The Oil Palm, Fourth Edition
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Chapter 12
Diseases and Pests of the Oil Palm

Until World War II it appears that the oil palm was largely free from serious diseases and pests (Hartley, 1988), but as the area under the crop has expanded, there have been serious, and at times devastating, outbreaks of disease in several parts of the world. Of greatest importance have been the devastation caused by *Fusarium* wilt in several parts of Africa, the considerable losses sustained through dry basal rot (*Ceratocystis*) in Nigeria and associated with *Ganoderma* in old and replanted areas in Asia, and the attacks of fatal yellowing and sudden wither on new plantations in Latin America.

Diagnosis and prevention or cure of some of these diseases have proved difficult. It is not clear in some instances whether a pathogen is involved, or whether the symptoms are a disorder caused by some abiotic factor. The fact that some, perhaps most, diseases only become serious under certain predisposing environmental conditions may further complicate matters. One approach has been to search for resistance to, or tolerance of, the diseases, both within *Elaeis guineensis* material and in interspecific hybrids with *Elaeis oleifera*. Good progress has been made in relation to *Fusarium* wilt with *E. guineensis*, and there is scope for this approach with *Ganoderma*. Hybrids may be tolerant to fatal yellowing, but poor yields limit their value at present.

Attacks by one pest, the leaf miner *Coelaenomenodera lameensis*, have been serious in West Africa, while sporadic defoliation has also been caused by caterpillars and bagworms of various species in Malaysia and Latin America. With the steadily increasing areas under oil palms there has been a general increase, particularly in Asia and America, in the number of pest species recorded; several natural orders are represented, but particularly the Lepidoptera and Coleoptera.

A comprehensive work on diseases was provided by Turner (1981). For pests, Wood (1968a) gave much information of general application on ecology and control, while detailed information on African and American pests is to be found in special issues of the journal *Oléagineux* (Genty *et al.*, 1978; Mariau *et al.*, 1981), and also in Mexzón and Chinchilla (1993). Readers should refer to specialist works if pesticide treatment is recommended. We have not given details here, because new pesticides are constantly being developed and older ones withdrawn.

Descriptions in this chapter must necessarily be condensed, but reference is made to original papers where greater detail can be found. Nutritional disorders are described in Chapter 11 and this chapter will therefore deal with conditions caused by pathogenic organisms, with important disorders of unknown cause, and with insect and other pests causing damage to the palm.

12.1 DISEASES AND DISORDERS

It is convenient to deal with diseases according to the stage of growth at which the palm is attacked and the organs affected. However, there is much overlap and some diseases have been rather arbitrarily listed for a particular stage of growth. For example, *Cercospora* is primarily a nursery disease, but also occurs in young palms in the field. *Ganoderma* may be characteristic of one age in some regions and of a different age in other regions, while other diseases may have different manifestations at different ages. Information on a number of 'minor' diseases is summarised in Table 12.1. Some of these caused serious losses at one particular time and place, but have not been a problem since. Several were observed in the early days of oil palm cultivation, when fertiliser inputs were low or absent, and poor nutrition was probably an important predisposing factor.

Pathologists set much store by Koch's postulates, conditions which must be met before the cause of a disease is considered proven. In particular, the requirements that typical disease symptoms be obtained after inoculation with a supposed pathogen, and that the pathogen then be reisolated from the inoculated plants, have not been met for several oil palm diseases. Even where Koch's postulates are proven, predisposing environmental factors may still be important.

Table 12.1 Minor oil palm diseases: diseases either causing little economic damage, or of rare occurrence

Disease	Symptoms	Cause	Location	Ref.	Comments
Nursery diseases					
Anthracnose	Necrotic lesions, slow growth	Various (see Ref. 1)	Widespread	1, 2	
Seedling blight	Elongated spots with yellow halo	*Curvularia eragrostidis* (?)	Malaysia	1	Treatment similar to *Cercospora*
Cylindrocladium	Brown lesions with white centres	*Cylindrocladium macrosporum*	Ivory Coast	1	
Leaf spotting		Various (see Ref. 1)	Widespread	1	See Ref. 1 for control recommendations
Nursery spear rot	Rotting of median leaflets of the spear leaf	*Phytophthora* sp.	Congo	3	Not serious enough to need control
Corticium leaf rot	Rot at base of unopened leaves	*Corticium solani*	Congo, Malaysia	3	See Ref. 1 for control recommendations
Dry bud rot	Yellow patches on leaves, then dry rot of spear	Unknown	Ivory Coast	4	Similar disease transmitted by *Sogatella* in coconut (see also Section 12.1.5.5)
Chlorotic ring	Conspicuous mottling	Potyvirus, related to sugarcane mosaic virus	S. America	5, 6	
Mature palm leaf diseases					
Necrotic spot	Brown spots, orange halo, premature withering	*Cercospora elaeidis*	Africa	7, 9	Different strain of *C. elaeidis* from that causing freckle (Section 12.1.2.1)
Crusty spot	Orange spots with black crust in centre	*Parodiella circumdata*	Africa	7	Mainly affects oldest leaves
Genetic orange spotting		Viroid?	Widespread	8	Transmission not demonstrated
Algal leaf spot	Pin-point yellow spots on upper surface	*Cephaleuros virescens*	Widespread	1, 9	Effect on yield unknown
Other mature palm diseases					
Armillaria trunk rot	Similar to vascular wilt, but leaf bases rot	*Armillariella mellea*	Congo	10, 11	Incidence has decreased since the 1950s
Basal decay	Sudden death of leaves, following trunk rot	Unknown	Africa, Malaysia	1	Rare
Charcoal base rot	Black rot at base, leaves chlorotic	*Ustulina* sp.	Malaysia	1, 12	Pathogenicity not proven
Stem wet rot	Internal rotting	Unknown	India	13	

References: 1: Turner (1981); 2: Robertson (1956); 3: Kovachich (1957); 4: Renard and de Franqueville (1989a); 5: Rivera *et al.* (1996); 6: Morales *et al.* (2002); 7: Kovachich (1956b); 8: Hanold and Randles (1991); 9: Robertson *et al.* (1968); 10: Wardlaw (1950a); 11: Moureau (1952); 12: Thompson (1936); 13: Chander Rao (1997).

12.1.1 Diseases of germinating seeds: brown germ

Symptoms and distribution: Brown spots appear on the emerging 'button'. These spread and coalesce as the embryo develops, and the tissues become slimy and rotten. The disease may occur wherever seeds are being germinated.

Cause: Duff identified a variety of *Aspergillus niger* from diseased embryos in Nigeria, and demonstrated pathogenicity by inoculation and reisolation (A.G. Prendergast, pers. comm., 2001). This may not be the only cause, though: Turner (1981) listed 27 fungi associated with the disease, of which *Aspergillus* spp. and *Penicillium* spp. were most frequent. Many are secondary invaders, as are bacterial species.

Control: Brown germ develops most readily under moist conditions at a temperature of 38–40°C; use of the wet heat treatment for germination (see Section 7.1) therefore encourages its spread. Although sanitary measures in the germinator may reduce incidence, the best method of control is to adopt the dry heat treatment method of germination, since the seeds are dry when being heated at 39.5°C, and when germinating they are at around 27°C, a temperature that does not encourage the growth of the organisms.

12.1.2 Seedling leaf diseases

Turner (1981) notes the importance of nursery management in minimising disease susceptibility. With adequate water supplies and balanced nutrition, nurseries in many areas remain largely free of serious diseases, and investigations into disease outbreaks may primarily involve examination of growing techniques, rather than a search for a pathogen. This emphasises the importance of predisposing factors in disease development, as mentioned above.

12.1.2.1 Cercospora *leaf spot, or freckle*

Distribution: Cercospora leaf spot is widespread throughout Africa but has not been reported in Asia or America. It is a disease of nursery seedlings which sometimes starts in the prenursery and is frequently carried to field plantings, where it can survive for many years.

Symptoms: The youngest leaves of nursery seedlings become infected and minute translucent spots surrounded by yellowish-green haloes enlarge and become dark brown. Conidiophores emerging through the stomata in the centre of the spots, mainly on the undersurface of the leaf, produce conidia which give rise to further, surrounding spots. This results in a freckled appearance, but later the lesions coalesce and the tissue dries out to become greyish-brown and brittle. The disease tends to become aggressive as the leaves age, and the process described above may proceed very rapidly at certain periods of the year. In West Africa, this is usually the middle or end of the wet season, and in the following dry season the drying out of the older leaves is much hastened by *Cercospora* incidence.

Cause: Cercospora elaeidis. Proof of pathogenicity was obtained by Kovachich (1954) in Congo and Robertson in Nigeria (1956). For details of growth and reproduction of *Cercospora* in the host, the papers of these authors and of Weir (1968) should be consulted. Nitrogen manuring may cause a small increase in the incidence of freckle in the nursery, but potassium substantially reduces it. Small favourable effects of phosphorus have also been noted (Robertson, 1960).

Effect on yield: Duff (1970) showed that *Cercospora* could depress yields by more than 10% over the first 7 years of production. Even moderate attacks materially reduced the green leaf area and might therefore affect early bunch production. Note, though, that quite severe defoliation during the first year in the field may have little effect on subsequent yield (see Section 12.2.1.2). Jacquemard (1998) describes the disease as depressing nursery growth, but not economically important.

Control: The obvious course is to try to eradicate the disease in the nursery and to prevent reinfection of the young seedlings in the field. Jacquemard (1998) recommended spraying with mancozeb and benomyl. In the nursery, if spraying is not done, all old dry leaves and any others badly infected should be removed by pruning. In the field, however, excessive pruning may reduce growth and delay flowering, whereas failure to prune may increase the severity and prolong the incidence of the disease. A compromise pruning standard suggested by Hartley (1988, p. 585) was to remove and burn any leaf that showed dead or badly necrotic areas over more than one-third of its total surface, but it is not clear whether this would control the disease.

Elaeis oleifera progenies planted in Africa have shown a marked susceptibility to the disease; interspecific hybrids are rather less susceptible. There are significant differences between *E. guineensis* progenies in *Cercospora* susceptibility (Robertson, 1963) and, since serious loss of crop through *Cercospora* attack in field plantings has been demonstrated, Duff (1970) suggested that breeding for tolerance would be worthwhile. With good control being obtainable with fungicides, however, it is doubtful whether breeding for tolerance can be justified.

12.1.2.2 *Other seedling leaf diseases*

Various diseases of minor importance or rare occurrence are listed in Table 12.1. Some nursery diseases, for which many causes (including virus infection) have been suggested but none established, have been constant enough in their symptoms to acquire distinctive names. These include bronze streak, ring spot and infectious chlorosis (which, despite the name, appears not to be infectious). Turner (1981) gives information on these.

Leaf distortions occur in young prenursery and nursery seedlings at the bifurcate leaf stage (Plate 12.1) and have been described as:

- leaf crinkle, in which the lamina between the veins is folded in lines across the leaf

Plate 12.1 Certain abnormalities of nursery seedlings. (A) Leaf Crinkle; (B) Leaf Roll and (C) Collante.

- leaf roll, in which the lamina is rolled under the leaf, giving it a spiky appearance
- collante, in which the lamina between the veins becomes laterally compressed at a band about halfway along the leaf so as to form a constriction there (Gunn *et al.*, 1961).

Other abnormal conditions that necessitate culling in the nursery are described in Section 7.2.2.4.

Malformed seedlings are not uncommon in the prenursery and are variously attributed to the after-effects of brown germ, or to incorrect orientation of the germinated seed at planting.

12.1.3 Seedling spear and bud rots

Several nursery spear and bud rots have been recorded, but none appears to be serious (Table 12.1).

12.1.4 Seedling root diseases: blast disease

Distribution: Blast has been a serious nursery disease throughout West Africa. It was particularly severe in the Ivory Coast and of considerable importance in Nigeria and Cameroon. The disease has also been recorded from Malaysia (Turner, 1966b), Indonesia, Brazil (Cardoso, 1961) and Colombia, and Turner (1981) considered that it could occur in any country where climatic conditions and nursery techniques are likely to favour its development.

Symptoms: The symptoms of blast disease were described in detail by Bull (1954) and Robertson (1959a). Affected seedlings lose their normal gloss and become dull and flaccid, the leaf colour changing successively to olive green, dull yellow, purple or umber (at the tips) and, finally, with full necrosis and drying out, to a brittle dark brown and grey (Plate XIA). Necrosis of the central spear is usual and death occurs in a few days. In a small percentage of cases the rot may not reach the growing point; the seedling then survives, but as a weak and unacceptable plant. In many of the roots of diseased plants the parenchymatous tissue within the hypodermis has been rapidly destroyed from the tip towards the stem base, the stele remaining loose within the hollow cylinder. When the rate of cortical rotting becomes greater than the rate of production of new absorbing roots, desiccation and death follow very rapidly.

Causes: Two quite distinct causes for this disease have been convincingly demonstrated. Robertson (1959b) showed that it was caused by a joint infection of the roots by two fungi, and satisfied Koch's postulates in proof of this. Subsequently, it has been demonstrated in the Ivory Coast that an insect vector is involved. Turner (1981) discussed the possibility of there being several causes of blast or of two apparently different causes being linked. The leaf symptoms are essentially those of acute water stress, and might be caused by any severe damage to the roots.

Robertson (1959b) isolated *Rhizoctonia lamellifera* from decaying cortical tissue in the roots, and a *Pythium* species, probably *P. splendens*, from primary infections of the root tips, where it was shown to penetrate the cells and cause their collapse. In laboratory experiments, Robertson (1959b) showed that the *Pythium* may be parasitised by *R. lamellifera*. In inoculation experiments, a mixed inoculum of *Pythium* and *R. lamellifera* produced more extensive root rotting, and the leaf symptoms were more pronounced than with either species individually. Inoculation with *R. lamellifera* alone was only successful when the roots had been artificially damaged, while with *Pythium* inoculation, damage was confined in the root tips. In all of these cases pathogenicity was established by reisolation of the organisms. It was concluded that *R. lamellifera* plays an important part in blast disease in the destruction of cortical tissues and that it gains access either through a prior invasion by *Pythium* sp., which it parasitises, or through root damage from some other cause. The *Pythium* species was thought to be important through its role as a primary invader and its ability to penetrate the parenchyma cells and develop within them.

Subsequent to Robertson's work, quite different results were obtained in the Ivory Coast, where the blast problem had always been severe. It was noted that plants grown in metal cages covered with mosquito netting showed less than 1% blast in comparison with 15% outside in unshaded areas. A polybag nursery trial compared a completely closed cage with very fine netting (to give the minimum shading effect), an open-top cage, plots treated twice weekly with parathion, and unshaded control plots which had natural grass between the bags (Renard *et al.*, 1975). The results were as follows:

	Treatment:			
	Completely enclosed	Open-top cage	Parathion	No treatment
Blast (%) by end of Dec.	0	6	27	46
Blast (%) by end of Jan.	2	9	35	63

These results led to the hypothesis that an insect vector was involved. Later, it was established that the insect was *Recilia mica* (Hemiptera: Delphacidae), for which the grasses *Paspalum* spp. and *Pennisetum* spp. were alternate host plants (Julia, 1979). Julia found that *R. mica* moved to the palm nursery from surrounding grass only in October and November. De Franqueville *et al.* (1991) found that the insects were most frequent in November and December, and introduction of *R. mica* to caged palms gave the highest disease incidence at that time. The exact connection between *R. mica* and blast disease has not been determined. Renard (1981) showed that tetracycline gave good protection, suggesting the possibility that a mycoplasma is involved, but this has not been confirmed.

Control: The precautions that are taken in nurseries against blast are briefly discussed in Chapter 7. The effect of shade in reducing blast incidence has been established, but the provision of shade for large plants nearing the end of their nursery life has disadvantages, and in Nigeria generally proved unnecessary. A significant negative correlation was found between blast incidence and rainfall during the 'short dry' season in August and September (Robertson, 1959a). The blast season normally extends from October to January, and experiments confirmed that irrigation during August and September substantially reduced blast incidence.

An interesting feature of blast disease is the importance of time of attack. It has been shown both in the Ivory Coast (Bachy, 1958) and in Nigeria (Robertson, 1959a) that a relationship exists between blast incidence and the age of the seedlings at the time of attack. If the seedlings are either very young (1–4 months) or old (11 months or over) at the beginning of the blast season, the casualties are few. De Franqueville *et al.* (1991) showed that seedlings with four or five leaves were more susceptible than older seedlings. In seedlings with two leaves the disease developed slowly, but eventually reached the same level as in plants with four or five leaves.

Desmier de Chenon (1979) found that the removal of grasses in the vicinity of the nursery reduced blast incidence; the application of aldicarb monthly from the start of the nursery was also effective and made it possible to eliminate the shade which had always been found necessary in the Ivory Coast (Quencez, 1982).

The control measures for blast in West Africa may be summarised as follows.

1. Time the planting of nurseries to ensure that the blast season has passed before the seedlings reach the susceptible stage. This will involve planting well-developed prenursery seedlings early in the rainy season, and ensuring their rapid growth.
2. Pay particular attention to irrigation during the short dry season and make sure that polybags have a sufficient, though not excessive water supply throughout the nursery period.
3. Where *Recilia mica* is prevalent, spray out host grasses in the vicinity of the nursery, and apply aldicarb monthly.

De Franqueville *et al.* (1991) tested several insecticides, and found that omethoate was also effective. Clones differ in their susceptibility to blast (IRHO, 1992b), but breeding for resistance would not be a sensible approach to an easily controlled nursery disease.

12.1.5 Adult palm leaf diseases and disorders

12.1.5.1 *Crown disease*

Distribution: The disease was most prevalent in the Far East, particularly in the early Deli plantations. All but the most severe cases normally recover during the second year after planting, and effects on yield are then not serious.

Symptoms: A palm suffering severely from crown disease has many of its leaves bent downwards in the middle of the rachis; at this point the leaflets are absent, or small and ragged (Plate XVA). These symptoms originate in the spear leaf, where the folded leaflets begin to show a rot of their edges or centre (Kovachich, 1957). This rot spreads throughout the central portion of the leaf so that when the leaf unfolds the leaflets of this section are disintegrating or already missing. The rachis bends at the point where the leaflets are absent. In severe cases all the leaves surrounding the spear may be bent down, and the spear itself may have a rot of its terminal portion which turns brown and hangs down. Under these extreme circumstances, crown disease may have a severe effect on early development and yields. The disease normally affects palms in the second to fourth year in the field, but instances have been reported in the nursery and up to 10 years of age.

Causes: No pathogen has been identified, and it was assumed in the early days that the disorder was physiological and might be inherited. The latter assumption proved correct (see below); with regard to the former it was suggested that palms suffering from the disease have low leaf magnesium contents and that the incidence of the disease might be affected by magnesium and potassium manuring (Hasselo, 1959). Breure and Soebagyo

Table 12.2 Reduction in yield of palms with crown disease

Class	Severity of symptoms	Palms in class (%)	Yield loss/palm (%)		Yield loss/ha (%)	
			1st 6 m	7–38 m	1st 6 m	7–38 m
0	No symptoms	80.8	0	0	0	0
1	Slight	8.0	15.1	2.7	1.2	0.2
2	Mild	6.3	22.8	3.4	1.4	0.2
3	Severe	4.5	36.1	4.5	1.6	0.2
4	Very severe	0.25	54.3	34.0	1.4	0.8
5	Extremely severe	0.12	43.2	27.1	0.5	0.3
	Total loss/ha (%)				6.1	1.7

From Dumortier (1998).
Loss per hectare = loss/palm × palms in class.

(1991) compared two sites, and observed lower leaf boron levels (and rather lower magnesium) at the site with more severe incidence of crown disease.

Thompson (1934) stated that the 'decreased rigidity' of the rachis was due to insufficient lignification of the parenchymatous tissue, and Monge *et al.* (1994) found that the fibres of vascular bundles in the rachis were very thin-walled in affected leaves. The leaves, however, tend to be quite rigid, although bent. Monge *et al.* (1994) considered that crown disease and spear rot might be manifestations of the same disorder. Alvarado *et al*. (1997) also suggested the two were associated, but in their trials with a susceptible progeny, poor drainage reduced the level of crown disease, but increased spear rot incidence (see Section 12.1.7.2). Boron application also reduced crown disease incidence.

Effects on yield: Severity of crown disease varies between environments (Breure and Soebagyo, 1991). In Papua New Guinea (PNG), where incidence can be severe, Table 12.2 shows a yield loss of about 6% in the first 6 months of production, and just under 2% over the next 2.5 years. Breure and Soebagyo (1991) estimated losses of 4.5% over the first 3 years of production in North Sumatra, with the greatest loss in the first year.

Control: De Berchoux and Gascon (1963) showed that pure Deli progenies in the Ivory Coast were highly susceptible. La Mé material, free of crown disease, gave crosses with Delis which were also free of crown disease, but Congo material, which showed several cases of the disease, gave Deli × Congo crosses with a quarter to a half of the palms showing the disease. The authors postulated that susceptibility to crown disease is due to a single recessive gene. Some examples from their results are given in Table 12.3, showing close agreement with the expected segregations. Thus, it appeared practicable to select palms that would not produce susceptible individuals in their progeny; in particular, it would be valuable to have *pisifera* shown to be homozygous for absence of crown disease (CC), as the Congo (Sibiti) palm S127P appeared to be.

Blaak (1970b) found that with some palms in Cameroon the expected inheritance occurred. However, other crosses gave segregations that could best be explained by the presence of an inhibitor gene which, when homozygous, suppressed expression of the disorder. Examples from Blaak's results are also given in Table 12.3.

If susceptibility is controlled by only one or two genes, then its elimination from a breeding programme should be easy, although Blaak (1970b) pointed out that the presence of an inhibitor gene complicates selection, since detection of a palm of *cc* genotype (susceptible) is only possible by test crossing with a palm that is known not to have the inhibiting gene. The losses noted by Dumortier (1998) are quite small, but 6% extra crop over the first 6 months of production is clearly worth having. However, Dumortier showed that *pisifera* DM742.207 transmitted crown disease susceptibility to its offspring, and yet it consistently gave the highest yielding progenies in most environments (Dumortier and Konimor, 1999). Thus, it is understandable that some oil palm breeders have not regarded eliminating suceptibility from their programmes as being very important.

12.1.5.2 *Leaf wither,* Pestalotiopsis *leaf spot or grey leaf blight*

Distribution: A virulent type of leaf withering has been troublesome in parts of Colombia, Ecuador and

Table 12.3 Incidence of crown disease in various crosses in the Ivory Coast and Cameroon, and expected segregation with and without Blaak's inhibitor gene; expectations shown are those if the inhibitor were dominant

Presumed genotypes	Cross	Observed (%)		Expected (no inhibitor) (%)		Expected + inhibitor (%)	
		Without	With	Without	With	Without	With
de Berchoux and Gascon (1963)							
cc × cc	D115D selfed	0.5	99.5	0	100		
CC × cc	L10T × D115D	100	0	100	0		
cc × CC	D115D × S127P	100	0	100	0		
Cc × cc	L219T × D115D	57	43	50	50		
Cc × cc	S7T × D115D	52	48	50	50		
Cc × Cc	L219T × D10D	81	19	75	25		
Cc × Cc	L239T × D128D	71	29	75	25		
Blaak (1970b)							
Cc ii × Cc ii	1.2229 selfed	79	21	75	25	75	25
Cc II × Cc ii	3.417 × 1.2229	77	23	75	25	75	25
Cc II × Cc II	3.417 selfed	100	0	75	25	100	0
Cc ii × Cc ii	5.37 selfed	76	24	75	25	75	25
Cc II × Cc ii	3.415 × 5.37	96	4	75	25	100	0
Cc II × Cc II	3.415 selfed	100	0	75	25	100	0
Cc Ii × Cc ii	15.4624 × 5.1295	85	15	75	25	87.5	12.5

From de Berchoux and Gascon (1963) and Blaak (1970b).

Honduras, and has caused much defoliation, with significant effects on yield. It is also commonly seen in Colombia on *E. oleifera* palms.

Symptoms: The first symptom is the appearance of small brown spots with yellowish haloes. These spots soon coalesce into brown necrotic areas which spread over the leaflet tissue and later become grey and brittle (Plate XIC). There is a sharp line between the brown and grey areas and in the latter a species of *Pestalotiopsis* is found, black specks indicating the location of spore-bearing acervuli (C.W.S. Hartley, 1974, unpubl.).

