with sea water at an osmotic potential of about −23 bars*. If dormancy is induced it would presumably be broken when the excess salts are leached away, as they would be by rainfall, once the seednuts are washed ashore [Fig. 2(c) and Appendix B].

What are the results of three germination rates? The slow germinating seednuts below existing adult palms ensure the continued presence of coconuts with similar genotypes in the same spot and against competition from other vegetation. The quicker germinating seednuts in the lagoon help to maintain homogeneity between populations on opposite sides of the same atoll that may be beyond the range of cross-pollination. The possible delayed germination of seednuts in the ocean increases the chances of reaching other beaches. However, since chromosome abberations in the embryo cannot reduce floating ability, it might be thought that the few successful arrivals would include an abnormally high number of mutants. In discussing accumulation of genetic damage and loss of viability in dry stored seeds, Villiers (1975), considers that wet storage might be useful where the maintenance of a high degree of genetic stability is required. He cites the viability of fully imbibed, apparently dormant weed seeds in moist soil as one natural example – perhaps coconuts floating in the sea are another.

In conclusion, it is postulated that germination adaptability leads to continuity, homogeneity and genetic stability of coconut populations. Superimposed on these factors is the uniformity of the coral atoll environment, whether in the Pacific or Indian Oceans, which exerts strong selection pressure for all characteristics of the Niu kafa genotype. Despite the small size and the isolation of pioneer coconut communities the effects of random genetic drift will be minimized. This can be substantiated by the remarkably similar phenotypes of coconuts on Palmyra Atoll in the Pacific and Seychelles Islands in the Indian Ocean. These islands, 16000 km apart and uninhabited when first discovered by Europeans, possibly represent the prehistoric extent of natural dissemination. The coconuts which reached them, by floating shorter distances amongst and between the archipelagos of southeast Asia and the Pacific, did so without human assistance – and without speciation.

* The osmotic potential of sea water may be estimated from more easily available statistics. Oceans in the tropics have a salinity value of around 35 parts per thousand and this degree of salinity depresses the freezing point by 1·91 °C. The osmotic potential (π) in bars is proportional to this freezing point depression (ΔT), thus: $\pi = -12.22\ \Delta T$ (Sutcliffe, 1968).

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APPENDIX A

Coconut germination methods

If coconut varieties are to be identified by their germination rates, if treatments to enhance germination are to be tested or if physiological studies are to be made into the process of coconut germination or the early growth of the seedling, then a standardized method of germination will be desirable. It should be similar, possibly identical, to the best available commercial nursery system. From the preceding analysis of germination studies it appears that there are a number of operations of doubtful value. When immature seednuts are used they simply take longer to germinate. If some of the germination period is spent in storage rather than in the nursery it means that a separate, sheltered place must be provided, that seednuts will be handled twice – once into the store and once into the nursery – and it implies that the loss of moisture from the husk will not be detrimental to germination. Early germinating varieties may sprout in storage or may be set upside down in the nursery. The removal of a slice of husk is a time consuming operation which is probably unnecessary in circumstances where there is adequate rainfall or irrigation. It may be positively harmful in dry, unirrigated conditions where it can only increase the moisture loss from the husk. Small amounts of dilute salt solutions show negligible effect whilst large quantities of stronger solutions (e.g. sea water) might even delay germination. Soaking in plain water seems to be the only beneficial treatment (see Appendix B). The difficulty of immersing buoyant coconuts in any watery medium, plus the unpleasantness of handling wet seednuts when setting them in the nursery leads to the conclusion that seednuts should be thoroughly soaked after setting. The following 10-point programme is proposed as a first attempt to standardize germination methods for coconuts.

1. Reap seednuts from the palm in preference to taking those which have fallen to the ground.
2. Reap at frequent, approximately monthly, invervals and take all seednuts from any bunch in which some are beginning to change from the fresh to the dry colour.
3. Set the seednuts in a pre-nursery as soon as possible after reaping, particulary early germinating Niu vai and dwarf types.
4. Choose a site that is in full sun, on well drained, preferably sandy, soil with access for trucks bringing in seednuts and taking out seedlings, and with a reliable source of water for irrigation.
5. Place seednuts close together on the ground, generally on their side on the broadest face or, for very spherical fruited varieties, on their end with calyx uppermost (see Appendix C).
6. A mulch such as moist coir dust, if available, can be used to barely cover the seednuts if irrigation water is likely to be short or rainfall unreliable.
7. Immediately after setting, irrigate by overhead sprinkler to thoroughly wet even the driest husks, and repeat irrigation at frequent intervals to replace moisture lost by evaporation. Water requirements can be readily estimated by weighing individually, samples of seednuts before and after the first soaking and at regular intervals afterwards.
8. As soon as a sprout is observed transfer the seednut into the main nursery, taking care not to damage any roots. The age of the seedling should be calculated from this date. This will facilitate selection of uniform seedlings before final planting in the field.
9. The sprouted seednuts in the main nursery can be grown in beds or in plastic bags depending upon the field planting method.
10. After about 100 days for Niu vai types or 150 days for Niu kafa types or when germination has reached 80–90 per cent any ungerminated nuts can be removed. De-husking will reveal some that have begun to germinate and others that are ungerminated but apparently normal. All of these can be kept for further observation, if experimental, or can be converted to copra, if commercial. Damaged or decaying seednuts should be examined in an effort to identify the cause and then split open and fed to pigs.