Cause: The disease has been described as *Pestalotiopsis* leaf spot and grey leaf blight in Malaysia, but there the fungus is only associated with old and near-moribund leaves and is not considered of economic importance (Turner, 1981). The severity of the attacks in Latin America seem to be due to the easy access given to the young leaves by the feeding activities of insects, but it is also possible that the strains of the *Pestalotiopsis* species involved are more aggressive.

Genty *et al.* (1975) showed that *Leptopharsa gibbicarina* (Hemiptera: Tingidae) was the principal means of infecting young leaves. This insect punctures the leaflets alongside the midribs, producing whitish spots with their surrounds stained with excrement (Genty *et al.*, 1983). In Ecuador, *Peleopoda arcanella* has been implicated in assisting infection of the leaves by *Pestalotiopsis* sp. (Turner, 1981). Two species of *Pestalotiopsis* are the usual entrants, but species of *Helminthosporium*, *Curvularia* and other genera may also gain access to the leaflets.

Effects on yield: The disease has caused considerable defoliation on some plantations and, as would be expected, this has been followed by serious yield decline. Bunch production falling from 18–20 to 12–15 t fresh fruit bunch (FFB)/ha in adult areas, and from 11 to 7–8 t/ha in young plantings has been reported (Jiménez and Reyes, 1977).

Control: The attacks on moribund tissue in Africa and Malaysia have often been associated with magnesium deficiency symptoms (Bull, 1961a). In Colombia, the disease is less severe if potassium and magnesium are in balance (P.L. Gomez, pers. comm., 2001).

Control of *L. gibbicarina* by aerial spraying of propoxur, fenitrothion or phosphamidon has had considerable success in checking the disease, but more recently trunk injection or root absorption of monocrotophos has been advocated; as noted in Section 12.2.1.4, these methods of application have advantages in terms of selectivity. Monocrotophos injection has also been

successful in Honduras (Vessey, 1981). The possibility of biological control has been studied (Genty *et al.*, 1983; Guerrero, 1985), and Mendez (2000) described successful management of the disease by encouraging *Crematogaster* ants and using *Beauveria* and *Paecilomyces* fungi to control the insect vector.

12.1.5.3 *White stripe*

Distribution: The condition is sporadic and, in Asia, is said to be more common on alluvial soils, particularly organic clays or mucks. Affected palms have reduced yield.

Symptoms: Narrow yellowish-white stripes are found on each side of the leaflet midrib and extending its whole length. The stripes are sharply divided from the adjoining green (often dark green) tissue. Affected palms usually recover, and Rajaratnam (1972b) reported that the chlorotic tissue might turn green after about 7 months and that the symptom was more prominent in young leaves than in old. He also showed that chlorosis was due to failure of the palisade mesophyll cells to elongate and that apparent recovery was through an increase in the chlorophyll content of the spongy mesophyll, and not through development of the palisade cells. Turner (1981) stated that symptoms are more severe in Malaysia than elsewhere, and that typically they appear at 2–3 years of age, becoming more severe at 3–5 years and then becoming chronic.

Effects on yield: Moderately affected palms yielded 15% less than healthy neighbours, and severely affected palms nearly 50% less (Rajaratnam, 1972b). However, Tohiruddin *et al.* (2002) found that yield was sometimes positively correlated with white stripe incidence (see below).

Cause: It has been suggested that the disorder is of genetic origin. A certain *tenera* × *dura* cross showed similar percentages of white stripe when planted in Ivory Coast and in East Cameroon; also certain Deli selfs in Ivory Coast showed the symptoms while others did not (Ollagnier and Valverde, 1968; Gascon and Meunier, 1979). However, the general view is that the cause is nutritional: boron deficiency and a high leaf N:K ratio have both been suggested. In boron-deficient seedlings, Rajaratnam (1972a) found chlorotic patches, in which the palisade mesophyll had not developed, but the patches did not form stripes. In one trial, palms showed a degree of recovery when boron was applied, but in another they did not.

Turner and Bull (1967) considered that a nitrogen:potassium imbalance was the main cause of white stripe, but Rajaratnam (1972b) observed the disorder in palms with N:K ratios well below that suggested as critical by Turner and Bull. Tohiruddin *et al.* (2002) found a positive correlation of white stripe incidence with N:K ratio in only one of five fertiliser trials studied. In that trial, there was a negative correlation with leaf K content, and a stronger correlation with rachis K content (rachis K is more sensitive to applied K than leaf content; see Section 11.4.2.2). In unfertilised palms in that trial, rachis K content was below 0.6%, much lower than in the other trials. The correlation of white stripe incidence and yield was negative and statistically significant.

In two other trials, where leaf N content exceeded 2.8%, white stripe incidence was positively correlated with leaf N content, and positively (but not significantly) correlated with yield. There were no correlations with leaf boron content. These results support the N:K imbalance hypothesis, but suggest that the leaf N:K ratio is not an adequate indicator of the imbalance.

Treatment: Turner (1981) suggested substantial applications of potash with reduction of nitrogen applications, but Tohiruddin *et al.* (2002) distinguished between white stripe caused by low K status, and by high N status. Where rachis K is low, potassium fertiliser should be applied. Where leaf N exceeds 2.8%, reducing N input may reduce white stripe incidence, but it is also likely to reduce yield. In this situation, symptoms can be expected to disappear with time, since as palms grow older, leaf N content tends to fall, and K reserves increase.

12.1.5.4 *Leaf mottle (mancha anular)*

Distribution: This condition, which often leads to death of the palm, has been reported from Ecuador and Peru and is described by Turner (1981). It has been called ring spot, but that term is already used for a nursery disease.

Symptoms: When the spears open they fail to become fully green, and spots of pale tissue remain. These may be circular, or elongated and almost rectangular, and may form almost continuous streaks. Younger fronds then become chlorotic. This leaf symptom is followed by the rotting of the root system and spear, although Turner (1981) considered the spear rot to be secondary. Developing bunches may also rot. Palms may die within 3 months of the first symptoms, but some palms continue to grow and yield for several years, despite showing leaf symptoms.

Cause: Martínez (1988) suggested that a virus might be the cause, but this has not been confirmed. Renard and de Franqueville (1989a) described nursery dry bud

rot as being similar (see Table 12.1). A similar disease of coconuts is transmitted by two species of *Sogatella* (Homoptera: Delphacidae) (Julia and Mariau, 1982).

Treatment: Fungicides, insecticides and antibiotics have been tested without effect. Diseased palms tend to be scattered throughout a field, but incidence is much higher with dense grass cover than with a legume cover (Dzido *et al.*, 1978). A good leguminous cover should therefore be maintained in areas subject to this condition.

12.1.5.5 *Patch yellows*

Distribution: This disease appears to be confined to Africa, where it is widely distributed, though sporadic and affecting only a small proportion of palms. A condition in Malaysia known as wither tip, from which both *Fusarium oxysporum* and *F. solani* have been isolated, was described by Turner (1981) who suggested that it was allied to patch yellows.

Symptoms: Infection takes place in the unopened spear leaf and for this reason the lesions at the sites of infection appear opposite each other on the leaflets when the leaf opens (Plate XIB). The lesions are circular or oval with rings of pale yellow, sometimes with brown centres. The patches may appear all along the lamina. Later, the centres of the patches dry out and drop away, giving a typical 'shot-hole' appearance, or, if the patches are towards the edge of the leaflets, a raggedly indented appearance. The purely yellow patches persist and darken, and can be seen to have small orange spots within them (Bull, 1954).

Cause: Wardlaw (1946a) reported that, following the discovery of *F. oxysporum* associated with vascular wilt disease, a second strain of *F. oxysporum* which closely resembled the first had been shown to be associated with patch yellows in Congo. Kovachich (1956a) later proved its pathogenicity. Prendergast (1963) found that a patch yellows strain of *F. oxysporum* did not cause vascular wilt in the nursery test (see Section 12.1.6.2 below).

Control: The disease affects up to 1.8% of palms in the areas where it is found, and evidence for genetic susceptibility was provided in Kovachich's pathogenicity tests. In Nigeria, a small proportion of families were susceptible (A.G. Prendergast, pers. comm., 2001). Kovachich suggested selection to eliminate susceptible lines, but the disease does not seem to be sufficiently serious to justify this.

12.1.5.6 *Minor leaf diseases*

The oil palm leaf is susceptible to patchy discoloration and necrosis from a variety of minor pathogens, some of which are listed in Table 12.1, and to surface covering by epiphytic and saprophytic organisms. These often cause the older leaves to appear far from healthy, but as the oldest leaves contribute relatively little photosynthetically, the effects may be small.

Black 'sooty mould' is often found to grow on the older leaves of adult palms and occasionally spreads over a large proportion of the leaf surface, giving the palms a blackish-grey appearance. Sooty moulds usually grow as epiphytes on honeydew, the exudate of partially digested plant sap from plant lice, but it is not certain whether this is always the case in oil palm (Wood, 1968a).

Several of the most common fungi to be found in Africa as constituents of the epiphytic flora are listed in Turner's *Micro-organisms associated with oil palm* (1971). Among these, the Ascomycetes *Apiospora* sp., *Meliolinella elaeidis* and *Meliola elaeis* may be mentioned. *Meliolinella elaeidis* is recorded as also being found in America (Costa Rica) on *E. oleifera*. Epiphytic flora may appear on the upper or lower surface of the leaves. In West Africa the black mould usually found on the upper surface consists of discrete circles of about 5 mm diameter; on the lower surface the black mould is in irregular patches of less dense material. In Malaysia, sooty moulds of *Brooksia*, *Ceramothyrium* and *Chaetothyrium* spp. develop on insect secretions on the leaves (Williams, 1965; Turner, 1981). *Brooksia tropicalis* is common in Africa.

Lichens are often found among the epiphytic flora on oil palm leaves, forming small grey–green encrustations on the upper surface of the leaflets (Turner, 1971).

12.1.6 Stem and root diseases

Root and stem diseases are characterised by fracture and drying out of fully developed leaves, leaving the spear leaf and some surrounding leaves standing erect. These early symptoms may be accompanied by a change in colour, drying out or wilting of one of the more erect younger leaves; bud and spear rots tend to be characterised by symptoms in the centre of the crown. The spear leaf may be directly affected or the surrounding leaves show a sudden chlorosis. Successive spear leaves may be shortened, have peculiar 'little leaf' formations, or cease to develop, leaving a palm with an empty centre. These general symptom differences between stem and root diseases on the one hand, and bud and spear rots on the others give a rough guide when deaths occur or alarming disease symptoms appear, but dissection of the palm must follow to determine exactly where the site of destruction is. The site of decay with the root and stem diseases is the bole, trunk

or roots, the disease killing the palm by denial of water and nutrients to the crown. Bud and spear rots, in contrast, kill the palm by growing towards and reaching the single growing point.

12.1.6.1 *Dry basal rot*

Distribution: This disease appears to be confined to West Africa and, although the pathogen is a common soil inhabitant, the disease was not discovered in epidemic form until 1960. One estate in Nigeria was devastated and thereafter minor outbreaks occurred in several parts of Nigeria, West Cameroon and Ghana. In the first, epidemic deaths were common, but recovery then became more usual and further serious outbreaks have not been reported.

Symptoms: The foliar symptoms, which usually appear at the end of the dry season, are preceded by extensive bunch and inflorescence rot. The rachis of certain leaves then becomes fractured submedianly, although the leaflets remain green for a considerable period before they eventually die (Plate 12.2A). Occasionally, a young leaf high up in the centre of the crown becomes necrotic and dries out, and this precedes the necrosis of the older leaves. It is quite common for a complete ring of leaves to exhibit the submedian fracture while the upper leaves are still erect, and this gives the newly affected palm its characteristic appearance. Later, the upper leaves and the spear will be similarly affected and the palm dies, or it may make a recovery at any stage. A palm that survives may take several years to come back into bearing. Attack has usually been on palms that have recently come into bearing, but 10-year-old palms have also been affected.

The characteristic internal symptom of the disease is a dry rot at the base of the trunk (Plate 12.2B). This rot is well established by the time the primary leaf symptoms are apparent. In the transition zone between rotted and healthy material many vascular bundles are necrotic, and it is possible to trace infection from an infected root or leaf base into the base of the trunk.

Cause: The cause of dry basal rot was shown by Robertson (1962a,c) to be the ascomycete *Ceratocystis paradoxa*, the imperfect stage of which is known as *Thielaviopsis paradoxa*. The latter has been implicated in fatal yellowing (Section 12.1.7.2). *Ceratocystis paradoxa* is a soil inhabitant widely distributed throughout the tropics of Africa and Asia, and causes diseases of several other crops. Its sudden appearance in West Africa as the cause of a serious condition was unexpected and gave rise to investigations on conditions conducive to its spread. An epidemic at Akwukwu in Nigeria occurred on acid sands soils with an unusually low clay content at depth (15–17% at 2 m), and minor outbreaks at the Nigerian Institute for Oil Palm Research (NIFOR) Main Station also occurred on

Plate 12.2 Dry basal rot, *Ceratocystis paradoxa*. (A) A severely infected palm showing sub-median fracture of the lower leaves. (B) A palm showing external symptoms of the disease, dissected to expose the dry rot at the base of the trunk.

fields with little clay in the profile. This led to the belief that incidence might be connected with soil–climate relationships. A further outbreak at NIFOR in 1967 followed a severe dry season. Incidence varied between fields from 0.1 to 10%.

Two features of the spread of the disease are important. In the outbreak at Akwukwu many deaths occurred in the first 2 years, amounting to about 30% in one area. Thereafter, very few deaths occurred and there was considerable recovery; although new infections occurred, these did not give rise to many further deaths (Hartley, 1988). All the palms that recovered were bearing bunches by 3 years after the last survey (Rajagopalan, 1965). The other feature of this disease at the NIFOR Main Station was that incidence in one field of 9-year-old palms was mainly confined to progenies having the same female parent. In Robertson's pathogenicity tests he found he could infect all seedlings through a root dipping technique; nevertheless, inoculated progeny lines planted in the nursery showed marked differences in disease incidence (Robertson, 1962b). Selection for resistance is therefore a promising line for the future should the disease once more become important.

12.1.6.2 Fusarium *wilt or vascular wilt*

Since its description by Wardlaw (1946b) in Congo, *Fusarium* wilt has been considered one of the most menacing of oil palm diseases. The disease has been observed on plantations in Congo, Nigeria and West Cameroon, in the Ivory Coast, and elsewhere in West Africa. It has also been recorded in Brazil and Ecuador. Its effects are serious: in the acute form the palm rapidly dies, while chronically affected palms yield little or nothing.

Symptoms: In the more usual, chronic form of the disease in mature palms, the older leaves become desiccated and the rachis breaks near the base or at some distance from the base, the ends of the leaves hanging downwards. This feature has been used to distinguish the disease from *Ganoderma*, in which the leaves collapse at the base and closely cloak the stem. The disease usually proceeds gradually along several leaf spirals, with younger leaves becoming successively affected. The erect and still green leaves in the crown become successively more reduced in size and are often chlorotic, and the palm may stay in this state for several years before the crown eventually collapses.

Occasionally, a mature palm suffers a rapid death through an acute attack. The leaves dry out and die rapidly while still in an erect position, and then snap off about 1 m or more from the trunk, usually during strong winds (Plate XIIB). The remaining leaves die quickly. All stages between the acute and chronic forms are encountered.

Symptoms of the disease in young palms in which no trunk has yet been formed are somewhat different. In these palms the 'lemon frond' symptom is frequent: a leaf somewhere in the upper middle part of the crown (fourth to 15th leaf) develops a bright lemon-yellow colour before drying out from the tip to the base. Leaves at about the same level then turn yellow and dry out, to be followed by some of the younger leaves, which will die while many of the older ones remain green. Newly developed leaves become successively smaller (Plate XIIA), and death of the whole palm usually takes less than a year. It should be noted that the striking lemon-frond symptom is not always seen, and in southern Congo a general yellowing of the leaves before death was more usual.

Internal symptoms of the disease are quite distinctive (Plates XII, XIII). The vascular bundles are normally pale yellow or whitish, but when diseased they become brownish-grey or black, and a cross-section of the trunk therefore shows a speckled appearance (compare Plates XIIID, E). Discoloration, which is associated with the presence of gum, is confined to the xylem vessels (Plate XIIE); blackened fibre strands do not indicate vascular wilt. Such blackening often occurs in older palms and sometimes in other conditions, and the inexperienced observer can therefore be misled into a wrong field diagnosis. Moureau (1952) pointed out that although discoloration of the xylem vessels is normal in palms over 20 years old, in these palms the blackening decreases towards the top of the palm instead of becoming accentuated as in the case of wilt. In palms with acute wilt, A.G. Prendergast (pers. comm., 2001) found large cavities, often more than 30 cm across, in the stem within 2 m below the crown; these cavities were filled with a dense mass of *Fusarium* mycelium.

Drying-up of the leaves and death of the palm are caused partly by the destruction of the roots and partly by the blocking of the xylem vessels by gels and gums. Diseased vessels may at first occur in only one section of the stem base, and this probably accounts for leaf symptoms being confined at first to certain spirals. Xylem vessels in the centre and at the top of the stem then become diseased and the symptoms spread across the stem, so that a large proportion of the vessels at the top are affected. In young palms, up to 6 years old, diseased vessels are usually widely dispersed throughout the base.

The disease is normally recognised in the field by the external symptoms, but Mepsted *et al.* (1991) showed that the internal symptom of vascular browning could be detected non-destructively by taking tissue samples

with an auger (Plates XIIC, D). Using this method, they found that 25% of a sample of palms, classed as healthy by external appearance, showed internal symptoms of the disease (latent infection). Buchanan (1999) used the auger method, and found a poor correlation between external and internal symptoms. In one palm family, 54% of apparently healthy palms showed internal symptoms, while, conversely, 40% of palms with external symptoms showed no internal browning. Buchanan noted that simultaneous infection by *Cercospora* and *Ganoderma* may produce external symptoms somewhat similar to those of *Fusarium* wilt, so erroneous identification of wilted palms may partly explain his results.

Palms may recover, and recovery has become increasingly common as plantings of tolerant material are extended (Renard *et al.*, 1991).

Cause: Fusarium oxysporum f.sp. *elaeidis* (abbreviated below to *Foe*). One isolate from Congo was found to be *F. oxysporum* var. *redolens* (Ho *et al.*, 1985). The pathogen is soil borne and it usually enters the palm through the roots, growing along the stele, which becomes blackened. Infection can take place through wounds in the stem base and through uninjured roots (Kovachich, 1948). Renard (1970) considered that entry of the mycelium was much impeded by lignification even with wounding and that rapid infection was mainly through the transmission of spores in the vascular system. Locke (1972), working with seedlings, showed that the pathogen is confined to the conducting elements of the xylem (Plate XIIIB) and can reach the stele from the tip of a lateral root or the damaged cortical tissue of a pneumathode. From the roots the mycelium penetrates into the xylem vessels of the vascular strands, where conidia and chlamydospores are also found. Locke considered that the plant had little defence against serious infection in spite of resin formation and tyloses (Plate XIIIC). However, Paul (1995) indicated that in resistant genotypes, gels and tyloses were produced earlier and accumulated to higher levels, and fungal colonisation was restricted compared with susceptible genotypes. In the latter, production of gels and tyloses was delayed and the fungus rapidly colonised the host.

Distribution: The first recording of the disease was briefly described by Wardlaw (1950b) as follows. 'During a visit to the Belgian Congo in 1946 I observed a wilt disease of the oil palm (*Elaeis guineensis*), and isolated *Fusarium oxysporum* from the necrosed vascular strands. In 1947, Messrs. S. de Blank and F. Ferguson, in a private report, announced the presence of this disease in Nigeria and submitted cultures to me for identification; and in 1948 I was able to confirm their diagnosis during a visit to the affected plantations.'

Pathogenicity was confirmed by Fraselle (1951). Thereafter, *Fusarium* wilt was found on several plantations in Nigeria and West Cameroon, in the Ivory Coast, and elsewhere in West and west Central Africa. The disease has been recorded in Brazil (van de Lande, 1983) and Ecuador (Renard and de Franqueville, 1989b), and Flood *et al.* (1989) confirmed the pathogenicity of a Brazilian isolate by inoculation of clonal plants. Dossa and Boisson (1991) showed that, while *Foe* strains from Africa were in many different 'vegetative compatibility' groups, strains from Brazil and Ecuador were in the same group as strains from Benin and the Ivory Coast. This close relationship was confirmed with restriction fragment length polymorphism (RFLP) markers (IRHO, 1992b). It is thus likely that the disease was introduced to South America from Benin or the Ivory Coast, probably on seed, as it has been shown that spores of *Foe* can be spread on seed (Locke and Colhoun, 1973; Flood *et al.*, 1990).

Incidence and spread of the disease: In southern Congo, the greatest devastation occurred in replants. In West Africa the disease was largely confined to plantations, particularly replants, and for a long time was not much noticed in the groves. However, Aderungboye (1982) found that it was widespread in the drier Ogun and Ondo states of Nigeria, but infrequent or absent in the high-rainfall areas of the south-east. Oritsejafor (1989) found that the average incidence in Nigeria was 0.77% in palm groves and 1.35% in plantations. The disease is less frequent in plantations on forest land than on former savannah (de Franqueville, 1991); in the latter, the disease usually takes the chronic form, whereas after forest the acute form is more common.

In plantations in southern Congo, and in Nigeria in replants, wilt is commonly found in young palms that have recently come into bearing. However, in West Africa the disease has also attacked older palms that have been in production for 10 years or more (Prendergast, 1957). Renard and de Franqueville (1989b) indicated that disease development depends on the previous history of the site. In new plantings, the first cases may not be seen until 6–10 years after planting, but in replants in previously infected areas, losses may occur within a year of planting. De Franqueville and Renard (1988) found that wilt incidence in a replant was correlated, not with total losses in the old stand, but with the percentage of previously infected palms which were still living at the time of replanting.

Prendergast (1957) stated that healthy, vigorous palms in good soil suffered little from the disease and he showed that, in areas of potassium deficiency, incidence was substantially reduced by the application of potassium fertiliser. This finding was confirmed in experiments in both

Table 12.4 Yield of palms with missing neighbours at Binga, Congo. The main cause of vacancies was death from *Fusarium* wilt

	Missing neighbours				
	0	1	2	3	4
Yield (kg FFB/palm) for palms without symptoms	93.0	98.5	104.5	77.9	15.7
Yield as % of that of palms without missing neighbours	100	106	112	84	17
Number of palms in class	400	179	23	8	1

From Dumortier *et al*. (1992).

the Ivory Coast and Benin (Ollagnier and Renard, 1976). In the nursery test, in contrast, Prendergast (1963) found that nitrogen reduced susceptibility, but potassium had no effect. Ho *et al.* (1985) found that drought stress increased the severity of symptoms in seedlings.

Prendergast (1957) showed that diseased palms occurred in pairs more frequently than would be expected by chance, indicating infectious spread between neighbouring palms. Dumortier *et al.* (1992) found that palms with missing neighbours, in an area where the main cause of death was *Fusarium* wilt, were more likely to have wilt themselves than those without missing neighbours: of 1600 palms without missing neighbours, 17% had wilt, compared with 24% of 1000 palms with one or more neighbours missing. Only 18 palms had three neighbours missing, but 35% of those had wilt. It has generally been assumed that the disease is soil borne, but Moureau (1952) mentioned aerial spread by spores, and Cooper *et al.* (1989) showed that the pathogen sporulates profusely on male inflorescences, and thus could be spread by spores.

Effects on yield: Acute wilt kills the palm, but Prendergast (1957) observed that infection rates as high as 20% had no apparent effect on yield, and suggested that this was due to yield compensation by palms adjacent to vacant points. However, Dumortier *et al.* (1992) compared the yields of apparently healthy palms, with and without missing neighbours, and found that, although yield did increase slightly in palms with one or two neighbours missing (Table 12.4), the increase was not sufficient to compensate for the missing palms. When more than two neighbours were missing, yield was depressed (although the number of palms with more than two neighbours missing was small). If this depression is real, an explanation could be that palms with several neighbours missing are themselves infected (see above). Yield in the year before a palm died from acute wilt was only 54% of that of healthy palms, while palms with chronic wilt gave a yield less than 30% of that of healthy palms. The effects of deliberate and systematic thinning on yield are discussed in Chapter 9, where it is concluded that, at the planting densities most widely used, the yield increase from palms adjacent to gaps is unlikely to be sufficient to compensate for the palms removed. This is even more likely to be true for the patchy thinning that would result from disease. Thus, it appears likely that any incidence of acute wilt will reduce yield.

With chronic wilt, palms remain alive and may recover. Renard *et al.* (1993) looked at the effects of chronic wilt on the yields of four classes of palms:

- healthy palms
- palms with typical chronic wilt symptoms
- palms which had had the disease but had recovered
- palms with internal signs of infection (browning of the vascular tissue) but no external symptoms, described as 'latent infection'.

They estimated yield losses due to the disease as 15% in a susceptible cross and 6% in a tolerant cross (Table 12.5). The difference was attributable to lower yields from, and a larger number of, recovered palms in the susceptible cross compared with the tolerant cross. In both crosses, palms with latent infection yielded much the same as healthy palms. Although healthy trees of the susceptible cross gave a slightly greater yield, overall yield was greater from the tolerant cross.

Physiology of diseased palms: In nursery seedlings, the main symptoms are a reduction in petiole length and leaf area. Mepsted *et al.* (1995a) observed symptoms of water stress in infected nursery palms (closed stomata, lower leaf water potential, greater resistance to water flow from stem to leaf), but they considered that water stress was not the cause of stunted leaf development, because stressed but uninfected plants did not show stunted growth. Application of a gibberellin inhibitor, paclobutrazol, caused stunting symptoms similar to those of *Fusarium* wilt. Application of gibberellic acid to infected palms restored petiole length to normal, but had no effect on leaf area. The authors concluded that wilt symptoms might be due, at least in part, to an upset in gibberellin metabolism.

Table 12.5 Effects of chronic *Fusarium* wilt on yield.
The weighted mean yield is (yield as % healthy) × (palms in class)

Class of palm	Yield (kg/ha per year)	Yield as % healthy	Palms in class (%)	Contribution to yield (tFFB/ha.yr) (143 palms/ha)
Cross L2T × D115D (tolerant)				
1. Healthy	111.8	100	75	11.99
2. Chronic wilt	35.6	32	3	0.15
3. Recovered from wilt	90.8	81	13	1.69
4. Latent wilt	107.4	96	8	1.23
5. Dead	0	0	2	0
	Weighted mean: 94			Total: 15.06
Cross L2T × D10D (susceptible)				
1. Healthy	121.4	100	61	10.60
2. Chronic wilt	26.4	22	4	0.15
3. Recovered from wilt	79.4	65	27	3.07
4. Latent wilt	113.4	93	6	0.97
5. Dead	0	0	2	0
	Weighted mean: 85			Total: 14.79

From Renard *et al*. (1993).

Chronic and acute wilt: Mepsted *et al.* (1995b) found that water stress symptoms in nursery palms were much more severe in the older leaves, opened before the palms became infected, than in the younger, stunted leaves. They suggested that stunting might be an adaptation by the palm to reduce the water stress caused by occlusion of the xylem vessels, and speculated that, in field palms, failure to adapt in this manner might result in the acute form of wilt, while in palms that were able, or had time, to adapt, the chronic form would result. Prendergast (1963) and de Franqueville (1991) found no obvious difference in behaviour in the nursery test between *Foe* strains isolated from acutely infected palms, and from palms with chronic wilt. This suggests that the difference between forms of the disease may be in the host reaction. According to de Franqueville (1991), however, the acute form is more frequent in plantations on forest land than on former savannah. Such a difference is more easily explained in terms of pathogen strains than by host reaction, but differences in climate could be a factor.

Control: In Congo, the destruction by fire of all diseased palms and their neighbours was recommended and the replanting of areas where *Fusarium* wilt had been prevalent was discouraged (Moureau, 1952). In the Ivory Coast, de Franqueville and Renard (1988) stated that all trees infected with chronic wilt must be removed at least 5 years before replanting. However, they were unsure how early such removal should start, and suggested as a compromise the removal of any infected palms not producing at least one bunch per year. *Calapogonium caeruleum* or *Pueraria* as cover increases wilt incidence, and Renard and Quillec (1983) recommended planting grass species such as *Brachiaria* instead, suggesting that competition for nitrogen between the grass and the palm discouraged *Fusarium* infection. Competitive grasses may themselves depress palm yield, though, and the recommendation of de Franqueville and Renard (1988) to keep a strip of bare soil on either side of the row of young palms seems preferable. Turner (1981) considered that any effect of fungicides was likely to be short lived. Renard and de Franqueville (1991) found a significant increase in wilt in plots mulched with EFB, and a reduction when potassium fertiliser was applied.

Breeding for resistance: The most promising method of control is by the breeding of resistant lines. Prendergast (1963) was the first to develop a technique for the screening of seedlings for tolerance to the disease at the nursery stage (Plate XIIIA); his method was adopted with little modification by Renard *et al.* (1972). The method involves inoculation by pouring a suspension of *Foe* spores onto the bulb of the seedlings or the exposed roots around the collar. Prendergast (1963) described the symptoms in nursery seedlings in detail, and showed that results were not much affected by the size of the seedlings at the start of the test. He also noted the importance of the inoculum level and the time of evaluation: with too light an inoculum, or too early evaluation, few cases might be observed, and differences would be hard to detect. However, if the inoculum was very heavy or evaluation was late, all plants might die.

The standard nursery test requires large numbers of plants of each family, and hence large areas of nursery space; Prendergast (1963) used 40 seedlings per family, and Renard *et al.* (1991) up to 160. Locke and Colhoun (1974) developed a method of inoculating very young seedlings grown in compost with two known levels of inoculum, and then compared their growth with that of seedlings grown in uncontaminated compost. Determinations were made of the number of propagules in the soil so that subsequent inoculations could be related to normal soil levels. The fungus was recovered from progenies showing both large and small reductions either in weight per plant or in 'leaf area product'. It was demonstrated that some progenies were tolerant of infection in lightly contaminated compost only, and some in both lightly and heavily contaminated compost; others showed high susceptibility at both levels. A high degree of repeatability was attained, but this method does not seem to have been adopted by oil palm breeders.

Flood *et al.* (1989), using clonal plants, were able to reduce the numbers required to only 12 plants per clone, by using inocula with a known, constant concentration of fungal spores, and by detailed classification of the severity of symptoms on each plant.

Sound statistical analysis of the data from nursery inoculation trials is essential, if reliable results are to be obtained (reviewed by Porter, 1989). In all trials, the percentage of infected plants in each family has been recorded. Prendergast (1963) then divided the progenies in a trial approximately into quartiles, or classified as resistant those that differed from the mean by at least one standard error. Renard *et al.* (1972) calculated a 'wilt index', as the percentage of wilt-infected plants in a progeny divided by the mean wilt percentage of all the progenies in the trial. The best method appears to be that described by de Franqueville (1984). A wilt index was calculated in the same way as by Renard *et al.*, but after angular transformation of percentages for individual plots, data were statistically analysed, and progenies were only accepted as resistant if they had significantly lower losses than either the mean of the trial, or standard crosses of known performance.

An alternative to the standard nursery test was developed by Mepsted *et al.* (1995c). This involved inoculation of 2.5 cm sections from near the tip of the rachis, by immersion in a suspension of *Foe* spores under mild vacuum. Within 8 days, rachis sections from susceptible clones turned completely brown internally, whereas those from resistant clones showed little or no browning. This test is much faster than the nursery test, which takes several months. In addition to speed, the method has the great advantage that it can be applied to individual palms. The nursery test is based on the average performance of a group of palms, so the only way to screen individuals is as clones, or by studying the progeny of a self-pollination. Subsequent experience has shown that the rachis test only works well on palms that are in good health; nutrient-deficient palms, or palms infected with *Cercospora elaidis*, showed severe browning in both susceptible and resistant clones (Buchanan, 1999).

The inheritance of resistance is discussed briefly in Section 5.3.5. Prendergast (1963) and de Franqueville (1984) considered that the most susceptible families could be quite consistently and repeatably identified by the nursery test. De Franqueville also found a reasonable correlation between results of the nursery test and disease incidence in the field, in a heavily infested part of Congo. Renard *et al.* (1972, 1980) also showed that tolerant seedlings in the nursery test give rise to palms with a low incidence of wilt in the field.

Porter (1989) described resistance breeding in Congo, where selection was based primarily on performance in disease-infested fields (Plate VID), backed up by the nursery test. He gave examples of parents consistently transmitting resistance or susceptibility to their offspring in field trials. For example, 14 crosses derived from palm 69MAB (see Fig. 5.4) were all more resistant than the trial mean, 12 of them significantly so. Conversely, of seven crosses from palm 2/5710 (see Fig. 5.5), six were more susceptible than the trial mean, five significantly so. Corley (1993) and de Franqueville *et al.* (1995) found differences between clones in susceptibility.

In Nigeria, Rajagopalan *et al.* (1978) found that, among 336 progenies, none was immune but 149 showed sufficient tolerance to be considered valuable for breeding; and certain *pisiferas* consistently gave tolerant crosses with a range of *duras*. Prendergast (1963) and Locke and Colhoun (1974) also observed that no progenies appeared to be wholly immune to the disease. However, Rosenquist *et al.* (1990) noted that pure Dumpy Deli *dura* material (see Section 5.1.1.2) appeared to be virtually immune: two families gave 0% and 1% wilt in the nursery test in Cameroon, while one family in Congo had suffered no losses after 10 years in the field, a figure recorded in only two other families out of more than 450 in the programme.

There are reports of resistant material from other countries proving susceptible when imported to Nigeria (Oritsejafor, 1989), but replicated trials were not involved. De Franqueville (1991) tested three strains of *Foe* on 66 different families. There were significant differences between the strains and between the families, but no strain × family interaction. Mepsted *et al.* (1994) tested three isolates of the fungus from different parts

of Africa, on 14 clones. The isolates differed in aggressiveness, but as in de Franqueville's trial, the clone × isolate interaction was not significant. These two studies indicate that resistant material selected in one area should remain resistant when transplanted elsewhere.

Symptomless infection: Ho *et al.* (1985) isolated *F. oxysporum* from roots of healthy palms in Malaysia; these strains were apparently non-pathogenic, causing no disease symptoms. Flood *et al.* (1989) showed that one such strain did cause mild wilt symptoms in a susceptible clone, however.

Mepsted *et al.* (1988) found that inoculation of seedling roots with a non-pathogenic isolate could prevent subsequent infection by pathogenic strains. Diabate *et al.* (1992) confirmed this 'cross-protection' effect, and showed that phenolic compounds accumulated in the palm roots after inoculation, whether this was with a pathogenic or a non-pathogenic strain. Susceptibility appears not to be due to a lack of these phenolics, as both resistant and susceptible palms produced them, at similar levels, in response to the non-pathogenic strain of *F. oxysporum*. Presumably, in susceptible palms the fungus normally spreads more rapidly than the build-up of phenolics; preinoculation with the non-pathogenic strain may allow sufficient build-up, in advance of infection, to confer resistance. Both preformed and induced antifungals were extracted from xylem fluids and petiole tissue by Mepsted *et al.* (1995c), with the effect being particularly pronounced in resistant material. Paul (1995) suggested that preformed antifungal compounds were also present in oil palm roots, but the identity of the compounds in roots or petioles was not determined.

Diabate *et al.* (1992) suggested that there might also be competition between pathogenic and non-pathogenic strains in the soil. Flood *et al.* (1989) had previously suggested that competition for an ecological niche may be the reason that *Fusarium* wilt is not present in Malaysia: any strains accidentally introduced from West Africa would face competition from native Malaysian strains.

Plant quarantine: The demonstration that spores of *Foe* can be carried on oil palm seeds (Locke and Colhoun, 1973), and even on the kernel surface inside the shell (Flood *et al.*, 1990), poses potential problems for plant quarantine. Flood *et al.* (1994) showed that the standard 40°C heat treatment used to break dormancy (see Chapter 7) greatly reduced the level of infection, but some viable spores remained. They developed a method of fungicide application involving vacuum infiltration, which eliminated spores, including any within the shell. This treatment should be applied whenever seeds are exported from areas where wilt occurs.

Spores of *F. oxysporum* were also found in batches of freeze-dried pollen used for oil palm breeding, and were shown to be pathogenic (Flood *et al.*, 1990). This contamination can be detected by plating out samples on a *Fusarium*-selective culture medium, but this is laborious if many samples are involved, and a method of decontamination would be useful.

Conclusion: There is no doubt that *Fusarium* wilt can be devastating, and there are instances of plantations in Africa being abandoned or converted to other crops because of the disease. Given the large quantities of seed and pollen exported from Africa in the past, it is surprising that the Far East has remained free of the disease. Perhaps symptomless infection by other strains of *F. oxysporum* gives a degree of cross-protection, but the very strict quarantine measures now enforced by Malaysia and other countries appear sensible (Section 12.1.10). Breeding of resistant material is clearly the best approach to controlling the disease, and as a precaution, breeders in the Far East would be wise to gather information on the performance of their materials in areas where the disease occurs.

12.1.6.3 Ganoderma *trunk rot or basal stem rot*

In the more severely affected areas in the Far East, over 50% of palms may succumb to *Ganoderma*. For many years, *Ganoderma* was regarded as a disease of old palms, of little economic importance because such palms would soon be replanted. In the mid-1950s, however, the disease started to attack much younger palms in the Far East, particularly in areas planted after coconuts or replanted from oil palms (Turner, 1981). In recent years, the disease has been the subject of much research in Malaysia and Indonesia. Most of this work was summarised in Flood *et al.* (2000a), which included a good general review of the current status of the disease (Ariffin *et al.*, 2000). Gurmit (1991) gave a useful review of research up to that date.

Symptoms: The usual first symptom of infection by *Ganoderma* is similar to that of drought conditions: a failure of the young leaves to open, so that a number of fully elongated but unopened 'spears' is seen in the centre of the crown (Turner, 1966a). This indicates that the stem is already extensively damaged, so that water uptake is restricted; it is apparently a direct response to water shortage, so is not necessarily diagnostic for *Ganoderma* (Turner, 1966a). In old palms the lower leaves collapse, hanging vertically downwards from the point of attachment to the trunk (Plate XIVC). This is followed by the drooping of younger leaves, which turn a pale olive

green or yellowish colour and die back from the tip. Later, the base of the stem blackens, gum may be exuded and the distinctive fructifications of *Ganoderma* sp. appear (Plate XIVA). The whole crown of the palm may then fall off, or the trunk may collapse (Plate XIVB).

Bull (1954) described and illustrated the internal symptoms of old palms exhibiting *Ganoderma* trunk rot. In brief, it was found that the peripheral tissues are hard and unaffected by the rot, the black fibres in this zone being normal. Within the stem at the base of the palm the majority of the tissue is yellow-coloured and breaks up easily; mycelium can be found extending through the tissue. Roots are also found to be infected, the cortex being brown and decaying, the stele black. Large numbers of sporophores may be formed, the early ones being small and rounded, the later ones being typical brackets.

Cause: Ganoderma species. Early work referred to *G. lucidum*, but that is a temperate species (Steyaert, 1967). The general consensus now appears to be that *G. boninense* is the main species pathogenic to the oil palm, at least in South-east Asia (Moncalvo, 2000). Idris *et al.* (2001) considered that two other species, *G. miniatocinctum* and *G. zonatum*, were also important. Khairudin (1990b) suggested that *G. tornatum* might be involved, but Idris *et al.* regarded that species as a non-pathogenic saprophyte. In this chapter we will follow most authors in referring to the pathogen simply as *Ganoderma*.

Navaratnam (1961) confirmed pathogenicity by inoculating both roots and stems of 40-year-old palms with *Ganoderma* mycelium. More recently, palms at the nursery stage have also been successfully inoculated (Amiruddin, 1993; Sariah *et al.*, 1994; Ariffin *et al.*, 1995b), and the pathogen has been reisolated (Khairudin *et al.*, 1993).

Distribution: In Malaysia, the disease is much more prevalent on low-lying alluvial soils, particularly the coastal clays, than on inland soils, and it is on the former that the most serious attacks on young palms have occurred. Turner (1965a), examining attacks on young palms, showed that incidence on areas where the preceding crop was coconuts was much higher than where planting followed forest or rubber (see also Fig. 12.1). Turner quoted two instances where fields of 15-year-old oil palms after rubber had 4 and 2% *Ganoderma* attack while adjoining areas which followed coconuts had incidences of 39 and 35%. The greatest losses were said to be where old coconut trunks had been buried, to prevent infestation by *Oryctes rhinoceros* (Section 12.2.4.1). Turner (1981) considered oil palm tissue to be a less conducive medium for the fungus than coconut tissue; he quoted survey results showing 24–28% infection in

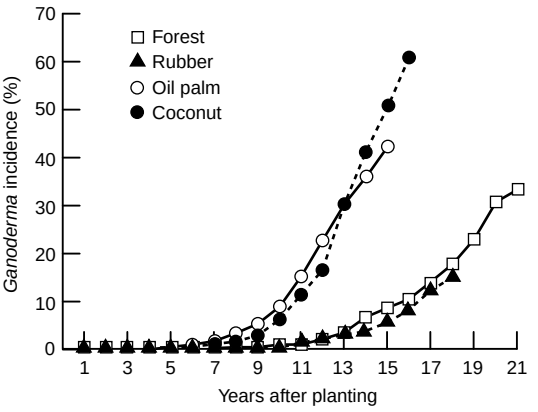

Fig. 12.1 Incidence of *Ganoderma* in oil palm in relation to previous crop. (From data of Gurmit, 1991.)

15-year-old palm to oil palm replants, but 6–81% in oil palms following coconuts (Turner, 1965b). However, Gurmit (1991) quoted a 15-year-old replant with 67% infection, and Fig. 12.1 suggests little difference in the rate of disease development in plantings after oil palm or coconut. On peat soils, a high incidence may be observed whatever the previous crop (Ariffin *et al.*, 1990).

The effect of soil type on disease incidence is not yet understood. Gurmit (1991) suggested that the usually high soil moisture of the coastal soils might favour *Ganoderma* over other, antagonistic soil fungi. According to Swinburne *et al.* (1998), three types of *Ganoderma* can be isolated from oil palms in Malaysia; these were subsequently identified as different species by Idris *et al.* (2001). *Ganoderma boninense* (type A), was significantly more aggressive than type B (actually two species, *G. miniatocinctum* and *G. zonatum*), while *G. tornatum* (type C) appeared to be a non-pathogenic saprophyte. Isolates from coastal soils, usually with a history of previous coconut or oil palm planting, were predominantly *G. boninense*, while those from inland soils were type B. This is consistent with the greater incidence on coastal soils, but it remains unclear whether it is simply coincidental that these types are associated with particular soils. Some live coconut palms were found to contain *G. boninense* as a symptomless endophyte, which could explain the high incidence in plantings following coconuts. Idris *et al.* (2001) speculated that infection by *G. tornatum* might offer some protection against the pathogenic species.

Spread of the disease: If palms in the early stages of the disease are dissected, infection usually appears to have started from the roots. This, and the demonstration that

neighbouring palms were often infected by the same strain of the fungus (Turner, 1965c), led to the assumption that infection under natural conditions is mainly by root contact with an infected palm orother inoculum source. Turner (1981) considered that *Ganoderma* was a weak parasite, and that it needed to develop saprophytically in large masses of dead palm tissue before it had sufficient 'inoculum potential' to infect live plants. More recently, though, Hasan and Turner (1998) showed that even isolated roots from diseased trees could be a sufficient inoculum source.

Seedlings planted very close to *Ganoderma*-infected stumps may show disease symptoms within 1 or 2 years (Hasan and Turner, 1998). These authors showed that poisoned stumps gave higher infection, presumably because they rotted more quickly, and could be invaded by seedling roots more easily. Short (20 cm) stumps gave higher infection rates than 50 cm stumps, perhaps again because they rotted more quickly. Diseased stumps had largely ceased to be sources of infection 2 years after felling. Stumps of healthy palms colonised by *Ganoderma* became sources of infection, and rotted, more slowly than diseased stumps. Hasan and Turner suggested that they therefore remained infectious for longer. They also noted that infected palms may remain apparently healthy for long periods, before the internal damage becomes so severe that external symptoms develop. Ariffin *et al.* (1995a) found, by extraction of trunk samples, that in a 22-year-old planting, between 13 and 17% of palms classified as healthy were actually infected.

Most attempts at control have been based on the assumption that infection is by root contact with an infected palm or other inoculum source. Work with molecular markers has confirmed that this assumption is sometimes correct, as the same genotype was detected in diseased stumps as in seedlings planted close to the stump (Flood *et al.*, 2000b). Some studies on spatial patterns of the disease have shown that diseased palms in some fields tend to be in clumps, which also indicates spread through root contact. However, in other areas the disease appears to be more randomly distributed, as might be expected if spread were by spores (Flood *et al.*, 1998). Recent work with molecular markers (Miller *et al.*, 2000) and mating compatibility studies (Miller *et al.*, 1999; Pilotti and Sanderson, 2001) have indicated that a range of genotypes may exist within quite a small area. Even a single palm may be infected by more than one genotype of the pathogen. This suggests that basidiospores (which are sexually produced and thus genetically variable) may be an important mode of spread.

Bridge *et al.* (2001) used a *Ganoderma*-specific molecular marker to show the presence of *Ganoderma*, in young palms without external symptoms, in the pruned leaf bases. This indicates that the cut leaf bases provide a site for infection by spores. It is possible that the fungus then develops very slowly in palm tissue, and it may be a decade before external symptoms appear, followed by the production of sporophores and a new generation of spores. These may again infect cut leaf bases, this time causing upper stem rot (Section 12.1.6.5).

It seems likely, therefore, that the disease can be spread in two ways. Root contact with an inoculum source, such as old oil palm or coconut trunks, would result in early infection, within a few years after planting. Outbreaks of the disease 15 or 20 years after planting may often be from aerial spores, although slow development of infection that took place more than a decade earlier is a possibility. In PNG it was concluded that spores had so far been the only source of the disease (Pilotti and Sanderson, 2001).

Predisposing factors: The effects of previous crop and of soil type have already been mentioned. The very strong influence of soil type does not appear to have received the attention it merits, but several studies of the effects of fertilisers have been made. Akbar *et al.* (1971) indicated that nitrogen and magnesium may have some role in combating the disease, but more recent trials have given equivocal results. Potassium chloride and urea application have both increased disease incidence in some trials, and decreased it in others (Gurmit, 1991). Tayeb Dolmat and Hamdan (1999) found similar conflicting results with phosphorus and potassium in three trials, two on peat and one on a coastal alluvial soil. Gurmit (1991) noted that high soil salinity and low soil pH appeared to discourage the disease.

Effects on yield: Yield reduction may occur both from death of palms, and from reduced yield in infected but still living palms. Disease losses might be partly compensated for if palms next to gaps gave increased yield, and Turner (1981) stated that there was circumstantial evidence that losses of up to 20% might be compensated for. This may have referred to Prendergast's comments on *Fusarium* wilt (Prendergast, 1957), but other work on that disease suggests that any yield increase is insufficient to compensate for the lost palms (Section 12.1.6.2). More recently, Hasan and Turner (1994) stated that yield compensation ceased at around 10% losses, but again presented no supporting data. The extent to which compensation occurs will depend on the optimal planting density, which varies with soil fertility and with type of planting material (see Section 9.3.3.1). In Sumatra, in plantings from the late 1960s

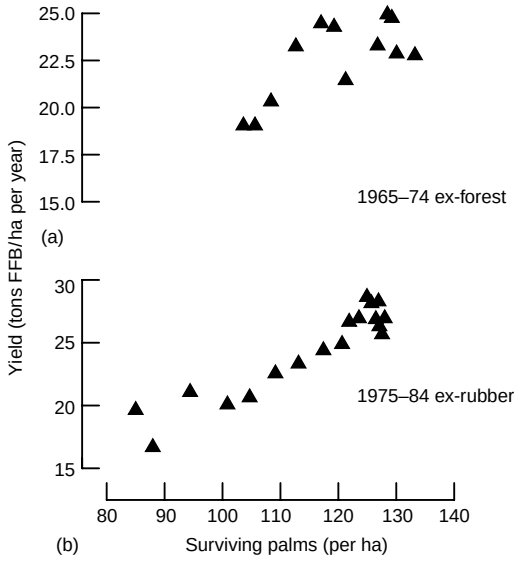

Fig. 12.2 Yield of individual fields in North Sumatra, with different amounts of *Ganoderma* losses. (From London Sumatra, unpubl.)

and early 1970s, there was little decline in yield until the surviving stand had fallen to about 115 palm/ha (Fig. 12.2a), but in more recent plantings, any loss of palms was associated with a loss of yield (Fig. 12.2b).