APPENDIX B

Soaking seednuts

The beneficial effect of soaking coconut seednuts might be accounted for in terms of water potentials. The liquid inside coconuts of all ages has an osmotic potential of about -7 bar whereas the hydrostatic pressure within the nut cavity ranges from 5 bar in the young fruit, decreasing with age, until fully ripe when there is a gas phase somewhat below atmospheric pressure (Scholander, 1955). If the different hydrostatic pressures are due to higher matric potentials in the young coconuts, as suggested by Sutcliffe (1968), then the matric potential may be greatest in the husk. This forms a proportionately larger part of the young fruit and, with age, becomes gradually cut-off from the water in the nut cavity by the increasing impermeability of the developing shell of the nut.

In a ripe fruit, the water in the nut cavity would tend to migrate to the husk because of the matric potential there. Very long storage could result in the moist endosperm being converted to copra, inside the shell (ball copra). Soaking seednuts with water, after reaping or after storage, would bring the matric potential to zero (and, similarly, the osmotic potential if the seednut had been in sea water). Water could then migrate into the nut, primarily through the 'soft eye' in the proximity of the embryo. Germination processes might be triggered immediately or when the negative osmotic potential of the nut water is raised to zero.

APPENDIX C

Seednut position

The recommendation to set angular seednuts on their broadest face and spherical seednuts on their base goes against advice given in many agricultural texts. Where these give specific directions they generally explain that the sprout, coming from the 'soft eye', will be adjacent to the broadest face and germination will be quickest if this face is uppermost. Seednuts set on end are considered to be at risk of dehydration since the embryo is out of contact with the water in the nut cavity. Experimental evidence does not rule out any position probably because the sprout, with 12 or more months supply of endosperm, can emerge even from an upside-down position. Extreme varietal differences in the rate of germination and in fruit shape may have been overlooked since much of the experimental data come from introgressed varieties in which these characteristics tend to have a fairly broad range of intermediate values.

From a consideration of first principles the original success of the Niu kafa coconut must, in a large part, be due to its natural method of germination in the wild. The chances are greatest that the seednut comes to rest, after falling from the palm, on the broadest face. It certainly floats on the broadest face and this will give it most stability and prevent it from being carried away again once it has washed ashore. Roots will penetrate the ground over the largest possible area beneath the broad face. The ridge of the husk that is uppermost certainly does not delay the sharp pointed sprout very much. In contrast it helps protect it from dehydration, from predators, pests and diseases and it gives strong support to the bases of the first leaves. Not all these factors may be vital in the commercial nursery but both nature and commerce require a simple method and one that gives maximum germination. To set angular seednuts on edge is more time consuming and needs a furrow or trench to stop them rolling over. If a mulch is used there is more chance of air pockets being trapped beneath the seednuts on edge. As has been shown, speed of germination is a varietal characteristic and the very spherical Niu vai type is easily set on its base when the broadest face may not be obvious. If, as suggested in Appendix B, the water in the nut cavity is less important than the water in the husk then an adequate irrigation system, rather than a particular setting position, is likely to be the most important aspect of coconut germination.

ADDENDUM

A possible case of osmotically induced dormancy in coconut was unwittingly reported 60 years ago (Chiovenda, E. (1921) La culla del cocco. Webbia 5, 199-294). Chiovenda stated that four pairs of coconut seednuts were kept in plain water or in 5, 10 or 15% solutions of sulphuric acid for 5 days before sowing. An untreated fifth pair acted as control and all ten seednuts were set in well watered soil and observed for 4 months. Chiovenda described the results (p233) and concluded that immersion in pure water constitutes the best treatment for the acceleration of sprouting, and that acid solutions delay it. Even if other factors are involved, the osmotic potentials of the three acid solutions are consistent with a theory of osmotic inhibition of germination.