Khairudin (1995) found that yield of infected palms was reduced by 20–40% in the year before infection was detected. Effects may not always be so large, though: Nazeeb *et al.* (2000) showed that palms with *Ganoderma* yielded between 13 and 21% less than healthy palms at the same age. Gurmit (1991) compared the yield of a field badly affected by *Ganoderma* with that of a less infected field of the same age. The heavily infected field yielded 26% less at 11 years after planting, and 46% less at 15 years, by which time incidence was 67%. It was not stated what proportion of diseased palms had died.

Control at time of replanting: It is generally accepted that incidence of *Ganoderma* increases from one generation of oil palms to the next, but there are few published data to support this contention, the evidence being mainly anecdotal. The 25-year time interval between generations makes reliable comparisons within the same field difficult, and possible genetic differences in susceptibility would further confound comparisons (see *Breeding for resistance*, below).

Table 12.6 shows data from three estates in Indonesia; there appears to be an increase in disease incidence

Table 12.6 *Ganoderma* incidence (% of palms severely affected or dead) in different generations, planted in different blocks at the same time

Estate	Age (years)	Generation			
		1	2	3	4
1	11–15	1.5	7.8	17.9	4.7
2	11–15	–	10.6	10.2	–
	16–20	–	14.9	17.5	–
	21–25	5.1	9.3	17.7	–
	>25	11.4	8.6	–	–
3	11–15	–	11.1	11.1	12.4
	16–20	20.5	20.6	17.8	9.4
	21–25	–	27.6	21.3	–

All blocks were replanted by felling and windrowing; all disease scoring was done in 1999–2000 (de Franqueville, 2000).

over the first three generations in estate 1, and perhaps in estate 2, but not in estate 3. These data are from different fields, recorded at the same time, so could be confounded by the possible effects of soil type already mentioned above. As further evidence against a build-up from one generation to the next, Gurmit (1991) found that fields that ranged from 40 to 60% infection before replanting all had the same level of disease 9 years after replanting. The high incidence in first replants, as shown in Fig. 12.1, suggests that a build-up could occur, but there is little evidence for a further increase after the second replant. Despite this, most control measures are aimed at preventing such a build-up, on the assumption that spread is by root contact with an inoculum source.

The recommended method of reducing *Ganoderma* incidence has been to deal with it at replanting time, by ridding the fields of as much oil palm tissue as possible although, as will be seen, the effectiveness of this is unclear. Mechanical methods of 'clean clearing' were outlined by Turner (1981). Stimpson and Rasmussen (1973) gave an account of a system used on the coastal clays of Malaysia which entailed burning or, if this was not possible, cutting up, splitting the boles and windrowing the old oil palms so that they rotted rapidly. The method included prior poisoning of the palms and subsequent root raking and ploughing to bring up and dispose of pieces of palm base and other material that might form a focus for *Ganoderma*. The operations are costly, but have been regarded as essential in coastal areas. In inland areas the incidence of *Ganoderma* is not usually so great, and the emphasis on clean clearing has been less strong.

Table 12.7 Effects of replanting method on *Ganoderma* incidence

Location	Age when surveyed (years)	Disease incidence and deaths (%)			Ref.
		Underplanted	Felled and windrowed	Clean cleared	
Inland (Johore)	17	5.7	5.0	–	1
Inland (Johore)	20	5.5	4.5	–	2
Alluvial (Sabah)	13	23.4	24.2	–	2
Alluvial (Selangor)	15	33.0	17.6	14.0	3
Alluvial (Perak)	15	–	5.4	0.5	4

References: 1: Loh and Rajaratnam (1977); 2: Pamol Plantations Bhd (unpubl.); 3: Khairudin (1990a); 4: Gurmit (1991).

Table 12.8 *Ganoderma* incidence in first and second replants of the same blocks

Block	First replant[a] (2nd generation of palms)		2nd replant[b] (3rd generation of palms)	
	Year planted	*Ganoderma* (%)	Year planted	*Ganoderma* (%)
1	1955	4.8 (10 years)	1978	2.8 (10 years)
2	1954	19.5 (12 years)	1976	21.6 (12 years)
3	1955	33.8 (9 years)	1975	32.4 (9 years)
4	1957	2.0 (9 years)	1980	3.5 (9 years)
Mean		15.0		15.1

From Gurmit (1991).
Method: [a]Felled and windrowed, stumps left *in situ*; [b]clean cleared by burning, and raking to remove root and bole tissue

Table 12.7 shows results of a number of comparisons of replanting methods. Disease incidence may be higher after underplanting, but in three out of four comparisons the difference was small. In two trials, the difference between felling and windrowing, and the clean clearing advocated by Turner (1981) and others, was also quite small.

Table 12.8 shows a comparison of first replants (the second generation of palms) with second replants (third generation). The first replant was done by felling and windrowing, without removal of stumps; the second replants of the same blocks were done by clean clearing. The almost identical figures in successive generations can be interpreted in several ways.

- Gurmit (1991) concluded that, because clean clearing had not reduced the incidence, the method needed improving.
- If a large increase from one generation to the next is expected, it could be argued that clean clearing has been effective in preventing such a build-up (but the evidence for such a build-up is equivocal; see Table 12.6).
- Comparison of clean clearing and windrowing in the same generation shows little advantage for clean clearing (Table 12.7), so the similar incidence in the two generations in Table 12.8 could, alternatively, be interpreted as evidence against a build-up from one generation to the next.

There is a danger of arguing in a circle, but considering all the results available, we suggest that:

- Clean clearing only reduces disease incidence by a small amount, if at all (although what is meant by clean clearing may differ from one organisation to another).
- Incidence does not increase much from one generation to the next, but is more dependent on the strain of *Ganoderma* prevalent in the area, the soil type or some other predisposing factor.

Hasan and Turner (1994) found that very few seedlings planted over 1.5 m away from infected stumps became infected. One approach to replanting severely *Ganoderma*-infected fields could therefore be to plant down the centre of the interlines (4.5 m from the old stumps). It would probably take the roots of the seedling more than 2 years to reach the stumps, by which time, provided they were poisoned, they should have rotted enough as to be no longer infectious. Hasan and Turner (1994) also suggested that a 2-year fallow period should precede replanting, but this would only be acceptable from the financial viewpoint if some other crop could be taken. Gurmit (1991) showed that 1 year under soya beans before replanting had no effect on subsequent disease incidence.

If spores are the main mode of spread, rather than vegetative contact (see *Spread of disease*, above) then clean clearing may make little difference. The important factor would be a source of spores; for instance, infected old palms adjacent to the young palm area.

Nazeeb *et al.* (2000) suggested planting at a higher than normal density when a high incidence of disease is anticipated. They presented yield data up to the seventh year of harvesting to support this suggestion, but by that stage deaths were only 3–7%. Wood (1999) noted that an underplanting with 80% *Ganoderma* losses by 20 years was more profitable, on a discounted cash-flow basis, than clean clearing, even if the latter completely prevented losses. This is because yield many years after the investment has relatively little value in a discounted cash flow.

Other methods of control: Various attempts to control the disease with systemic fungicides have been made. Early work was not successful (Loh, 1977; Jollands, 1983), perhaps because massive lesions may already be present by the time external symptoms are seen. Ariffin and Idris (1993) found that trunk injection of dazomet had some effect. George *et al.* (1996) obtained a significant reduction in incidence from a combination of carboxin and quintozene, which were more effective than dazomet. The effect was probably to retard development in infected palms, rather than to prevent infection. Effects on yield were not quoted.

Biological control by inoculating lesions with cultures of various micro-organisms was suggested by Varghese *et al.* (1976), and subsequent work was reviewed by Sariah and Zakaria (2000). Soepena *et al.* (2000) described the use of conidia and chlamydospores of *Trichoderma koningii* as a 'biofungicide', but presented no data on its effects. Sariah and Zakaria (2000) studied the effects of *Trichoderma harzianum*, alone and in factorial combination with a mycorrhizal preparation, dried palm oil mill effluent and calcium nitrate, on *Ganoderma* development in inoculated seedlings. Table 12.9 is based on their data, and suggests that $Ca(NO_3)_2$, dried effluent and mycorrhizal inoculation may all have had some effect, but *Trichoderma* did not. Yow and Jamaluddin Nasir (2001) claimed that young palms, inoculated with mycorrhiza in the nursery and planted next to diseased stumps, remained free of infection by *Ganoderma* for at least 3 years, whereas uninoculated plants were 'mostly infected'.

Excision of large, discrete lesions ('surgery') has been practised (Turner, 1968), sometimes successfully, but it is expensive, and treated palms may later collapse. Surgery is less likely to work with young palms than with old palms, but it is with young palms, with a long life ahead of them, where the greater benefit would be obtained from a 'cure'. Gurmit (1991) indicated that a back-hoe could be used to do the surgery mechanically, and gave

Table 12.9 Effect of various treatments on *Ganoderma* development in seedlings

Treatment		Foliar symptoms[a] (%)	Roots with lesions (%)	Bole infection (%)
Calcium nitrate	+	18.9	0.0	0.0
	−	41.0	27.6	23.8
Dried palm oil mill effluent	+	22.8	2.1	0.6
	−	37.1	25.5	23.2
Mycorriza	+	26.0	3.4	1.1
	−	33.9	24.2	22.8
Trichoderma harzianum	+	28.2	13.9	13.0
	−	31.7	13.8	10.8

Four-month-old seedlings were inoculated with rubber-wood blocks. Data are main effects from a factorial design, from Sariah and Zakaria (2000).

[a] Percentage of leaves that were desiccated or chlorotic.

figures for costs, but not for efficacy. Hasan and Turner (1994) obtained some benefit from surgery, in terms of better survival and yield 36 months after treatment.

Removal of diseased palms is probably more widely practised than surgery. Such palms are identified in regular inspection rounds, and removed by poisoning, felling, cutting up the trunk and excavating the bole tissue to hasten decay. Gurmit (1991) presented data which showed that this approach only slightly reduced the rate of spread of the disease. Over a 4-year period, incidence increased from 13 to 50% where infected palms were removed, and from 12 to 57% without removal.

Mounding of the base of diseased palms with soil, after surgery, was suggested by Lim K.H. *et al.* (1995) (Plate XIVD). Numerous new roots developed from the trunk above the point of surgery, with treated palms suffering fewer deaths and some remission of symptoms. Hasan and Turner (1994) found that surgery was unnecessary, mounding alone being just as effective. Ho and Khairudin (1997) found that mounding reduced the death rate from 34% to 2%, over 24 months after treatment. Yields were over 30% higher because of this. Treatment with dazomet as well as mounding gave only a small additional benefit, insufficient to cover the extra cost. By 36 months, only 14% of mounded palms had died, compared with 71% of untreated palms, and yield was over 50% greater as a result (Ho, 1998).

Sanderson and Pilotti (1997; also Sanderson *et al.*, 2000) argued that the disease could be controlled by ensuring that fruiting bodies were never allowed to develop to the point where spores were released. Whether this is a valid approach will depend on the extent to which spread is by spores, rather than root contact. The method needs to be tested.

Breeding for resistance: This is an obvious approach, particularly given its success against *Fusarium* wilt (Section 12.1.6.2). Differences in incidence between West African and Deli material were observed in Indonesia (Akbar *et al.*, 1971), and de Franqueville *et al.* (2001) showed significant differences between families in *Ganoderma* incidence in eight of 12 breeding trials, and between clones in six of seven clone trials. In one trial, for example, incidence in individual families ranged from 12 to 75%, 24 years after planting. An index was calculated, in the same way as for *Fusarium* resistance (Section 12.1.6.2), and showed reasonable consistency for the same parents in different crosses and trials. The development of inoculation methods for plants at the nursery stage should make resistance breeding easier, provided that the processes of infection in seedlings and in mature palms are similar. Amiruddin (1993) used several different *in vitro* inoculation methods to compare three clones, and observed consistent differences among the clones in susceptibility, but Ariffin *et al.* (1995b) found no differences among 20 progenies in a nursery inoculation trial.

Conclusion: Ganoderma has been a serious problem in some areas in Malaysia and Indonesia for 40 years. Despite recent collaborative research (Flood *et al.*, 2000a), our knowledge of the disease still depends heavily on anecdotal evidence, and several aspects remain surprisingly obscure. A great deal has been invested in clean clearing at replanting time, but there is little evidence that this has had much effect. Nor is there convincing evidence that the problem is getting worse; it still needs to be confirmed that the disease increases from one palm generation to the next. An attempt to collate the extensive data that must be available in plantation records, in relation both to palm generation and to replanting methods, might be very informative (Wood, 1999). More research on predisposing factors also appears to be needed.

Mounding of diseased palms, perhaps combined with fungicide treatment, can delay death and improve yield. This appears to be preferable to the removal of diseased palms, which does little to prevent disease development. Systematic removal of all fruiting bodies, to prevent spread by spores, has yet to be tested as a means of control. It appears to us that, in the longer term, the best approach to controlling the disease in areas where it is prevalent may be to develop tolerant material, using nursery inoculation for screening, in much the same way as has been done for *Fusarium* wilt.

12.1.6.4 *Marchitez sorpresiva, sudden wither or 'hartrot'*

Distribution: This disease has been serious on plantations in Colombia, Ecuador and Peru (Plate XID). In Surinam the disease has been described as 'hartrot' (van Slobbe *et al.*, 1978), and a similar condition has occurred in Bahia, Brazil.

Symptoms: The disease is characterised by a sudden rotting of all developing bunches, a reddish discoloration of the top of the petioles and rapid drying out of the leaves from the oldest ones upwards. This drying out is preceded by the appearance of reddish-brown streaks at the ends and centres of the lowest leaflets. The leaf then becomes successively pale green (as in nitrogen deficiency), yellow, reddish-brown and ash-grey (Genty, 1981). The palm dies in 2–3 weeks and as soon as the external symptoms appear the root system will be found to have rotted and to a large extent dried out. Similar symptoms, though proceeding at a slower rate,

are sometimes seen, and in Colombia this has been referred to as 'marchitez progresiva'. However, there may be confusion with fatal yellowing (Corrado, 1970). In the typical marchitez symptoms, the spear is initially unaffected. The root rot is cortical. The cortex decomposes in wet weather, but in the dry season tends to become necrotic and to detach itself from the stele. The rot starts to develop from the extremities and moves towards the trunk and towards the lower roots. The trunk itself usually remains healthy, but cases are reported where the base is rotted sufficiently to form a cavity (Martin, 1970; van den Hove, 1971). Palms have been attacked by marchitez from the age of 1 year.

Cause: Evidence has been accumulating that the cause is infection by a protozoan flagellate, *Phytomonas staheli*. These have been found in several countries in association with the disease, in the phloem of roots, meristem zone, spear base and inflorescence stalks (Dollet *et al*., 1977; Dollet and Lopez, 1978; Dzido *et al*., 1978), and are also present in certain weed species (Dollet, 1982).

A connection between infection and insect attack has been suggested. Lopez *et al*. (1975) considered that the root miner, *Sagalassa valida* (Genty, 1973) (Section 12.2.7.1) might be a carrier, although the disease is often absent in areas where the miner is present. In Colombia, where the disease devastated an area of palms growing in a heavy stand of *Panicum maximum*, the bug *Myndus crudus* (*Haplaxius pallidus*) was found on palm leaves while the nymphs were present on the roots of *P. maximum*. The use of herbicides and insecticides reduced the incidence of marchitez (Mena Tascon *et al*., 1975), while inoculation experiments (Mena Tascon and Martinez-Lopez, 1977) also suggested that *M. crudus* might be playing a part in the transfer of the disease.

Desmier de Chenon (1984) and Perthuis *et al*. (1985) claimed that the bug *Lincus lethifer*, which lives in the axils of the leaves (Dollet *et al*., 1977), was the vector of the flagellate. Symptoms of the disease developed within a few months of the bug being released onto young palms, in the first instance at sites far from any cases of the disease, and in the second on a caged palm surrounded by other, healthy palms. It has also been shown that *L. lethifer* and another species, *L. tumidifrons*, can transmit the flagellates to coconut palms, where they cause hartrot (IRHO, 1992b).

Control: In view of the uncertainty of diagnosis it is difficult to recommend definite control measures. On the grounds that *Sagalassa valida* was likely to be playing a part in the transmission of the disease, applications of insecticide around the base of the palms have been used to suppress the insect, and were strongly recommended in Colombia, Ecuador and Peru (Lopez *et al*., 1975; Genty, 1977). As noted above, it now appears that *Lincus* spp., not *S. valida*, are probably involved, and Gomez *et al*. (1996) indicated that a combination of insecticide and herbicide (to eliminate alternate host plants for *Lincus*) has proved useful.

Cases of marchitez in *E. oleifera* × *E. guineensis* hybrids have not been recorded until recently, so it is possible that the planting of hybrids may be a method of avoiding the disease, although, as with fatal yellowing (Section 12.1.7.2), we doubt whether such a policy can be justified, because of the poor oil yield of hybrids. In Surinam, however, some hybrids have suffered from 'hartrot', although wild *E. oleifera* palms have not been observed with the disease (Alexander and Kastelein, 1983). Certain *E. guineensis* palms on a plantation devastated by this disease remained healthy (Hartley, 1988), so it may therefore be possible to select resistant progenies within the species.

12.1.6.5 *Upper stem rot*

Thompson (1937) described a lethal trunk rot that was serious only on deep peat and inland valley soils. The disease has appeared on other soils in both Malaysia and Indonesia, but is usually sporadic and not of major importance.

Symptoms: Typically, the lower leaves first become yellow and this symptom gradually extends to the middle leaves and then to the spear. It is evident that spore infection of leaf bases takes place and that from these the fungus gains entry to the peripheral tissues of the stem. The brown decay appears to proceed slowly inwards from the leaf bases and in many cases a typical collapse of the stem at one point occurs, this usually following high winds (Plate XVB). The rot spreads upwards and downwards in the stem, eventually killing the palm by invading the crown. Two forms of fruiting bodies (normal and resupinate) appear, but only on palms where the leaf bases are extensively decayed. These are small, greyish-brown bodies with velvet-brown margins and are inconspicuous among the leaf bases. The disease is confined to the stem and does not enter the roots.

Cause and distribution: Phellinus (Fomes) noxius; perhaps also *Ganoderma*. Thompson (1937) described the disease, but little work was done on it until Navaratnam and Chee (1965) and Turner (1969, 1981) gave accounts of its symptoms, incidence and control. The pathogenicity of *P. noxius* was proven by inoculation experiments. *Ganoderma* (Section 12.1.6.3) is also often found in association with upper stem rot, perhaps usually as a secondary infection, but Turner (1981) noted the

possibility that this fungus might sometimes cause the disease, and isolations made in Sumatra have confirmed the presence of *Ganoderma* in all cases of upper stem rot examined (J. Flood, pers. comm., 2001).

Control: As there is usually much penetration of the stem by the time sporophores appear, it is desirable to detect the disease at an earlier stage. This can be done on palms of 10 years or older by striking the leaf bases with a wooden pole to detect the dull sound of an infected base. Incidence is insufficient to justify surveying palms below 10 years old. When the diseased leaf bases are cut away the extent of the infection can be explored. The lesion is excised from the stem with a harvesting chisel and the cut surfaces are treated with a preservative (Turner, 1969). Coal tar has been reported to give the best overall results. Treated palms give as high a yield as untreated palms, so the measures are considered worthwhile wherever incidence is likely to be significant.

In a fertiliser experiment containing different progenies, there was evidence first that fertilisers containing potassium reduced incidence, and secondly that progeny differences in susceptibility existed (Navaratnam and Chee, 1965).

12.1.6.6 *Red ring disease*

Distribution: Red ring is confined to South America, where it has been found in oil palms in Venezuela, Surinam, Brazil and Colombia, where the similar disease of coconuts is prevalent. It has been studied on an estate in Brazil where it did considerable damage (Schuiling and Dinther, 1982). In unprotected areas, incidence can rapidly become high; Malaguti (1953) cited a group of 100 palms showing only 16 doubtful cases in January which by August had 22 deaths, nine doubtful or affected cases and only 69 palms remaining healthy.

Symptoms: The symptoms of this disease have been described by Malaguti (1953). The centre of the crown takes on a dwarfed appearance and the newly opened leaves become bundled together into an erect, compact mass, the leaflets being corrugated, twisted and sometimes adhering to the rachis. Gum is exuded. Later, this crown of leaves turns slowly yellow and dries out, the rachis being a light brown colour with yellow spots. One or two of the intermediate leaves become bronzed and after 2–5 months all of the leaves gradually become yellow or bronzed, although remaining erect. Developing bunches rot and inflorescences fail to set fruit.

The most striking interior symptom is the brown cylindrical ring found in the trunk, 7–8 cm from the periphery and 1–2 cm broad (the ring is red in coconut, hence the name). This ring is most distinct towards the base of the palm (Plate 12.3), but the infection proceeds upwards into the petioles and rachis of the leaves in the crown in which, on cross-sectioning, necrotic areas or spots can be found. This infection does not, however, invade the tissues of the stem apex or surrounding very young leaves.

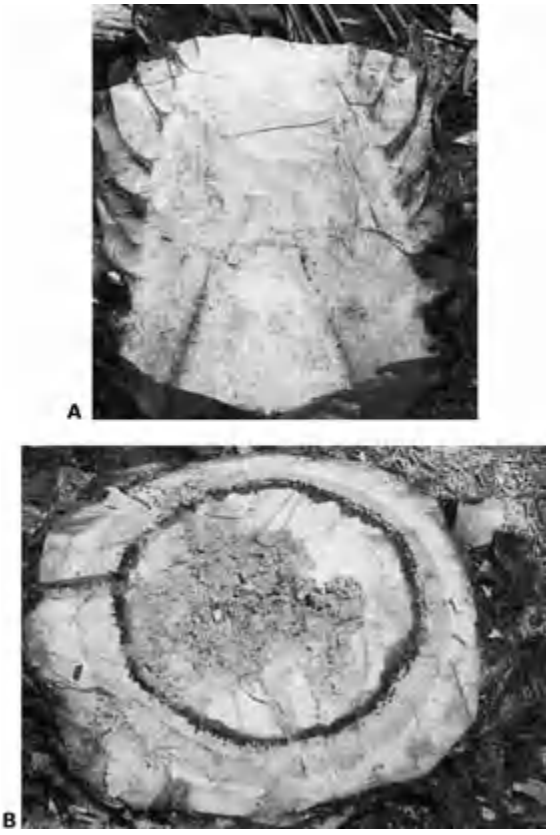

Plate 12.3 Longitudinal (A) and transverse (B) sections of an oil palm suffering from 'red ring' in Venezuela.

Cause and spread: The coconut nematode, *Rhadinaphelenchus* (formerly *Bursaphelenchus* or *Aphelenchus*) *cocophilus*, seems first to have been recorded on oil palms by Freeman (1925) in Trinidad. Proof that the nematode was the cause of red ring was obtained by Malaguti (1953), who did tests with inoculum from both the oil palm and the coconut. The disease appeared 2–10 months after inoculation.

Giblin-Davis *et al.* (1989) described the nematode as an obligate plant parasite, which is only able to reproduce in palm tissue, but can also parasitise the weevil *Rhynchophorus palmarum*, which thus acts as an important vector for the palm disease. Gerber and Giblin-Davis (1990) found that 90% of the weevils emerging from

infected palms carried the nematode either internally or externally. According to Gomez *et al*. (1996), *Metamasius hemipterus* is the main vector in Colombia, but Chinchilla *et al*. (1996) considered that the latter species was not a vector in Costa Rica, and Schuiling and Dinther (1982) found that *M. hemipterus* did not carry the nematode in Brazil. Warwick and Bezerra (1992) showed that transmission in coconuts could also occur by root contact, so this possibility cannot be ruled out for oil palm.

In Brazil, Schuiling and Dinther (1982) found both the nematode and *R. palmarum* on wild *Oenocarpus distichus* palms, and suggested that these may form a reservoir for infection of plantation palms.

Control: Incidence on an affected estate in Venezuela was greatly reduced by the taking of regular sanitary measures (Hartley, 1988, p. 629). Any diseased palm was poisoned, felled and burnt. The whole estate was inspected every 2 months for diseased palms. Most important was the protection of the palm against the type of wounding that provides sites for *R. palmarum* to lay its eggs. A high incidence of red ring in Brazil was preceded by very close leaf pruning which had resulted in wounding of the trunk (Schuiling and Dinther, 1982); care must be taken when removing leaves to make a clean cut sufficiently far up the petiole to avoid this. Circle-weeding with herbicides instead of with hand tools may also help to prevent wounding. Regular disinfection of tools has been suggested, together with treatment of the cut leaf and bunch-stalk surfaces, but provided that wounding is avoided, it is doubtful whether such precautions are necessary.

Oehlschlager *et al*. (1993) described a pheromone-based trapping method for the vector, *R. palmarum*. Chinchilla *et al*. (1995) showed that after a year of trapping, red ring incidence was reduced by two-thirds. Chinchilla *et al*. (1996) showed that pheromone trapping could also be used against *M. hemipterus*. Biological control of *R. palmarum* has been proposed (Moura *et al*., 1993).

12.1.7 Diseases of the bud or stem apex

Under this heading are grouped diseases occurring in the emerging spear and younger leaves inside the crown. Such diseases normally move towards the growing point through the enclosed developing leaves of the 'cabbage', and when they reach it the palm is killed. Bud and spear rots have occurred widely in all three continents and provide, perhaps, the most difficult problems of oil palm pathology. Investigation is difficult owing to the position of the transition zone, often in the heart of the palm, the rapid entry of secondary organisms into any rot within the cabbage and the multiplicity of confusing symptoms, some of which may be similar to those of deficiencies or genetic abnormalities.

Turner (1981) suggested that the term 'spear rot' should apply to diseases in which the primary rotting affects the spear, while 'bud rot' should be used only for diseases first destroying the unemerged leaves and the hidden base of the spear and also, usually, the apical meristem. The latter diseases are usually fatal, the former frequently not.

Plate 12.4 Young palm suffering from spear rot, with no central leaves, Panama.

12.1.7.1 *Spear rot–little leaf disease*

Distribution: This disease, previously called bud rot–little leaf, caused serious losses in the oil palm areas of southern Congo, where deaths exceeding 30% were recorded. Elsewhere in West Africa and in Asia cases rarely exceed a few per cent and are often confined to certain progenies; deaths occur but are rare.

Symptoms: The first sign of attack is a wet, brown rot on the lower part of the unopened spear leaf. Duff (1963) described how in very mild cases only the leaflets may be affected; the leaflet rot is passed from spear to spear until either it develops further or the palm grows out of the attack. Normally, however, the rachis becomes infected and the spear collapses and hangs down; it is not uncommon to find a spear leaf, in which the infected portion has rotted away altogether, lying on the ground where it has fallen. The spear rot grows downwards and may become a bud rot, but it is only if this reaches the growing point that the palm dies. In other cases, the first leaves to emerge after the spear rot are stumps consisting of the malformed basal portion of the rachis. Subsequent 'little leaves' are very short with a few corrugated shortened leaflets, but each successive leaf will be longer, and the leaflets less abnormal, until fully normal leaves are again produced. Little leaf is therefore a recovery symptom and does not precede rotting. Very similar symptoms may occur after damage by insects such as *Oryctes* (Section 12.2.4.1).

Cause: Many causes have been assigned to the 'little leaf' symptom; for the early history of investigations, the paper by Bull and Robertson (1959) should be consulted. One common cause is boron deficiency (Ferwerda, 1954) (see Section 11.4.1), but this is not preceded by spear rot. Robertson (1960), working in Nigeria on palms of a susceptible progeny having regular cycles of infection, showed that spear rot–little leaf disease was an active pathogen, since the appearance of little leaves and bud rot could be prevented by cutting off the spear below the rotted portion. Although prior insect attack is often suspected, it is not known for certain how spear infection takes place.

A bacterium of the genus *Erwinia*, similar to *E. lathyri*, was consistently isolated in Congo by Duff (1963) from young lesions and from tissue in advance of visible rotting, and inoculation experiments showed that spear rot–little leaf symptoms could be induced by it. Susceptibility seems to be genetic, physiological and seasonal. In a field in Nigeria the disease was confined to one progeny. Genetic differences were also found in Congo, where there was an association between rate of growth and disease incidence. The former was judged by the rate of elongation of spears and in susceptible palms the elongation rate fell below normal levels 2 or 3 weeks before an attack of the disease. It was believed that these circumstances, encountered in 'unhealthy' palms, allowed susceptible tissues to be exposed to infection for longer periods than normal. Palms in which the growth rate was artificially reduced by root or leaf cutting showed greater than normal susceptibility. In some instances there has been high incidence at either the beginning or end of the rains (Turner, 1981).

Kochu Babu (1988) described a similar disease from Kerala, southern India, where frequency of the disease increased with proximity to coconuts affected by root wilt or *Areca* palms affected by yellow leaf disease (Kochu Babu and Ramachandran, 1993). Mycoplasma-like organisms have been found in tissues of palms with these diseases, but were not found in oil palms with spear rot (Kochu Babu, 1988). Spear and bud rots in America have different and varying symptoms (Section 12.1.7.2).

Control: Duff (1963) provided growth and health records showing that the more vigorous progenies suffered less from the disease, and he inferred from this that anything interfering with vigorous growth increased susceptibility. While, therefore, the disease is not likely to be serious enough for control measures to be taken in areas where growth conditions, particularly those of water and nutrient supply, are good, in marginal areas the planting of particularly vigorous progenies might be considered (Hartley, 1988).

12.1.7.2 *Fatal yellowing or lethal bud rot (pudrición de cogollo, amarelecimento fatal)*

A bud rot with variable symptoms, but not usually including the typical 'little leaf' progression, has caused serious damage on plantations in Central and South America. Some plantations have been totally devastated, while others have suffered serious losses with many palms remaining in a moribund, unproductive condition for long periods. There has been extensive research on this disease in recent years, much of it reviewed by Gomez *et al*. (2000). Turner (1981) called the disease fatal yellowing, from one of the characteristic symptoms. However, symptoms differ quite considerably between different areas, and the disease is not always fatal. There appear to be both 'acute' and 'chronic' forms, which may be different manifestations of the same disease, as with *Fusarium* wilt (see above), but it appears more likely that more than one disease is being described under one name (IRHO, 1992b; de Franqueville, 2001) (see below, under *Cause*).

Symptoms: In the Llanos Orientales region of Colombia typical symptoms were described by Gomez *et al*. (2000) as dry or wet spear rot, accompanied by yellowing of young fronds (Plate XVD) appearing during wet periods, but disappearing during the dry season. The rot spreads downwards towards the growing point, but affected palms usually recover. Turner's description (1970) of the symptoms in La Arenosa plantation in northern Colombia was quite similar, but it appears that the disease killed many palms when the rot spread to the growing point. Turner noted a tendency for four to six young spear leaves to remain unopened and stuck together, as a 'baton', but he was not convinced that this was a valid disease symptom. When this symptom was seen, spear rot was said to follow within 10–30 days. The rot spread downwards, and within 1–9 weeks the spear collapsed, the rot reached the growing point and the palms died (Plate 12.4). This seems to be the typical 'acute' form of the disease.

As already noted, the symptoms and the severity of the disease appear to vary considerably from one country to another. De Franqueville (2001) described the disease as having two phases: in the first phase, which may last for up to 12 years, increase is more or less linear, but then as foci start to develop, it moves into a phase of exponential increase. Table 12.10 lists the symptoms described by various authors. The main differences are in the extent of chlorosis, the speed with which the spear rot develops, and whether or not the rot reaches the growing point, causing death. The disease appears to take its most acute form in Ecuador, while the most extreme chronic form is that seen in Brazil (Para state) (Plate XVC) and Surinam. De Franqueville (2001) noted that more acute symptoms were seen elsewhere in Brazil. Swinburne (1990, 1993) reviewed symptoms in Brazil, Ecuador and Colombia; he noted that chlorosis is a common response to stress in many plants, and is poor evidence for a common cause. The symptoms that he described for Brazil are similar to those for leaf mottle (Section 12.1.5.4); they are also similar to those described for iron deficiency by Setyobudi *et al*. (1998).

Cause: A wide range of causative agents has been suggested, including insects, fungi, bacteria and viroids. It should be noted that, as symptoms vary from country to country, it is not certain that they are of the same disease or have the same cause. Nieto (1992) believed that the Colombian and Brazilian forms were different diseases, as did Swinburne (1990, 1993). No direct evidence of infectious spread has been found, but in Surinam, van de Lande (1993a) and van de Lande and Zadoks (1999) found a tendency for the disease to spread with the prevailing wind. Downwind spread was also noted in Brazil (Swinburne, 1990, 1993), but this observation was contradicted by Bergami Filho *et al*. (1998) and Laranjeira *et al*. (1998), who found, in later results from the same plantation as Swinburne, no preferential direction of spread, and a tendency for diseased palms to occur near water courses. These authors concluded that the disorder had an abiotic cause.

Ochoa and Bustamante (1974) isolated *F. moniliforme* var. *subglutinans* from diseased palms, and inoculation of palms grown in high humidity and low light intensity caused spear rot. This fungus was said to cause diseases with similar symptoms in sugar cane, maize, sorghum and *Musa* spp. However, Turner (1981) considered that symptoms were unlike those normally associated with *Fusarium* attack.

Recently, it has been reported from Colombia that *Thielaviopsis paradoxa* causes the disease; drying and necrosis of the central leaves was induced by inoculation of seedlings (Gomez *et al*., 2000). These authors imply that *T. paradoxa* was also isolated from diseased palms in Ecuador and Brazil, with different isolates stated to have 'different pathogenicities' and with significant variation in the reaction of seedlings to different isolates. However, de Franquville (2001) stated that *T. paradoxa* was very rarely found in Brazil or Ecuador. It is possible that the chronic form of the disease seen in Colombia is caused by *T. paradoxa*, but that the acute form elsewhere has some other cause. It should be noted that the perfect stage of *T. paradoxa*, *Ceratocystis paradoxa*, is associated with dry basal rot (Section 12.1.6.1), which has quite different symptoms. The fungus is described by Turner (1981) as 'one of the most common fungi recorded on the oil palm throughout the world', and is not normally pathogenic. If this is the pathogen, therefore, it is not yet clear what renders palms susceptible to it in Latin America, but not elsewhere.

Other fungi that have been isolated from diseased spears include *Fusarium oxysporum* and *Botryodiplodia* sp. in Colombia and *F. solani* and *Sclerophoma* sp. in Ecuador. Invasion of bud tissue by many species of bacteria follows the basal spear rot. Pathogenicity of these organisms has not been demonstrated, but de Franqueville (2001) speculated that a joint infection by a fungus and a bacterium may be involved. In Brazil, a viroid was suggested as the cause (Singh *et al*., 1988), but viroid-like RNA was found in both diseased and healthy palms (Beuther *et al*., 1992).

Insects have also been associated with the disease. In Colombia a *Cephaloleia* sp. was found to induce symptoms similar to those of the early stages of the disease, and Urueta (1975) studied a range of other insects in diseased material. In Ecuador, Dzido *et al*. (1978)

Table 12.10 Symptoms of fatal yellowing in different countries

Symptoms	Colombia La Arenosa	Colombia Llanos Orientales	Ecuador	Surinam	Brazil	Panama	Nicaragua	Costa Rica
'Baton' effect	Often	No	No	–	No	–	–	–
Chlorosis (no. of leaves)	A few	A few, mild	A few	Few initially, later many	Many	Often none	Some	A few
Spear break or collapse	Yes	Yes	Yes	Yes	Yes	–	–	Yes
Spear rot	Yes	Yes	Rapid	Usually	Eventually	Yes	Yes	Often
Leaves reduced in size	No	No	No	–	Yes	–	Yes	No
Spread to meristem	Rapid	Rare	Rapid	Slow	Slow	Slow	Slow	Rare
Bunch rot	No	No	–	No	Sometimes	No	–	No
Root rot	–	–	No	No	Yes	–	–	Malformation
Recovery or remission	Rare	Yes	No	Yes	Yes	Yes	Yes	Yes
Death	Yes	Rare	Yes	Yes	Eventually	–	Yes	Rare
Time from 1st symptom to death	4–5 months	Rare	1–2 months	1–2 years	1–3 years	–	–	Rare

Based on Turner (1970, 1981), van de Lande (1993b), van Slobbe (1986), Swinburne (1990, 1993), Chinchilla and Duran (1999) and personal observations (R.H.V. Corley).
–: no information available.

found larvae of *Alurnus humeralis* (Coleptera: Chrysomelidae: Hispinae) and several other insects on diseased palms, but no definite connection between these insects and the disease has been established. Intensive efforts to identify vectors for the disease in Ecuador and Brazil have been unsuccessful (IRHO, 1992b; de Franqueville, 2001).

Wood (quoted by Swinburne, 1990, 1993) found that application of several different herbicides to the roots could cause symptoms similar to fatal yellowing. This suggests the possibility that, if diseased palms were poisoned as a control measure, transmission of herbicide to healthy neighbours may occur through root contact. This could be a contributory factor to the rapid spread of disease sometimes observed, as the neighbours would then show symptoms, and would be poisoned in turn. Swinburne noted that this could not be the only cause, as fatal yellowing has been observed on smallholdings never treated with herbicides.

Predisposing factors: Whatever the pathogen, it is clear that there must be predisposing factors for the disease to develop. It has frequently been associated with poor drainage; Alvarado *et al.* (1997) found, in nursery trials with a susceptible progeny, that poor drainage led to significantly higher spear rot incidence than 'excessive drainage'. However, drainage improvements did not slow the spread of disease in Ecuador (de Franqueville, 2001). Compacted soils and unbalanced nutrition have been mentioned as predisposing factors: in northern Colombia, areas with compacted ex-pasture soils suffered the highest casualties. A low potassium/magnesium ratio was also suspected, but corrective manuring did not stop the disease spreading in La Arenosa (Hartley, 1965; Turner, 1981). Munevar *et al.* (2001) recorded higher incidence of the disease on soils with high clay content, on compacted soils and on poorly drained soils, and they found a much slower rate of spread of the disease where drainage was improved. De Franqueville (2001) mentioned several studies on trace elements, but noted that differences between diseased and healthy palms may be effects, not causes. In Colombia, leaf levels of phosphorus, copper and particularly potassium were lower in infected than in healthy palms, while calcium and magnesium levels were higher (Munevar *et al.*, 2001).

Chinchilla and Duran (1999) described a 'dry spear rot' in Costa Rica, which appears similar to the milder forms of fatal yellowing in Colombia. They noted particularly that the root systems of both healthy and diseased palms in affected areas were poorly developed, with many malformations (corky texture, abnormal branching), and that in affected palms vegetative vigour was reduced before symptoms developed. In some areas recovery occurred after drainage and other management aspects were improved (see *Control*, below). They concluded that any pathogens were a secondary problem, and that the disorder resulted from stress caused by poor soil aeration, in areas with a high water table and inadequate drainage, or suffering from soil compaction or with shallow soil overlying gravel. However, de Franqueville (2001) quoted several studies in other countries showing that the root system of affected palms was normal and healthy.

Effects on yield: Very heavy losses of palms have occurred on certain plantations in Colombia, Ecuador and Brazil, with severe effects on yield. The heaviest losses have often been associated either with surgery to remove rotting spear tissue, which may expose the growing point and increase subsequent damage, or with deliberate destruction of diseased palms, and sometimes of healthy palms surrounding diseased points, in an effort to prevent the disease spreading. It appears not always to have been appreciated that, if 14% of palms show symptoms (whether fatal or not), and those palms and their six immediate neighbours are destroyed, close to 100% mortality will result. Van Slobbe (1988) noted that 46,000 palms had been 'lost to the disease' on one plantation in Brazil, but also that 'all diseased palms have been eliminated within a month after detection'. De Franqueville (2001) later reported that this plantation had been abandoned because of disease losses. Van de Lande (1993b) recommended that even recovering palms should be destroyed in Surinam, as it was not certain that they were not still infectious.

In Colombia and Costa Rica, affected palms usually recover if they are left untouched (Chinchilla and Duran, 1999; Gomez *et al.*, 2000). Santacruz *et al.* (2000) stated that 80–90% of palms recovered within 1.5–3 years. If palms are left to recover naturally, then yield also recovers, although this may take some time. Chinchilla and Duran (1999) stated that 2 years after the first symptoms had been seen, yields were still below those expected from palms of that age. Santacruz *et al.* (2000) found that yields of fruit were depressed by 30–40% in the first 2 years; oil/bunch was also slightly depressed. Acevedo *et al.* (2000) showed that both FFB yield and oil/bunch were reduced, and oil yield was halved in the worst affected palms.

Control: Speculative prophylactic applications of mixed fungicides and insecticides have not been successful (e.g. Gomez *et al.*, 2000). Surgical removal of rotting spear tissues was widely practised in Colombia at one stage, but Santacruz *et al.* (2000) stated that recovery was just as good if no surgery was done. Destruction

of infected or suspect palms has been widely practised but, as noted above, this has probably contributed more to the problem than to control.

Chinchilla and Duran (1999) indicated that the disorder could be prevented by improving drainage, mulching with composted empty bunches, and paying particular attention to potassium and phosphate nutrition. Affected blocks more than 20 years old were replanted, after subsoiling to rectify soil compaction. In Colombia, the problem has been greatly reduced where drainage was improved (Munevar *et al.*, 2001). Deep ploughing, to improve soil aeration, and fertiliser application to lower the (Ca + Mg)/K ratio, also reduced disease incidence (Acosta *et al.*, 2002).

Breeding for resistance: It is possible that there may be resistant lines within *E. guineensis*: there are several reports of differences between progenies in disease incidence (e.g. Santacruz *et al.*, 2000), with Deli × Avros material apparently being more susceptible than other origins in Colombia. In Ecuador, de Franqueville (2001) reported differences in rate of disease development between crosses of Deli × La Mé origin. Ayala (1999) described a method for testing the susceptibility of individual palms by inoculation of petiole sections with *T. paradoxa*.

On La Arenosa plantation in Colombia several plots of *E. oleifera* × *E. guineensis* hybrids survived while large numbers of the surrounding *E. guineensis* palms died. Similar observations have been made elsewhere (IRHO, 1992b). In areas subject to fatal yellowing, the planting of this hybrid has been regarded as a possible method of combating the disease, and large parts of La Arenosa were replanted with hybrids (Turner, 1981). However, oil yield of these hybrids is generally poor, because of low oil/bunch (although they may have other advantages; see Section 5.5.1.6 for further discussion).

Conclusion: In Ecuador and parts of Colombia, this complex of symptoms is undoubtedly a serious problem, but in many areas it seems that its importance has been exaggerated, and losses have been exacerbated by the measures taken to 'control' the 'disease'. Good agronomic management appears to be the answer in most places. Planting of interspecific hybrids is unlikely to be justified, given the poor oil yield of such material, and we think that other reasons besides resistance to this disease are needed to justify the efforts put into breeding of such hybrids.

12.1.8 Diseases of the bunches and fruit

The occasional bunch and fruit rots that are encountered have not been extensively studied. Bunch-end rot has been associated with the Deli palm, particularly in Malaysia (Thompson, 1934). Where neither lack of pollen nor insect attack is implicated, both this condition and complete bunch failure have been attributed to 'overbearing' (Turner and Bull, 1967): the number of bunches is thought to be more than can be sustained by the palm's processes of assimilation. As discussed in Section 4.3.6, however, the evidence for this is not convincing.

A bunch stalk rot has been connected with an unexplained condition in West Africa known as leaf base wilt (Bull, 1954). The leaves bend down towards the ground and the stalks of bunches in the leaf axils also bend and may then begin to rot. The disease seems to be of purely mechanical origin and provided the rot is not so extensive that the bunch falls, the majority of fruit will develop. The small splits that appear in the stalk are invaded by a variety of saprophytic bacteria and fungi.

Marasmius palmivorus is common as a saprophyte on the cut leaf bases and on the decaying debris between these and the trunk. It appears that, under moist conditions in the Far East, sufficient inoculum potential may sometimes build up for healthy bunches to be invaded (Turner, 1965d). For a full discussion of the factors involved in the spread of the disease, Turner (1981) should be consulted. The obvious means of control is to reduce, through sanitary measures, the medium on which the fungus grows on the palm. Rotting bunches should also be removed. Prophylactic spraying against *Marasmius* is not generally recommended, but Turner (1981) considered that on acid sulfate soils in Malaysia spraying may be economically justified.

12.1.9 Other abnormal conditions

The oil palm is subject to many abnormal conditions of growth and development, the causes of which are not known. Usually, although not always, these abnormalities are encountered where conditions are in some way adverse: impoverished sandy soils, long dry seasons, excessively wet conditions or intermittent waterlogging, grass competition, pockets of unusual soils, etc. In the more severe conditions bunch yield is usually negligible (Courtois, 1968). Only a few are mentioned here.

The term plant failure was used by Wardlaw for palms that almost ceased to grow. The rate of root and spear production, and the number of green leaves, decreases and the leaves that remain are erect and crowded. This, in turn, leads to a tapering of the trunk and progressive deterioration of the leaves, which are subject to various kinds of chloroses, dry out prematurely and become brittle. There has been much speculation on the reasons for such palms being found dotted about among normal ones. The condition rarely occurs

in Asia. In Africa it is either considered to be of genetic origin, or may be associated with severe potassium and magnesium deficiency, or where soil depth varies sharply from point to point.

A condition known as choke, or dwarfed crown, has been encountered in fields in America suffering from red ring disease (Section 12.1.6.6), but does not appear to have the same cause (Malaguti, 1953). It has been referred to as hoja pequena (little leaf), but the term 'little leaf' should be reserved for the recovery symptom of spear rot–little leaf. In this condition all the leaves are smaller than normal, green, erect, bunched together and twisted with varying amounts of atrophy or corrugation of the leaflets. A sudden recovery from the condition is frequent, a tall cluster of normal new leaves being produced in the centre of the deformed ones, giving the palm a two-tier appearance. This type of deformity is not unknown elsewhere, and the term 'choke' has been used in Malaysia to describe a similar condition.

The oil palm is occasionally killed by lightning strike. Young palms can collapse rapidly and wither, but a sublethal condition known previously as rachis internal browning is now also believed to be caused by lightning (Turner, 1981). In older palms the trunk base is often charred. Lightning strike can usually be distinguished from other causes of death because surrounding palms show scorching on the side facing towards the strike.

Oil palms are quite tolerant of short-term flooding, and have been successfully established in river flood plains. However, if young palms are flooded to a level above the leaf axils, so that silt is deposited in the axils, extensive inflorescence abortion, and sometimes death of the palm, may follow. The risk diminishes as the palms grow taller, but significant losses have sometimes occurred in young plantations (Teoh *et al.*, 2001).

12.1.10 Plant quarantine

The existence of serious diseases in some areas but not others justifies strict plant quarantine measures. Fungal spores are the most likely contaminant, but nematodes (unidentified, but in this case apparently harmless) have been found on germinated seeds (Kushairi and Rajanaidu, 2000). There are already examples of diseases spreading: as noted in Section 12.1.6.2, *Fusarium* wilt was spread from Africa to South America with oil palm seeds. The precautions adopted in Malaysia were described by Kang (1986), and included prohibitions on import of seed or pollen from areas where diseases of unknown aetiology occur, prohibition of import of secondary hosts or insect vectors of disease, and limits on the quantities of seed imported. Precautions must start in the country of origin, with inspection of parents palms for disease and thorough cleaning of materials. Where possible, seed and pollen should be screened for spores of important fungal diseases at an intermediate quarantine centre, between the country of origin and the importing country.

Flood *et al.* (1994) developed a method of fungicide application involving vacuum infiltration, which eliminated *Fusarium* spores from seeds, including any within the shell. This treatment should be applied whenever seeds are exported from areas where significant fungal diseases occur (see Section 7.1.5).

12.2 PESTS

The most important pests of oil palms are arthropods (insects, mites) and mammals, but other groups of animals may cause problems from time to time. In this section we have grouped the arthropod pests according to the damage that they do to the palm. We believe this arrangement will be more useful to the non-specialist than the conventional arrangement by zoological classification. We have attempted to give the correct Latin names for pest species, but taxonomic changes are regrettably frequent. For some species we have also given well-known but no longer valid names.

Wherever possible, growers should use integrated pest management (IPM) systems. These involve the encouragement of biological control of pests, the adoption of agronomic methods that minimise the risk of pest outbreaks and, if pesticide application is unavoidable, the use of selective chemicals and application methods with minimal side-effects. IPM has been widely applied in the oil palm industry for several decades, and much of the current understanding of the principles of IPM developed from work on tropical crops. As early as 1962, it was recognised that insecticides were causing pest attacks in oil palms, by upsetting the ecological balance between the pest and its natural enemies (Wood, 1971). In *Pests of oil palms in Malaysia and their control*, Wood (1968a) enunciated the principles of what was then known as integrated pest control, with more than one-third of the book being devoted to explaining the reasons for pest outbreaks, methods of monitoring pest populations and ways of controlling pests without disruption of the natural balance in the agroecosystem (see also Wood, 1976c, 1987). As a result of the understanding of pest

ecology that has been built up in all the main areas where the crop is grown, oil palms generally remain free of damaging pest outbreaks, without much need for intervention with insecticides.

Smith and Reynolds (1966) proposed an ecologically based classification of pests.

- Key pests are perennially occurring, and would cause severe damage in the absence of control measures. These are pests for which the limitation by natural enemies is generally inadequate.
- Occasional pests may cause sporadic economic damage, if the usually good environmental control, including biological control, is disrupted.
- Induced or potential pests cause no significant damage under current conditions, but have the potential to do so if environmental control were disrupted by changes in agricultural practice (usually the application of an insecticide).

This classification can be useful in considering how to manage a pest, although in practice it may be difficult to apply, as it refers to the natural balance between pests and their enemies, and not necessarily to that actually existing in the plantation.

There are no key pests of the oil palm, but a number of occasional pests can cause serious damage. For example, Wood *et al.* (1973) showed that a single bagworm outbreak, causing more or less complete defoliation of 10-year-old palms, reduced yield by 40–50% over the next 2 years. Many factors may disrupt natural balance, and when an outbreak does occur, it is important to try to understand what caused it. This can be difficult, because outbreaks may persist for some time after the original disturbance has disappeared. Wood (1979) suggested that this was because it can take time for natural enemy numbers to build up to match the numbers of pests. The more important occasional pests are discussed later in this chapter.

There are numerous potential pests. For example, in South-east Asia Wood (1968a) mentioned over 80 arthropod species; in Latin America, Mexzón and Chinchilla (1993) listed 41 species, and Genty *et al.* (1978) over 70; in Africa, Mariau *et al.* (1981) listed 22 species, and Wood (1983a) 26 species. Some potential pests are listed in Table 12.11.

We have not given detailed recommendations on pesticides, as these are constantly changing, with new compounds being developed and older ones withdrawn. The most recent general recommendations appear to be those of Mariau (1993) and Jacquemard (1998).

12.2.1 Integrated pest management

The important aspects of an IPM system can be summarised as follows.

- Knowledge of the life cycle and ecology of the pest, and of its natural enemies, is required, if biological control is to be understood and manipulated.
- A monitoring or census system to ensure early detection of outbreaks should be in place, so that control measures can be planned, and applied at the most appropriate time.
- Economic damage and action thresholds should be established, so that control measures are not taken unless and until they are necessary, giving the natural balance a chance to be re-established.
- Control measures must be selective, so that swift re-establishment of the natural balance is promoted.

Each of these aspects is discussed briefly below. For more detailed discussion in relation to oil palms, see Wood (1971, 1976c, 1979, 1987). Recent reviews are given by Teh (1996), Ho and Teh (1997) and Chung and Sharma (1999). Specific examples are also mentioned in the sections on individual pest species. Oil palm workers have not always adhered to IPM principles, though; numerous papers have been published describing potential oil palm pests and testing insecticides for control, without any evaluation of the severity of damage or the extent of natural control. Many of the older recommendations took no account of the possibilities of IPM. In some instances these have not been updated, probably because it has become apparent that control by natural enemies is sufficient, and no action is necessary.

12.2.1.1 *Pest ecology*

As Wood (1976c) pointed out, the environment in an oil palm plantation, with a uniform expanse of the crop and a more or less constant environment, would appear to favour the build-up of pests. Many occasional pests are commonly present in a stand of oil palms, and the reason that outbreaks do not usually occur is that numbers are restricted by the action of natural enemies; these include both predators on the pests and species that parasitise the pests. Outbreaks may occur if the natural balance between a pest and its enemies is upset for any reason.

One of the major factors in pest outbreaks in oil palms in the past was the use of broad-spectrum (killing a wide range of species), persistent-residue, contact insecticides. These were often applied as a precautionary measure against minor pest infestations, but their

Table 12.11 Potential oil palm pests

Pest	Stage attacked	Damage	Occurrence	Ref.	Comments
Pests causing leaf damage					
Red spider (*Olygonychus* sp.)	Nursery	Leaf turns brown, necrotic	Widespread	1	Often induced by pesticide application. Not a problem with overhead sprinkler irrigation
Aphids	Nursery	Growth rate reduced	Malaysia Congo	1, 2	Severity has not justified treatment
Mealy bugs, scale insects	Nursery, field	Leaf, fruit		2, 3	Often tended by ants; control of ants may eliminate pest; serious damage rare
Grasshoppers	Nursery	Defoliation	Widespread	2	Several species; hand-removal effective
Grasshopper, *Valanga nigicornis*	Young palms	Defoliation	Malaysia	2, 4	Particularly in new plantings, after drought; spraying may be necessary
Stink locust (*Zonoceros variegatus*)	Young palms	Defoliation	West Africa	2, 5	Damage followed slashing of overgrown covers
Leaf-cutting ants	Mature palms	Defoliation	Latin America	2	
Alurnus humeralis	Mature palms	Defoliation	Ecuador	6	Coleoptera: Chrysomelidae: Hispinae
Homophylotis catori	Mature palms	Defoliation	Africa	5, 7	Caterpillar: Zygaenidae (syn. *Chalconycles*)
Leptonatada sjöstedti	Mature palms	Defoliation	Africa	5	Lepidoptera: Notodontidae
Hispoleptis spp. (Hispinae)	Mature palms	Leaf miner	Ecuador	2, 8, 9	Damage similar to *Coelaenomenodera lameensis*; control by trunk injection (Ref. 9)
Promecotheca cumingi	Mature palms	Leaf miner	Malaysia	1, 8	Coconut pest, occasionally attacks oil palm Coleoptera: Chrysomelidae: Hispinae
Norape argyrrhorea	Mature palms	Defoliation	Peru	18	Lepidoptera: Megalopygidae; controlled by virus
Beetles	Mature palms	Bore into petioles	Malaysia, Africa	2	*Xylotrupes gideon, Platygenia barbata*
Retracus elaeis, orange spotting mite	Field	Orange spots	Colombia	10	Eriophidae; may cause 50% crop loss; wettable sulfur gave effective control

Pests damaging trunk or roots					
Eldana saccharina	Nursery	Larvae bore into spear/bud	Africa	5	Lepidoptera: Pyralidae
Dynastes (Augosoma) centaurus	Nursery, field	Similar to *Oryctes*	Africa	2, 5	Coleoptera: Dynastinae
Scapanes australis	Young field palms	Similar to *Oryctes*	SE Asia	11	Coleoptera: Dynastinae
Sufetula spp. (Lepidoptera: Pyralidae)	Mature palms	Destroy aerial roots	Widespread	5, 12	No evidence that loss of aerial roots is harmful
Monolepta apicicornis	Mature palms	Mines within root	West Africa	5, 13	Coleoptera: Chrysomelidae: Galerucinae
Termites (*Coptotermes curvignathus*)	Mature palms	Bore into trunk, palm falls	Malaysia, Indonesia	1, 11, 14	Should be eliminated at time of planting; may be a particular problem on peat (Ref. 15)
Cockchafer larvae	Nursery, field	Root damage	Malaysia	1, 16	*Leucopholis*, *Apogonia*, *Adoretus*
Cockchafers	Nursery, field	Leaf damage	Malaysia	1	
Pests damaging fruit					
Tiquadra spp.	Mature palms	Spear, bunch	Colombia	2	Damage similar to *Tirathaba* (12.2.8.1)
Prosoestus spp.	Mature palms	Stigma damage, poor fruit set	West Africa	2, 17	Effect small, undamaged fruits enlarge to fill space of damaged; treatment expensive
Elaeidophilos adustalis	Mature palms	Stigma damage, poor fruit set	West Africa	17	Effect small; treatment expensive
Scale insects	Mature palms	Not serious		1	

References: 1: Wood (1968a); 2: Hartley (1988); 3: Ponnamma (1999); 4: Han and Chew (1978); 5: Mariau *et al.* (1981); 6: Mariau (1976b); 7: Airede *et al.* (1999); 8: Mariau (1999a); 9: Le Verdier and Genty (1988); 10: Genty and Reyes (1977); 11: Mariau *et al.* (1991); 12: Genty and Mariau (1975); 13: Mariau and Djob Bikoi (1990); 14: Mariau *et al.* (1992); 15: Lim and Silek (2001); 16: Wood and Ng (1969); 17: Philippe (1993); 18: Zeddam *et al.* (2003).

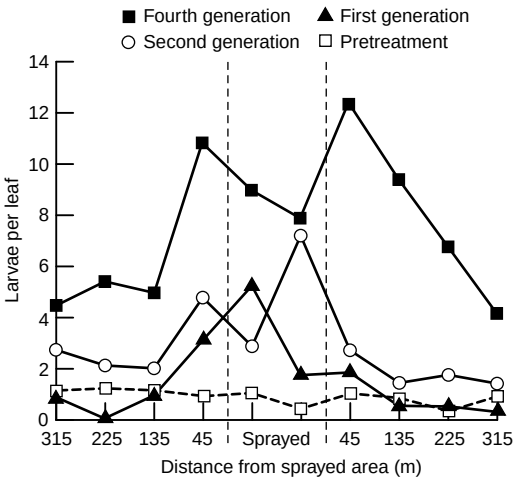

Fig. 12.3 Effects of dieldrin spray on population of *Metisa plana*. The population increased after spraying, centred on the sprayed area. (From Wood, 1971.)

use could exacerbate the problem, by killing the natural enemies of pests, so that any biological control ceased to operate. The pest which became a problem after spraying was not always the same as that which had provoked the initial precautionary application. The possible effect of spraying with a broad-spectrum chemical is clearly illustrated in Fig. 12.3. When a 0.8 ha plot of palms was sprayed regularly with a low dosage of dieldrin, the population of the bagworm, *Metisa plana*, built up considerably over the next four generations, spreading out from the sprayed area. Wood (1968a) noted that it is difficult to prove that insecticides have caused outbreaks, but the coincidence has been sufficiently frequent as to leave little doubt.

One reason why spraying with broad-spectrum chemicals can cause a pest outbreak is that it is likely that a few of the pests will survive the spraying, but almost none of their enemies, simply because the pest is usually present in larger numbers than its enemies. In that case, the pest can then build up uncontrolled. With contact insecticides, patchy or uneven application is likely to make matters worse, because the natural enemies are usually mobile and exploratory in their behaviour, so will move into sprayed patches, while the more static pest remains untouched elsewhere. Wood (1987) noted that a high kill of the pest with moderate survival of enemies was probably better than a moderate kill of the pest with complete survival of enemies. An additional factor is that only one particular stage in the life cycle of the pest may survive; if so, then subsequent generations will be highly synchronised (e.g. Mariau, 1976a). Under normal conditions in the tropics, all stages tend to be present, and there has thus been no pressure for the natural enemies to evolve co-ordinated life cycles. If pest generations do become synchronised, natural enemies may be heavily outnumbered, so that control of the pest breaks down.

Pesticides are not the only cause of outbreaks, which sometimes occur in areas where pesticides have not been applied. Syed and Shah (1977) quoted circumstantial evidence to suggest that complete eradication of weeds by herbicide spraying had contributed to pest outbreaks in Sabah. They argued that weed species were important food plants for the adults of parasitic wasps; weed eradication thus reduced the level of parasitism and allowed pest numbers to build up. Prior (1988) demonstrated the importance of two weed species in supporting a wasp parasitic on grasshoppers in PNG (Section 12.2.5.4). Delvare and Genty (1992) recommended protecting and spreading certain weed species in Latin America, to support beneficial insects. In Malaysia, Ho (1998) showed that numbers of the bagworm, *Metisa plana*, were suppressed for about 200 m on each side of a planted strip of *Euphorbia heterophylla*, a species shown to be attractive to a wide variety of different insects.

Wood (1968a) suggested that dust from dry dirt roads in plantations might be a disturbing factor. Dust can kill insects by abrasion of the cuticle, and may affect the active natural enemy species more than relatively inactive pests such as caterpillars. Syed and Shah (1977) considered that any effect of this would only extend a few palms away from the road, but that pockets with high pest numbers might develop in consequence, which could then lead to larger outbreaks when other conditions were favourable. Siburat and Mojiun (1998) observed outbreaks of leaf-eating caterpillars after floods, which might have eliminated natural enemies whose adults lived on ground vegetation. They suggested that drought could have a similar effect.

Knowledge of pest life cycles can be useful, particularly when synchronised generations occur. Life cycles for many Malaysian pests were given by Wood (1968a). Siburat and Mojiun (1998) gave a life-cycle table for *Setora nitens*, showing the control measures appropriate for each stage. Studies of natural enemies can also be useful, although the enemies important under normal conditions may not be the most effective in containing outbreaks (Wood, 1979). Mariau *et al.* (1991) illustrated a number of the more important predators and parasites in South-east Asia.

12.2.1.2 *Economic damage thresholds*

Response should be related to pest numbers, rather than following a predetermined programme. Regular prophylactic pesticide applications can appear to give control, but by removing natural enemies, may ensure that the problem persists. Defining a critical level of a pest provides the necessary link between ecology and economics (Wood, 1979). A warning level may be useful, as an alert to potential danger. It is important also to understand whether the pest population is increasing, stable or decreasing.

As an example, studies of the damage caused by *Oryctes* in young oil palms have shown that, during the first year in the field, quite extensive defoliation has little or no effect on subsequent yield (Wood *et al.*, 1973; Liau and Ahmad Alwi, 1995). This appears to be because growth at that stage is not limited by photosynthetic activity, so after partial defoliation, the remaining leaves can photosynthesise more rapidly to meet requirements for vegetative growth (see Section 4.2.2.1 for further discussion of this). Some degree of control of *Oryctes* is needed, because the beetle may kill young palms, not just defoliate them. In addition, if damage persists into the second year, it starts to affect yield (Liau and Ahmad Alwi, 1995; Chung *et al.*, 1999). The important point, though, is that apparently severe damage in the first year may have little economic effect, and the control strategy should take account of this.

12.2.1.3 *Census systems*

If responses are to be based on pest numbers, then a regular monitoring system must be in place. Pest numbers may be counted directly, or an assessment of damage may be made. Monitoring systems for leaf-eating caterpillars were discussed by Wood (1976c). Most systems involve at least two stages: a superficial inspection for signs of pest incidence, the 'detection' stage, and more detailed assessment where such signs are found, the 'enumeration' stage. Chung *et al.* (1995) described a system for bagworms, based on unpublished work by Wood, with three stages.

1. The *alert* stage involves looking for the small holes in leaves, which are signs of feeding damage. This inspection can be undertaken by harvesters, and is frequent (fortnightly) but superficial.
2. When feeding damage is noticed, the *census* stage is activated. An upper frond from 1% of palms is cut down, and the number of individual bagworms and nettle caterpillars, both alive and dead, is counted by a specially trained team. The census is repeated in affected areas every 1 or 2 weeks, different palms being used each time to avoid excessive defoliation.
3. The results of the census determine whether the *action* stage is needed. Control measures are implemented if the census in affected and adjacent blocks shows that all of the following conditions are met.
   - Infestation is spreading.
   - Natural control appears to have failed.
   - The pests are at the small larval stage, with cocoons absent or very few.
   - Numbers exceed 5–10/frond for the smaller species, or 1–5 for the larger, indicating that there is a high risk of crop loss.

Mariau (1994) gave a more general review of census systems in various parts of the world, together with a list of advice notes on pests published in *Oléagineux* between 1967 and 1994. The recommended frequency of the alert stage depends on the expected pest species. The choice of leaf for detailed recording will depend in part on the particular pest, as some damage young leaves and some older leaves (Wood, 1976c). The action level for a pest may depend on the weather; Mariau (1999b) noted that the leaf miner *Coelaenomenodera lameensis* multiplies more slowly during drought, so the action level can be higher.

12.2.1.4 *Control measures*

Various management practices are important components of IPM, in ensuring that outbreaks do not occur. The probable importance of the weed flora as food plants for natural enemies has already been mentioned. Ground cover also plays a role in limiting *Oryctes* damage (Section 12.2.4.1). Study of the life cycle of a pest may reveal an alternate host plant, the elimination of which from the plantation will help to control the pest.

If pesticide application is needed, it should be selective. Bio-insecticides (preparations of parasitic fungi or insect viruses, or *Bacillus thuringiensis*) can be effective (e.g. Desmier de Chenon *et al.*, 1988; Sipayung *et al.*, 1990; Ramle *et al.*, 1995). The damaging effects of some of the older broad-spectrum, persistent-residue chemicals have already been mentioned, but some modern chemicals are also broad spectrum and can cause problems if wrongly used. The synthetic pyrethroids, for example, break down rapidly and have little residual effect in the tropics, but they are broad spectrum and repeated use can damage natural enemy populations.

Selectivity can be achieved not only by choice of chemical, but also by the timing and method of application. Knowledge of the pest life cycle may allow application to be timed to a stage when the maximum

kill can be achieved, while sparing natural enemies. For example, with *Coelaenomenodera lameensis*, spraying may be most effective against adults; larvae in galleries within the leaf lamina are protected from contact pesticides (Mariau, 1999b). One of the best methods of insecticide application to oil palms is by trunk injection (Wood *et al.*, 1974) or root absorption (Ginting and Desmier de Chenon, 1987). In this instance, the application method provides selectivity. A systemic pesticide moves into the leaves, and only species that eat the leaves will be affected. The risk of affecting non-target species is usually minimal, although Prior (1988) noted effects on crows and domestic chickens after they had eaten grasshoppers that had been treated by trunk injection of monocrotophos. Sarjit (1986) showed that trunk injection could be done effectively and economically on a large scale. The equipment is cheap and may have other uses. This is important, as where pest outbreaks are rare, equipment may remain unused for long periods.

Insect pheromones, volatile chemicals produced as signals to other insects, are increasingly being used in pest-control strategies. For example, female bagworms are wingless and immobile, and attract males by releasing a pheromone. Baiting traps with the pheromone to collect males could, clearly, disrupt mating and contribute to control of bagworms (Rhainds, 2000). Pheromone-baited traps may also be used for monitoring populations.

12.2.2 Nursery pests

Several potential nursery pests are listed in Table 12.11. Red spider mite may have severe effects, but is rarely a problem in nurseries irrigated by overhead sprinklers. Boron applications have been found to reduce spider mite injury (Rajaratnam and Law, 1975).

12.2.3 Leaf pests of immature palms

Most of the leaf pests of mature palms may also attack young palms. The pests listed in this section appear to attack mature palms only rarely, however.

12.2.3.1 *The African spear borer*

Distribution: This moth, *Pimelephila ghesquierei* (Pyralidae, Pyraustinae), first described from Congo, is found in all African territories. It is not a common pest, but on occasions the damage done has been severe. It has perhaps been more troublesome in Central than in West Africa.

Life cycle and damage: Damage is most common between the second and fifth years in the field, but both nursery seedlings and older palms are sometimes affected (Buyckx, 1952). The eggs are laid by the moth at the base of the spear leaves and even one larva hatching can do considerable harm. Usually, two or three are found on young palms or up to a dozen on older ones and, typically, they penetrate the rachis and leaflets of the growing, unopened spears, forming galleries through them. The attack may proceed downwards towards the growing point and the rachis may be so damaged that later, in a strong wind, several young leaves may snap near the base. When unbroken spears open, the holes left by the caterpillar are seen to be symmetrically placed on either side of the rachis. The caterpillar does not kill the palm, but may be followed by weevil larvae, e.g. those of *Temnoschoita*, or a bacterial rot that may prove lethal (Buyckx, 1952).

The caterpillars reach a length of 3–4 cm before pupating in a cocoon of fibrous debris. The colour of the caterpillar changes from dark red to yellowish as it develops. The olive to brown moths are not long in emerging from the pupae and the whole life cycle takes 35–45 days; attacks can therefore be made at frequent intervals.

Control: Light attacks can be dealt with by removal of infected leaves and collection of the caterpillars and pupae. In the Ivory Coast spraying has been carried out at intervals of 2–3 weeks in nurseries and for the first 2 years in the field, but older palms are less vulnerable to attack and are not usually treated (Mariau and Morin, 1971).

12.2.4 Stem damage to young palms

12.2.4.1 Oryctes *species (Dynastinae): rhinoceros beetles*

Distribution: Species of *Oryctes* are found throughout the palm-growing areas of Africa, Asia and the Pacific. Damage is worst in young palms, and comparatively rare in palms older than 3 or 4 years, although Dhileepan (1988) recorded damage up to 15 years after planting in India, and isolated tall palms are often attacked.

The following species are the most important oil palm pests:

O. rhinoceros	The common rhinoceros beetle of the Far East, which has spread to the Pacific islands (Plate 12.5)
O. gnu (*O. trituberculatus*)	Asia, less common
O. boas	Probably the most common species in Africa
O. monoceros	Africa
O. ovariensis	Africa

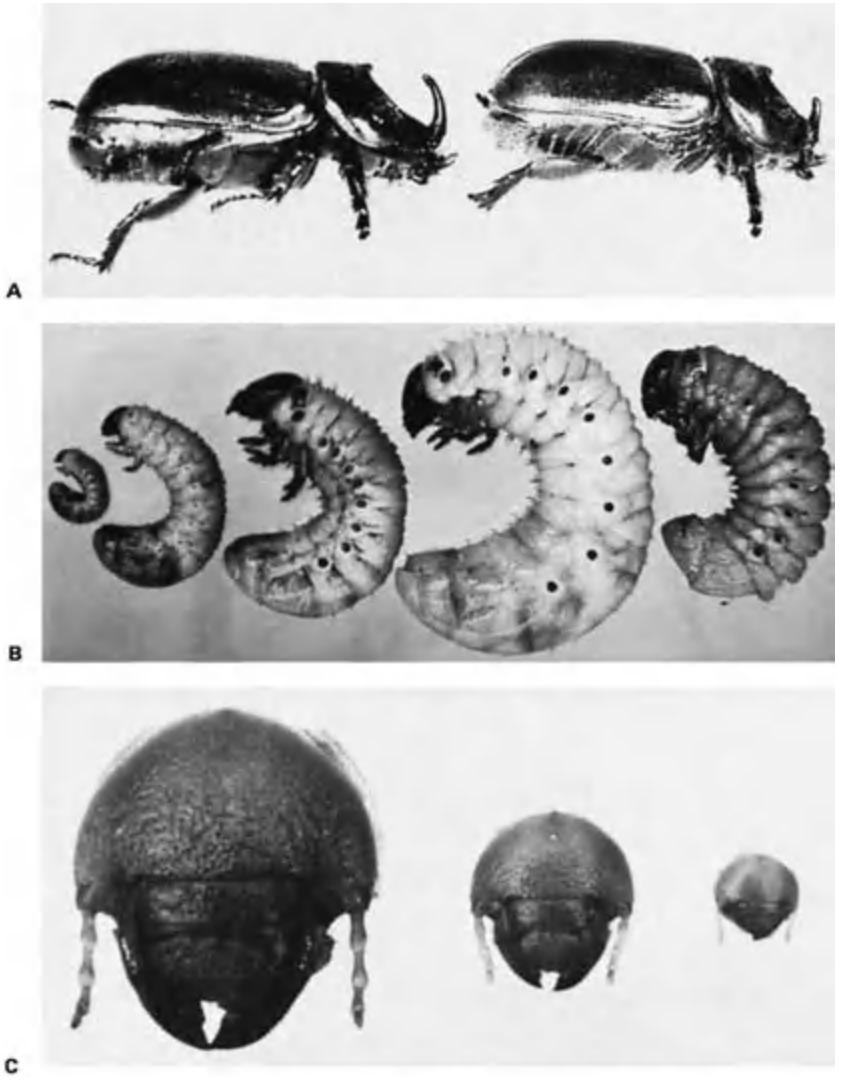

Plate 12.5 *Oryctes rhinoceros* in Malaysia. (A) Adults, male (*right*), female (*left*). (B) Larval instars, 1st, 2nd, 3rd (early, late, prepupal). (C) Head capsules of larval instars; (*left to right*) 3rd, 2nd, 1st.

The Asian species are primarily pests of the coconut palm, but they attack other palms, both cultivated and wild. The African species attack the coconut and *Borassus* palms but, owing to its ubiquity, the largest population is to be found on the oil palm.

Description, life cycle and damage: The male adult has the characteristic 'rhinoceros horn'; in the female the horn is smaller or, in the African species, is reduced to a triangular protuberance. The beetle is black and measures 4–6 cm long and 2–3 cm broad according to species, *O. trituberculatus* being larger than *O. rhinoceros*, and the African species *O. owariensis* being larger and *O. boas* being smaller than *O. monoceros*. The horn of *O. boas* is particularly long and curved.

The eggs are white, 3–4 mm in diameter and easily observed on breeding sites. About 20 eggs are usually laid, but higher numbers have been recorded; they hatch after 11–13 days. The young larva is white at first, but its head soon becomes brown and its body blue–grey, then yellowish or greenish-white; it reaches a length of 4–10 cm. The duration of the larval stage varies considerably, ranging from around 100 to 200 days. Similarly, the adult stage may last for a few months or extend to over half a year. Before pupation there is a

short prepupal stage of a week; the adults emerge after a further 3 weeks. The eggs are laid on rotting vegetable matter. On an oil palm estate decaying palm trunks and bunch refuse are common breeding grounds. Empty bunches stacked prior to use as mulch may be a problem; the length of the larval stage is such that spreading should usually be done before pupation takes place, but the life cycle may sometimes be completed.

The oil palm is damaged by the adult beetle, which burrows into the cluster of developing spears in the crown and bores its way through the petioles into the softer tissues of the younger, unopened leaves. The effect can be seen when these leaves develop and open, but the regularity of wedge-shaped cuts so characteristic with the coconut palm is not always so clearly seen in the oil palm. Where the rachis has been penetrated, leaves may later snap off. Previous attacks may be detected by the presence of holes in the petioles of older leaves. Attack is most damaging in young palms, since the growing point is occasionally reached, or bud rot may develop and kill the palm. The holes may also give *Rhynchophorus* access to the palm (Section 12.2.6.1), with *Rhynchophorus* damage, in turn, providing conditions suitable for *Oryctes* larvae (Zulnerlin and Fatah Ibrahim, 1999).

Apart from the occasional young palm that is actually killed, the effect of *Oryctes* damage on yield may be very small. Wood *et al.* (1973) compared two 2.4 ha plots, one with over 80% severe or medium damage by *Oryctes*, and one with only 6%, and found that the former yielded 2% less over the first 18 months of production. In this trial, damage probably ceased at least a year before harvesting started. Later damage can have more effect. Liau and Ahmad Alwi (1995) found that artificial defoliation of 2-year-old palms did affect yield: 50% defoliation on a single occasion reduced subsequent yield by 12%, and repeated ('chronic') defoliation reduced it by 24%. Chung *et al.* (1999) found that palms damaged by *Oryctes* 21 months after planting yielded 80% less than undamaged palms in the first 12 months of production (although this comparison was based on groups of only 20 palms). With more than 70% of palms damaged, they estimated a loss of 2.1 t FFB/ha in the first year. Liau and Ahmad Alwi (1993) observed less damage in the second year in the field, and harvested 5 t more fruit over the first 18 months of production from palms in a clean clearing than from plots with windrowed trunks.

Control: Older methods of control involved destruction of breeding sites, and hand-collection of adult beetles. Hartley (1988) advocated that all rotting vegetable matter should be dispersed and rotting palm trunks disposed of. Where the palm trunks were not burnt, regular inspection to break up the rotting material and collect larvae was recommended (Barlow and Chew, 1971). This method was labour intensive, but Zulnerlin and Fatah Ibrahim (1999) found that in Indonesia hand-picking was cheaper than insecticide application. In some countries, the larvae are hand-picked and cooked and eaten as a delicacy. Complete pulverising of trunks to sawdust-sized particles, thus largely eliminating breeding sites, has been claimed to reduce the population to less than 3% of that with the usual chipping, which cuts the trunk into fragments weighing 1.5–8 kg (Ooi *et al.*, 2001).

It was noticed in Malaysia that palms along or near roadsides might be heavily attacked while those within the field escaped injury, and Wood (1968b) showed that interrow vegetation may from a barrier to beetle movement and, in young areas, may blur the palm silhouette which is believed to attract the beetle. When areas of young palms either kept bare or sown with a legume cover crop were compared, *Oryctes* breeding and damage were considerably higher on the bare areas (Wood, 1968b). In addition to its many other advantages, the planting of leguminous cover is undoubtedly an effective way of suppressing *Oryctes* attack. It has been confirmed that this approach is also effective against *O. monoceros* in Africa (Boyé and Aubry, 1973). Wood (1976a) noted that ground cover does not totally eliminate attack, but reduces it to a very low frequency, such that effects on yield are unlikely to be important. He suggested that *Oryctes* attack is rare on older palms, because the closed canopy itself forms a 'vegetative barrier'; as noted above, isolated older palms are often attacked.

Ethyl chrysanthemumate was found to be a strong attractant to *Oryctes*, and Turner (1973) suggested baiting traps with this compound, but Wood (1976a) thought that the density of traps required (25/ha) was too great for the method to be cost-effective. Hallett *et al.* (1995) found that the aggregation pheromone, ethyl-4-methyloctanoate, was ten times more attractive to *Oryctes* than ethyl chrysanthemumate. This allows a much lower trap density, and Chung (1997) showed that one trap per 2 ha gave good control of damage, provided that the *Oryctes* population was not too large. Costs were lower than for insecticide application. Where risk of attack is thought to be high, a systemic insecticide (carbofuran) may be applied. Desmier de Chenon *et al.* (1998) advocated trapping in the old stand for 6 months before replanting, to reduce the population. N. Kamarudin *et al.* (1999) suggested using pheromone trapping to monitor beetle populations and

identify 'hot spots' where chemical control would be worthwhile.

Much attention has been paid to the introduction and spread of insect parasites, fungi or viruses. A virus, *Rhabdionvirus oryctes*, first identified in Malaysia (Huger, 1966), has been introduced over most of the South Pacific where *O. rhinoceros* is a coconut pest. Infected beetles stop feeding, and fly and mate less frequently (Zelazny, 1977), and beetle populations have been reduced following introduction of the virus (Young, 1986). In Malaysia, there is a regular, although small, larval mortality from the virus (Barlow and Chew, 1971), and it is likely that the virus and its host have reached an equilibrium. Barlow and Chew (1971) also identified a fungus, *Metarhizium anisopliae*, which infects the larvae; Tey and Ho (1995) applied cultures of this to *Oryctes* breeding sites and achieved high infection rates, coincident with reduced numbers of larvae. Ho (1996) recommended an integrated approach to *Oryctes* control, involving pheromone traps, release of trapped beetles inoculated with *Metarhizium*, inoculation of breeding sites with the fungus, and the use of synthetic pyrethroids when damage reached unacceptable levels. He quoted costs equivalent to about 3 t FFB/ha in the first year of production. Given the rather small effects of *Oryctes* damage on yield, noted above, it must be doubtful whether such measures are justified. It should also be noted that Hochberg and Waage (1991) used a model to show that, if *Metarhizium* were to be applied to a population already regulated to low levels by a virus, the ensuing mortality may result in the virus being eliminated from the population, so that a later resurgence of *Oryctes* may occur.

There is a view that the adoption of zero-burn replanting methods has increased problems with *Oryctes*, but we should not forget that, until about 30 years ago, all replants were zero-burn. The belief that the old stand must be completely uprooted to prevent *Ganoderma* attack (which may have little foundation; see Section 12.1.6.3) led to burning or windrowing of the old trunks. Where windrowing was done, if the old trunks were not adequately covered by vegetation, *Oryctes* could invade. Wood (1999) noted that there have been *Oryctes* outbreaks in recent years, which have led some to question the 'vegetative barrier' effect mentioned above, but he considered that in such cases there was always some evidence that development of vegetation cover had been restricted, for example by felling too late after poisoning, by stacking the palm trunks well above the vegetation, or by flooding.

Kamarudin and Basri Wahid (1997) surveyed 640 estates in Malaysia, with a total of 280,000 ha of immature palms. *Oryctes* infestations were reported from 16% of the area, with 13% of outbreaks described, subjectively, as 'serious' or 'very serious'. However, only 3% of outbreaks were in palms older than 18 months, and we have seen that before that age damage has little effect on subsequent yield.

Samsudin *et al.* (1993) found much higher *Oryctes* numbers in an underplanting than in an area where the old stand had been felled and trunks chipped before planting. Incidence was particularly high if the underplanted old stand was poisoned and left standing, as expected from the absence of vegetation cover. Similar observations have been used as an argument against underplanting (Section 8.3.4.3), but provided that the old stand is felled and quickly covered by ground vegetation, there should not be a problem (Hakim *et al.*, 1998). If *Oryctes* does built up in an underplanting, though, there could be significant effects on yield. If the last of the old stand is cleared 2 years after underplanting, there might be damage to palms aged 2 years or more, and damage at that age has been shown to affect yields (see above). Jacquemard *et al.* (2002a) found large differences between oil palm families in amount of damage (though with no indication of statistical significance), and considered that some genotypes were more attractive to *Oryctes* than others. While this might not be important for seed production, they suggested that it should be considered in clone selection.

Conclusion: If a good legume cover is established early in an oil palm replant, this effectively suppresses *Oryctes*, and the amount of damage to young palms should be small. As it has been clearly established that quite severe defoliation during the first year in the field has little effect on subsequent yield, in most situations it is unlikely that *Oryctes* control measures will be needed. Only if severe damage continues beyond the first 18 months in the field would the possible loss in yield justify treatment.

12.2.4.2 Strategus aloeus *(Dynastinae)*

This beetle, which somewhat resembles *Oryctes*, is distributed throughout tropical America, where it has been troublesome in several oil palm plantations (Mariau, 1976b).

Incidence and damage: The adults attack young palms in the field or nursery by digging a hole in the ground near the palm, from which they bore their way into the plant just above the roots. Often, in a young palm, the growing point is reached and the plant killed. Eggs may be laid in the palm, which is then consumed by the developing larvae, or in rotting stumps, trunks and vegetation.

Control: In view of the lethal attack on young palms by the adult, control measures are required in areas where the beetle is common. As eggs may be laid in rotting stumps and trunks, the measures to be taken against the larval stage are the same as for *Oryctes* species: destruction of breeding sites and collection of larvae. During wet weather fortnightly inspections have been recommended; in dry weather *Strategus* attack is rare.

It does not appear to be recorded whether the 'vegetative barrier' effect which controls *Oryctes* is effective against *Strategus*.

12.2.4.3 Temnoschoita *species (Curculionidae)*

These weevils are found throughout Africa, but appear to be more common in Congo than in West Africa. The most common species is *T. quadripustulata (T. quadrimaculata)*; *T. delumbata* is less common. Young palms may be killed, but the pest appears to cause no significant damage to mature palms (Mariau *et al.*, 1981) (Plate 12.6).

Life cycle and damage: Asante and Kumar (1986) described the life cycle of *T. quadripustulata* in Ghana. The adults are 8–10 mm long and dark brown, with the thorax spotted with indentations. The light brown wing cases have four reddish blotches and do not fully cover the abdomen. The females lay their eggs on cuts and wounds on the leaf petioles. On young palms, both those recently transplanted and palms in early bearing, and on nursery plants the young larvae tunnel their way through both dead and living tissue towards the heart of the palm, and pupate in the tunnels formed. The damage is sometimes severe, and young palms may be killed through penetration to the growing point. In bearing palms the adults are attracted to the inflorescences, where eggs are also laid.

Control: In areas where the weevil has been noted, care should be taken to avoid wounding the palms by excessive leaf pruning, particularly just before transplanting (Buyckx, 1952). This injunction may conflict with control measures against *Cercospora* leaf spot (Section 12.1.2.1), and it may be useful to treat pruning cuts with tar. With bearing palms the collection and destruction of rotted bunches and scattered fruit are also recommended, as these may contain eggs, larvae and pupae. When harvesting begins it may be advantageous to undertake a general cleaning of the crown followed by dusting with an insecticide at intervals of 3 weeks, the dust being applied in the crown from the centre to the base, not on the leaves. Traps for the adults have been constructed from recently cut and split petioles or banana trunks (Buyckx, 1952). Banana plants are an attractive host and should not be grown near nurseries or young plantations where infection with *Temnoschoita* is feared.

Plate 12.6 *Temnoschoita* damage to leaves in West Cameroon. Note typical 'windows'.

12.2.5 Leaf pests of mature palms

Numerous species eat leaf tissue of mature palms and have the potential to cause significant defoliation. The effects of this on yield were investigated by Wood *et al.* (1973), who used manual defoliation to simulate the effect of attack by a leaf-eating pest on 8-year-old palms. Figure 12.4 shows that, in the first year after defoliation, 50%

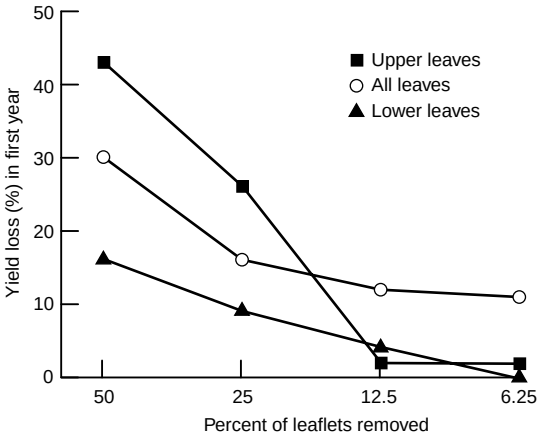

Fig. 12.4 Effects of artifical defoliation on subsequent yield. Different degrees of defoliation were applied by stripping off leaflets, to upper leaves, lower leaves or all leaves. (From Wood *et al.*, 1973.)

damage caused a crop loss of over 40%, if restricted to the upper half of the canopy (i.e. all leaflets in the upper half destroyed). This corresponded well with observations in a severely attacked area. Damage to the lower leaves had comparatively little effect, because those leaves are shaded by younger leaves at the top of the canopy, and contribute relatively little to total canopy photosynthesis. Less severe damage caused smaller losses.

The most severe treatment caused a further 17% crop loss in the second year. Study of monthly yields showed that there was a large shortfall about 10 months after defoliation, attributable to inflorescence abortion, and a further shortfall between 22 and 26 months, due to an effect on sex ratio (see Chapter 4 for discussion of these yield components). A mature oil palm canopy consists of about 40 leaves, and as leaf production rate is around 24 per year, the palm will take over a year to recover from damage to the younger, upper leaves.

This study allows economic damage levels to be estimated for any pest that causes defoliation. Wood (1977) noted that the cost of treatment by aerial spraying or trunk injection would be covered by a yield gain of no more than 3%. Figure 12.4 suggests that even quite mild defoliation could cause a loss of that order. The question, then, is not whether the cost of spraying will be recovered, but whether the outbreak will come under natural control anyway. If surveys indicate that numbers are increasing, and if a proven integrated control measure, such as trunk injection or an insect pathogen, is available, it will be advisable to take action at a fairly early stage.

12.2.5.1 *Leaf-eating caterpillars*

A wide variety of different caterpillars feeds on oil palm leaves. Nettle and slug caterpillars and bagworms are the most frequent pests. Mariau *et al.* (1991) presented good colour photographs of most of the important species, and of their natural enemies, but little information on control. Syed and Saleh (1993) described IPM systems for these pests in Indonesia.

Nettle and slug caterpillars: Members of this group, the Limacodidae, have been recorded as pests in all oil palm-growing areas. Wood (1987) listed the species that have been recorded as causing significant damage to oil palms (Table 12.12) and other crops. Some species, such as *Darna trima*, are common, yet severe damage may be unusual. Outbreaks of several species have been attributed to prior use of contact insecticides.

Life cycles and damage: Severe infestations may develop rapidly, as the life cycles are only a few weeks long and reproduction rates are high. The eggs are deposited on the leaflets; the caterpillars usually feed on the underside, often stripping the surface when young, but when larger they may eat away the whole lamina, leaving only the midrib (Plate XVIA). Pupation may be on the ground, in cracks in the soil, or attached to the leaf.

Mariau *et al.* (1991) gave critical levels, in terms of number of larvae per frond, for most species in South-east Asia, together with recommendations on insecticides. Different species attack different parts of the crown: *D. trima* is first found on leaves 9–17, *Setothosea asigna* and *Setora nitens* (Plate XVIB) on leaves 9–25, and *Ploneta diducta* and *P. bradleyi* on older leaves (Mariau *et al.*, 1991). In severe outbreaks the entire crown may eventually be defoliated. The effect on yield depends on the extent of defoliation, and on which part of the crown is damaged. As noted above, loss of young leaves is more damaging than loss of older leaves.

Control: Numerous parasites and predators of the Limacodidae have been recorded. Species attacking *S. nitens* (Plate XVID) included five species of wasp, four parasitic flies and a bug (Wood, 1966, 1968a). *Setothosea* and related species are attacked by a virus, a fungus (*Cordyceps* sp.), and several predatory or parasitic insect species (Tiong, 1979).

Wood *et al.* (1977) described a series of experiments on the control of nettle caterpillars in Malaysia. They tested a range of chemicals and *Bacillus thuringiensis* insecticides, and considered the latter to be very promising. The trials confirmed the need for chemical intervention on occasion, choosing insecticides on grounds of good kill, selectivity, low cost and low toxicity to humans. The utilisation of diseased pests by spraying suspensions of crushed bodies was in several cases very successful. Tiong (1982) described control of *Setothosea asigna* by an integrated programme similar to that advocated by Wood *et al.* (1977), in which chemical intervention was confined to quelling high-density infestation and combined with the encouragement of the natural fungal and insect enemies. In Sarawak, good progress has been made with the control of *Darna trima*. A virus inoculum was prepared from diseased late-instar larvae, and from healthy larvae confined with them. The larvae were naturally infected by the virus and the inoculum was prepared by simple maceration, straining and dilution with water. This was sprayed with mist blowers, repeated until the larval census showed that resurgence was not taking place. There was a high mortality within 8 days in comparison with unsprayed areas, and resurgence, such as was common after 5 weeks with chemical insecticide spraying, did not take place (Tiong and Munroe, 1977).

Table 12.12 Nettle and slug caterpillars reported to have reached outbreak levels on oil palms

Species	Synonym	Location	Frequency[a]	Ref.
Susica malayana	*S. pallida*	W Malaysia	Occasional	1
Setothosea asigna	*Thosea asigna*	W Malaysia, Sabah	Often	2
Setora nitens		W Malaysia, Sabah, Sumatra	Frequent	2, 3
Birthosea bisura	*Thosea bisura*	W Malaysia	Occasional	2
Ploneta diducta	*Darna diducta*	W Malaysia	Occasional	2, 3
Darna trima		W Malaysia	Often	2, 3
		Sabah	Often	4
Darna mindanensis	*Darna* sp. nr. *trima*	Philippines	Often	2
Darna furva		South Thailand	Often	5
Darna catenatus		Sulawesi	Often	6
Thosea vetusta		Borneo	Occasional	3
Parasa pallida	*Latoia pallida*	West Africa	Often	7
Parasa viridissima	*Latoia viridissima*	West Africa	Often	7
Episibine intensa		Guyana, Colombia	Frequent	8
Episibine sibinides		Peru	Often	8
Euclea diversa		Central & S America	Often	8
Euclea cuprostriga		South America	Often	8
Euprostema elaeasa	*Darna metaleuca*	Central & S America	Frequent	8, 9
Natada pucara		Central & S America	Occasional	8
Natada subpectinata		South America	Occasional	8
Sibine fusca		South America	Occasional	8
Sibine nesea		South America	Occasional	8

[a] Occasional: one or two recorded outbreaks only; frequent: extensive, heavy and recurrent outbreaks in more than one location, for some period of time; often: intermediate between occasional and frequent.
Based on Wood (1987).
References: 1: Wood (1968a); 2: Wood *et al.* (1977); 3: Ho and Sidhu (1986); 4: Wood and Nesbit (1969); 5: Wood (1987); 6: Mariau *et al.* (1991); 7: Mariau *et al.* (1981); 8: Genty *et al.* (1978); 9: Genty (1976).

The biology of *Euprostema elaeasa*, which is among the more serious of the numerous South American caterpillar pests, was studied by Genty (1976), who found several important parasites, including a wasp, *Casinaria* sp. Genty recommended that the parasite population be carefully examined before control measures are decided upon. *Sibine fusca*, another American species, is attacked by several bugs, and Genty (1981) recorded a wasp, *Apanteles* sp., and two flies, *Palpexorista coccyx* and *Systropus nitidus*, which not only parasitise the larvae but also transmit a viral disease (Meynadier *et al.*, 1977). This virus can be artificially spread: 20 g of infected larvae macerated in 220 ml of water and applied at 50 ml/ha was shown to spread the disease over the whole population within 18 days. Mexzón *et al.* (1996) controlled *S. megasomoides* in Costa Rica by spraying with *B. thuringiensis* and deltamethrin.

Species of *Parasa* have defoliated oil palms in West Africa. Specimens from Cameroon, Nigeria, Liberia and Uganda have been identified as *P. viridissima*, while *P. pallida* has been a pest of oil palms in the Ivory Coast (Mariau and Julia, 1973; Mariau *et al.*, 1981). Normally, fungi and natural predators and parasites keep the populations in check by attacking the larvae and pupae. In the Ivory Coast, spraying 3 weeks after the appearance of the first caterpillars has been recommended (Mariau and Julia, 1973). Fediere *et al.* (1990) described the use of a virus for control of *P. viridissima*.

Monitoring: A pheromone produced by the female of *D. trima* has been identified by Sasaerila *et al.* (2000), who suggested that it could be used to trap males and hence to monitor the population. Desmier de Chenon *et al.* (1996) recommended using pheromone traps for monitoring populations of *S. asigna*. They indicated that this was cheaper than conventional census systems, and might give an earlier warning of pest build-up.

12.2.5.2 *Bagworms*

Several members of the Psychidae have been pests of the oil palm in Asia since the start of the plantation industry, but the prevalent species appear to have changed. In the period between World Wars I and II *Mahasena corbetti* was extensively studied, but since

1945 *Pteroma pendula* (formerly *Cremastopsyche pendula*) and *Metisa plana* have been the common species in Malaysia. In Indonesia *M. corbetti* is the principal species, and it can be a serious pest throughout South-east Asia. As with nettle caterpillars, effects on yield will depend on the extent of defoliation.

Life cycle and damage: The larvae of bagworms are encased in bags constructed of pieces of leaf bound with silk. *Metisa plana* and *P. pendula* feed on the upper surface of the leaf, the scraped portion first becoming dried out and then forming a hole. Further damage is done by the removal of pieces of leaf to make the case. Badly damaged leaves soon dry up and this gives the lower and middle part of the crown a characteristic grey appearance, the only green leaves being the youngest. *Mahasena corbetti* feeds on the undersurface of the leaf. Surviving caterpillars pupate in their cases on the underside of the leaves.

The size and form of the bags and the manner in which they are attached to the leaf help to distinguish the species. *Metisa plana* has a short, hooked attachment and the bag is about 13 mm long (Plate 12.7). The case of *P. pendula* is about 6 mm long, is rather rough and hangs on the end of a long vertical thread. *Mahasena corbetti* is much larger and the case is more ragged (Plate XVIE); Syed *et al.* (1973) studied the life cycle of this species. The male moths of all species fly from their cases, but the females are wingless and remain in the case. They attract the males with a pheromone and mate while still in the case, each then laying 100–300 eggs. On hatching, the caterpillars acquire their own cases and feed in groups. The life cycles take between 2.5 and 4.5 months (Syed, 1978).

Kamarudin *et al.* (1996) described 18 species of parasitoid associated with *M. plana* and *M. corbetti* in Malaysia. The caterpillars die in large numbers from parasitic and predatory attacks and other causes, but explosions of population may occur locally from time to time when the natural balance is disturbed for one reason or another. The probable role of contact insecticides, sprayed both against other minor pests and against the bagworms, in these population explosions has already been mentioned.

Control: Owing to the risks associated with broad-spectrum contact insecticides, hand-picking was long recommended for small attacks, and stomach poisons such as lead arsenate or trichlorfon (which has short-lived residues) for larger outbreaks. Aerial spraying over wide areas was successful with trichlorfon (Wood, 1968a). Later, the systemic insecticide monocrotophos, applied by trunk injection, was found to be effective (Wood *et al.*, 1974). The injection was done by pouring the chemical into holes made with modified chainsaw drills. Tractor-mounted generators with electric drills and special equipment for immediate injection following drilling may now be used (Sarjit, 1986); one team with a tractor and two drills can treat 15–20 ha in a day.

Plate 12.7 Bagworms in Malaysia: (*left*) *Metisa plana*; (*right*) *Pteroma pendula*. (B.J. Wood.)

Syed and Saleh (1993) described a census system for *M. corbetti*. Syed and Saleh (1998) achieved effective control of this pest by spraying part of an infested area with a granulosis virus. Basri Wahid *et al.* (1996) tested preparations of *B. thuringiensis* against *M. plana* and *M. corbetti*. The best preparation was as effective as trichlorfon, but some were much less effective. Rhainds (2000) suggested that control should be possible using pheromones to trap males and disrupt mating; this has been done successfully with another bagworm species, *Thyridopteryx ephemeraeformis* (Klun *et al.*, 1986).

Chung and Sim (1993) discussed a situation where bagworms had become a constant problem in a particular area, and were apparently not easily controlled. They showed that standard procedures (census twice per month, trunk injection where the threshold of ten larvae per leaf was exceeded), provided they were correctly followed, could reduce an apparently chronic infestation within a few months to a level where natural enemies took over control.

Ho (1998) demonstrated the value of *Euphorbia heterophylla*, a ground cover species which supports several of the natural enemies of bagworms, in minimising build-up of *M. plana*.

Other bagworms: Wood (1968a) mentioned species of *Pteroma*, *Clania* and *Amatissa* as showing limited

increases in Malaysia from time to time. *Oiketicus kirbyi* occurs in Costa Rica (Genty *et al.*, 1978).

In Colombia and Ecuador, *Stenoma cecropia* (Stenomidae) has occasionally caused extensive damage. This species has a fixed bag, and eats by journeys from it while remaining attached by fibres (Genty, 1978). There are some natural enemies, but control by them is reported to be weak and, in serious outbreaks, aerial spraying with trichlorfon has been necessary for effective control.

12.2.5.3 *Other caterpillars*

Damage by caterpillars of other families is also reported from time to time. *Homophylotis catori* (formerly *Chalconycles*) (Zygaenidae), which has a life cycle of about 30 days, was reported as causing serious local damage in the Ivory Coast (Genty, 1968). Outbreaks followed the use of BHC against leaf miner. *Pyrrhochaleia iphis* (Hesperiidae) and *Epimorius adustalis* (Psychidae) have been reported from Congo (Frazelle and Buyckx, 1962).

In Malaysia, Wood (1968a) and Mariau *et al.* (1991) recorded a large number of leaf-eating caterpillars, few of which, however, have done any significant damage. Cutworms (Noctuidae), usually *Agrotis* sp., can cause damage in prenurseries and *Spodoptera litura* may strip the leaf epidermis in nurseries.

In America, colonies of mixed species of Lepidoptera have characteristically developed on some plantations, and the method and timing of control has influenced the balance between species. *Opsiphanes cassina* (Brassolidae) did much damage as a leaf eater and was reported to be encouraged by carbaryl spraying, but reduced by using lead arsenate or *B. thuringiensis* (Rojas-Cruz, 1977). In the mixed colonies there have been species of *Megalopyge* (Megalopygidae), species of Dalceridae and Hesperiidae, and *Herminodes insula* (Noctuidae) in the spear leaf, and some Psychidae.

12.2.5.4 *Grasshoppers*

Bush crickets, long-horned grasshoppers or treehoppers (Tettigonidae) are described as the principal pest of oil palms in PNG (Prior, 1988; Caudwell, 2000). Three species, collectively known as Sexava, are oil palm pests: *Segestes decoratus*, *Segestidea defoliaria* and *S. novaeguineae*. Prior (1988) noted 80–90% defoliation by *S. defoliaria*. Prior listed a number of species parasitic on Sexava, but according to Caudwell (2000), experience suggests that populations are not well controlled by natural enemies; once light damage is observed, this will steadily increase until severe defoliation has occurred.

Control: Bush crickets can be controlled by trunk injection of monocrotophos (Prior, 1988), but treatment must be in the early stages of an outbreak to be effective. Caudwell (2000) described a census system based on the amount of visible leaf damage, rather than on pest numbers. Mass rearing and release of egg parasites was described by Prior (1988), but it seems that these methods do not give complete control, and further work on biological control methods is in progress (Kathirithamby *et al.*, 1998; Caudwell, 2000).

12.2.5.5 *Leaf miner,* Coelaenomenodera lameensis *(*C. minuta*,* C. elaeidis*)*

This beetle is found on oil palms and, to a lesser extent, on coconut and *Borassus* palms throughout West and Central Africa. Serious attacks, causing widespread defoliation, have been reported from Ghana, Benin, the western part of Nigeria, Ivory Coast and West Cameroon, although for a long period the leaf miner was only reported from Ghana. There are numerous species of *Coelanomenodera*. Until 1980, the main oil palm pest was thought to be *C. elaeidis*, but then two species were recognised, with *C. minuta* thought to be the more important. It now appears that the pest is a third species, *C. lameensis* (Berti and Mariau, 1999). Although *C. elaeidis* occurs on oil palms, it is not thought to be involved in outbreaks (R. Philippe, pers. comm., 2001).

Life cycle and damage: The method of feeding and life history were recorded in Ghana by Cotterell (1925). Very detailed studies have been made of the biology of this insect and of its control (reviewed by Mariau, 1976a). The life history in days is as follows: eggs, 20; larvae, 44; pupae, 12; adult to egg laying, 18; total, 94. The adults continue to live on the undersurface of the leaf for 3–4 months during and after laying eggs. The length of the life cycle accounts for the pest damage reappearing in some cases every 3 or 4 months.

A single female of *C. lameensis* may lay several hundred eggs; *C. elaeidis* is less prolific, perhaps explaining why outbreaks of that species do not occur (R. Philippe, pers. comm., 2001). The larvae, which grow to about 7 mm in length, are brown and their heads are squeezed into the thorax, their flattened bodies being transversely divided by deep furrows. They mine under the upper epidermis of the leaflets of palms of all ages except, normally, those below 3 years old in the field. The galleries are longitudinal, and in a severe attack the greater part of the leaf tissue will be destroyed (Plate XVIC). A single gallery mined by a larva to attain its full development measures about 15 cm in length and is 1 cm broad. Severely attacked palms have a typical appearance; the

young leaves are green, being little attacked, while the remainder are grey–brown and withered, with desiccated, rolled-in leaflets. Later, the withered laminae shatter, leaving the leaflet midribs only.

The pupae are found in the dead tissue of the leaves, and the adults, which are 4–5 mm long, emerge after about 12 days. The pupae are mobile and are found in the centre of the galleries. The adult emerges through the upper epidermis and shows a preference for migrating to the higher leaves. These adults are pale yellow with reddish wing cases; they also do some damage, making grooves about 1 cm long on the leaflets. The female lays her eggs in a small cavity on the underside of the leaf.

The effect of damage on yield is similar to that of other pests which cause defoliation. Philippe *et al.* (1979) estimated that there was a 40% yield loss in the 2 years following an outbreak.

Control: The census method developed in the Ivory Coast (Mariau and Bescombes, 1972) involved counting of adults and larvae on a leaf between 25 and 30 (i.e. in the lower part of the canopy), with small and large larvae, nymphs and adults being recorded separately. The palms selected for counting are changed at each census round. Counting is done every 3 months when the number of larvae is below 10 and of adults below 1; monthly when the numbers are 10–20 and 1–3, and weekly if more than 20 and 3, respectively. When the latter stage is reached treatment is considered necessary.

Spraying with Evisect (thiocyclam), using a tractor-drawn sprayer or a helicopter, or by fogging, was recommended by Philippe (1990a, b). A single treatment was usually effective, but sometimes a second application 3 weeks after the first was needed. There was only a small effect on the population of the pollinating weevil, *Elaeidobius kamerunicus*, and there were no detectable residues of thiocyclam in palm oil. Trunk injection has also been recommended (Philippe and Diarrassouba, 1979); with suitable equipment, this is easily done over large areas (Sarjit, 1986).

Cotterell (1925) reported hymenopteran parasites of both the eggs and the larvae, as well as fungal parasitism. In the drier parts of the West African palm belt where leaf miner damage has been serious in some years, the attacks seem ordinarily to have been controlled by natural predators, and resurgence has not occurred again until, for some reason, the parasite population has fallen below normal. Parasitism of *Coelaenomenodera* was studied in detail by Morin and Mariau (1974), Mariau and Morin (1974) and Mariau *et al.* (1978). The eggs are parasitised by the chalcid fly, *Achrysocharis leptocerus*, and by *Oligosita longiclavata* (Trichogrammatidae). There were three larval parasites: the eulophid flies *Sympiesis aburiana, Pediobius setigerus* and *Cotterellia podagrica*. None of these was sufficiently numerous to have much limiting effect in outbreaks (Mariau *et al.*, 1978), so a search has been made for possible parasites to introduce into the Ivory Coast for control of the pest. The eulophid wasp, *Chrysonotomyia* sp., was successfully introduced from Madagascar, but it failed to parasitise *C. lameensis* (Lecoustre *et al.*, 1980). In Cameroon, Timti (1991) found that leaf miner attacks were fewer where *Crematogaster* ants were present, and suggested that the pest could be controlled by collecting these ants and distributing them in affected areas.

12.2.6 Stem pests of mature palms

12.2.6.1 Rhynchophorus *species (Curculionidae): palm weevils*

Rhynchophorus is a potentially lethal pest. In Asia and Africa its incidence on the oil palm is not very high; deaths have been noted in Africa where leaves have been cut abnormally short and wounding of adjacent leaf bases has resulted. In America, incidence may well be higher. Deaths from *R. palmarum* attack have been noted in young plantings within the grove areas in Bahia, Brazil, and the pest is quite frequently encountered on oil palms in other parts of the continent. Its greatest importance in America may be as the vector for the nematode that causes red ring disease (Section 12.1.6.6).

Distribution and description: Species of these large weevils are to be found attacking palms in all parts of the tropics. The larvae tunnel into the crown and trunk, and the palm may be killed. As pests of the oil palm the distribution of the more important species is as follows:

R. phoenicis	Africa	
R. palmarum	America	Gru-gru beetle
R. ferrugineus	Asia	Red palm weevil, red-stripe weevil
R. papuanus	Celebes, New Guinea	

The larvae attain a length of some 5 cm and are ovoid or rounded, legless and yellowish-white, with small, brown heads. The last abdominal segment is flattened and has brown edges carrying bristles. The cocoons of the pupae, constructed of concentrically placed fibres, extend to 8 cm in length and 3.5 cm in breadth. The adults show distinct specific differences but are usually about 4–5 cm long and 2 cm broad. *Rhynchophorus phoenicis* is black with two narrow longitudinal dark

brown bands on the thorax; the wing cases have about a dozen longitudinal grooves. The underside of the body is light brown with diffuse black spots. *Rhynchophorus ferrugineus* is the common red palm weevil of the east; it is the species most commonly found in Sumatra and Malaysia (described under the synonym *R. schach*, and known as the red-stripe weevil). The oil palm has, however, proved far less liable to attack than the coconut palm. *Rhynchophorus ferrugineus* is rather variable in length (2–5 cm) and is red–brown with a few irregular black spots on the thorax. The variety known as *R. schach* is black with a longitudinal red–brown line down the centre of the thorax. The American species, *R. palmarum*, is entirely black with a velvety thorax, slightly prolonged at the base, and shiny grooved wing cases.

Life cycle and damage: Rhynchophorus weevils lay their eggs, which are 2–3 mm long, on cut or damaged surfaces of many palms. The eggs hatch in 3 days, and the larvae tunnel into the crown and trunk (Plate 12.8). The tissues around the growing point then begin to decay and the palm may be killed. The external symptoms of attack have been described as similar to those of *Fusarium* wilt: the leaves show a gradually increasing chlorosis and fracture in strong winds.

The larval stage lasts for about 2 months and pupation then occupies about 25 days, the larvae moving towards the periphery of the trunk to pupate. The whole life cycle lasts for less than 3 months. The weevil more commonly breeds in the stumps of a felled palm field, newly cut stumps being preferred. *Oryctes* and *Rhynchophorus* species are often present in a plantation at the same time. Wounds made by *Oryctes* adults give a means of *Rhynchophorus* infection, while *Rhynchophorus* damage will provide conditions suitable for *Oryctes* larvae (Hartley, 1988; Zulnerlin and Fatah Ibrahim, 1999).

Control: Effective control of *Rhynchophorus* attack is not easy. In the first place, wounding of the palm must be avoided and the petioles must not be cut close to the trunk. Secondly, all dead or felled palms should be destroyed within the period of the beetle's life cycle. Measures for the control of *Oryctes* and other large beetles will help to reduce the incidence of *Rhynchophorus*. Mariau (1968) described various preventive and curative measures, including hooking the larvae from their tunnels with the aid of a wire.

The most promising approach is to trap the adult weevils. Initially, traps were baited with sugar-cane, pineapple, banana or palm tissue, but pheromone-baited traps are more effective. Oehlschlager *et al.* (1992) described the aggregation pheromone of *R. palmarum*. This compound, 'rhynchophorol', is released by male weevils, and attracts others of both sexes to the site of release. Pheromones have also been described for *R. phoenicis* (Gries *et al.*, 1993), *R. ferrugineus* (Hallett *et al.*, 1993) and various other species. Additional attractants include ethyl acetate and ethyl propionate, which are produced by damaged palm tissue, and the most effective traps were baited with the pheromone and palm tissue pieces (Gries *et al.*, 1994). The work on pheromones is summarised by Giblin-Davis *et al.* (1996). Chinchilla *et al.* (1995) described the use of pheromone-baited traps to capture *R. palmarum* and hence to control red ring disease.

Several parasites of *Rhynchophorus* species have been recorded. Moura *et al.* (1993) described a tachinid fly, *Paratheresia menezesi*, which parasitises *R. palmarum* in Brazil.

Plate 12.8 *Rhynchophorus palmarum* larva found in a 'spear rot' palm in Nicaragua. (B.J. Wood.)

12.2.7 Root pests of mature palms

12.2.7.1 *Oil palm root miner*

The caterpillar of the moth *Sagalassa valida* (Brachodidae) has been found mining in the roots of oil palms in several South American countries including Colombia, Ecuador, Peru and Brazil. Up to 80% of the root system may be destroyed, and attacked palms may die.

Life cycle and damage: The female moth has a wing span of 2.1 cm, the male 1.8 cm. They live in the undergrowth and among the cut palm leaves in the interline, and their dull colour blends with that of the withered material. The position of egg-laying has not been

observed, but it is presumed that it is in moist material such as lichens, mosses or humus at the base of the palm. The young larvae, which are no more than 1 mm long, penetrate the primary roots immediately after hatching, but can also move through the soil to attack roots some distance from the point of hatching. They at first eat the external part of the root, leaving the central cylinder intact; this partial destruction stimulates the production of new branch roots. Older larvae grow to 2 cm long, and cause complete destruction of the tissues of the roots in which they mine (Genty, 1973).

In areas of attack it has been noted that the number of caterpillars increases with the age of the palm, and in some palms 50–80% of the root system has been destroyed, including old and recent damage. Some attacked palms fall over (Genty, 1981). The amount of damage is highly variable, but tends to be greater on the edge of a plantation near the forest or near to rivers and streams.

Control: The possibility that sudden wither is associated with damage by this caterpillar has already been mentioned (Section 12.1.6.4). Genty (1977) considered that the extent of the damage done to the roots in itself justified treatment, and stated that a generalised yellowing of the leaves may be due solely to *Sagalassa*. He recommended routine checks by examination of one hole, 40 × 40 × 50 cm deep, at the foot of one palm/20 ha every 6 months. If more than 20% of the primary roots are attacked more intensive checks are done, and if 20% attack is still found then an insecticide should be applied around the bases of the palms. Treatment with endrin (now banned) was always followed by rapid regeneration of the root system.

12.2.8 Pests attacking fruit and bunches

In addition to the insects listed below, rats do considerable damage to fruit bunches (Section 12.3.1).

12.2.8.1 *Oil palm bunch moth*

Distribution: Tirathaba rufivena (Pyralidae: Gallerinae; formerly *T. mundella*) is widespread in Malaysia and Indonesia and can reach epidemic proportions, especially in young areas.

Life cycle and damage: Eggs are laid in the bunches, especially those overripe or rotten, and in inflorescences or bunches lying on the ground. Caterpillars bore into developing fruit or feed on the surface of ripening fruit. They are sometimes found tunnelling into the base of a spear leaf. They are light to dark brown and grow to 4 cm before pupating as dark brown pupae inside the bunch.

Control: Wood and Ng (1974) recommended spraying with endosulphan, but Basri Wahid *et al.* (1991) found that Thuricide (*B. thuringiensis*) was more effective than endosulphan, and cheaper than other effective insecticides. Two larval parasites have been identified: a chalcid wasp, *Antrocephalus* sp., and an ichneumon wasp, *Venturia palmaris*, of which the latter was more common and appeared to be the more promising for possible biological control (Ng, 1982).

12.2.8.2 Eupalamides cyparissias *(Castniidae): oil palm bunch miner*

This pest (formerly known as *Castnia daedalus*) has done serious damage to bunches in Guyana, Surinam and Peru.

Life cycle and damage: The butterfly, which has a wing span of 17–21 cm, lays its eggs on unripe bunches. The larvae grow to 13 cm in a period of about 8 months, passing through 14 larval stages. The insect then pupates in the leaf bases for a period of 30 days. The larvae bore into the peduncles and bunches, causing rotting, and also into the stem. There is a high mortality from wasp and fly parasitism (Korytkowski and Ruiz, 1980).

Palms are attacked as soon as they start bearing, and provided harvesting is complete the larvae will be detected in the bunches and a measure of control obtained (Huguenot and Vera, 1981). Mariau and Huguenot (1983) described methods of estimating populations of larvae of different stages with the object of initiating control measures before the dangerous later larval stages are reached.

Control: Various control methods have been tried. Van Slobbe (1983) found injection of monocrotophos and carbofuran ineffective, but application of granular carbofuran in the spear region was successful. Huguenot and Vera (1981) recommended trichlorfon or carbaryl.

12.2.8.3 Demotispa neivai

Following the extended planting of the oil palm in Colombia, *Demotispa neivai* (previously *Pseudimatidium* or *Himatidium*) was reported from the Magdalena valley, and it has become a pest of the oil palm in all parts of South America, although not usually causing serious losses. A new species, *P. elaeicola*, was discovered on the Pacific coastal plain near Calima.

Life cycle and damage: The adult of *D. neivai* measures 5 × 3 mm and is at first white but rapidly becomes shiny brown with fine longitudinal lines along the wing cases. Single eggs are laid. The larvae are more flattened than the adult and their feet are short and withdrawn; they are at first translucent, later turning dull red, and

reach 7 × 4 mm. The pupae are brown and otherwise resemble the larvae. The insect is found on the undersurface of leaves, but the main point of attack is the fruit (Figueroa and van den Hove, 1967). Most damage is done by the larvae, which nibble the exocarp beginning at the apex. A fungus then develops at the point of attack and the exocarp becomes lignified and grey.

It has been estimated that a heavy attack leads to a loss of 7–9% of oil production, but that losses from the more usual mild attacks are, in spite of the alarming appearance of the bunches, negligible (Genty and Mariau, 1973). Young plantations are more vulnerable.

Control: The pupae of *D. neivai* are parasitised by *Tetrastichus* sp. and *Psychidosmiera* sp., but the amount of control exercised by these appears small. Ants are considered to play a more important role in limiting the population. Disbudding of young palms was recommended as a control measure by Mariau (1976b), if incidence exceeded 30%. Only if the attack becomes severe (a general attack of more than 70% of the palms, or more than 10% attacked heavily) is insecticide treatment thought necessary (Genty and Mariau, 1973).

12.3 MAMMALS AND BIRDS AS PESTS

12.3.1 Rats

Distribution: In the past, the most important mammalian pest of oil palms in Malaysia was *Rattus tiomanicus* (formerly *R. jalorensis*), the Malayan wood rat. Young plantings may be infested by the rice field rat, *R. argentiventer*, but *R. tiomanicus* is found in virtually all established oil palm plantations. The black, house or roof rat (*R. rattus diardii*) has also become an oil palm pest in parts of Malaysia (Wood *et al.*, 1988), and may now be almost as common as *R. tiomanicus*. Wood and Chung (1990) found that *R. r. diardii* occurred in areas where *R. tiomanicus* had developed warfarin resistance (see *Control*, below), and suggested that *R. r. diardii* could only compete with *R. tiomanicus* where the latter species had been weakened by the rapid evolution of resistance. Other rat species found in Asian oil palm fields are *R. exulans* and the bamboo rat, *Rhyzomis sumatrensis*.

The genus *Rattus* only occurs in West Africa as introduced species in populated areas, but several other species are found in plantations. *Dasymys incomtus*, *Lemniscomys striatus*, *Lophuromys sikapusi* and *Uranomys ruddi* were recorded in the Ivory Coast by Bellier (1965) and Brédas *et al.* (1968).

A long-term study showed that the population of *R. tiomanicus* in a Malaysian plantation without rat control fluctuated slowly between about 200 and 500 rats/ha (Wood, 1984). Wood and Liau (1984b) showed that *R. tiomanicus* was potentially capable of doubling in number every 46 days. However, in the absence of control measures, the actual population remained quite stable over long periods, rarely exceeding about 500 rats/ha. The reasons for this were not clear, but external environmental variables were deemed unlikely to be controlling factors, and predation appeared to depend on rat numbers, rather than the reverse. It seemed that there was some intraspecific mechanism, with population pressure affecting breeding success or survival of young rats. This needs to be remembered when considering possibilities for biological control by predators (see below).

Damage: Wood (1976b) estimated that a population of 300 rats/ha would consume about 480 kg of mesocarp/year, representing a loss of about 240 kg oil (Plate 12.9). This is about 5% of a good plantation yield, but the estimate ignored the loss of detached fruit. Taking account of detached fruit, Liau (1990) estimated total losses at up to 10% of production.

In an untreated area, palms showing fresh damage ranged from 0 to 39%, with an average over 10 years of 11% (Wood and Liau, 1984a). Wood (1976b) showed that there was a relationship between amount of fresh damage and rat population, and considered that 5% fresh damage indicated an economically damaging infestation. However, the correlation between amount of damage and rat population is not very strong, either for fresh damage or for detached fruit removed (Liau, 1990).

Young palms are sometimes attacked, probably mainly by *R. argentiventer*. If necessary, palms can be protected with wire-netting collars, as against the 'cutting grass' (see below), although the collar must be turned in at the top (Wood, 1968a).

Control: Poison baiting has been the main method of control, using anticoagulants, but there has been much interest in recent years in the possibility of biological control by owls.

Detailed instructions for baiting were given by Wood and Nicol (1972). Baits consisted of warfarin in cubes of maize and other ingredients, solidified with wax. The baiting procedure was a simple one: one bait per palm was distributed, with replacement of missing baits at 4-day intervals, until acceptance fell below 20%. With this system, rat populations could be reduced to negligible levels by four or five rounds of baiting. The recommendation was to repeat baiting every 6 months, although reinfestation could take over a year. Reinfestation appeared to be partly from outside, and partly

Plate 12.9 Fruit damaged by rats; the apical part of the mesocarp, and the kernel, have been eaten (from Corley, 2001).

from survivors (Wood, 1970). The former source is reduced by systematic baiting over large areas. Costs of control by baiting are typically equivalent to between 10 and 25% of the value of the lost oil (Wood, 1977; Chung and Balasubramaniam, 2000).

Warfarin baiting worked well for many years, but warfarin resistance eventually developed (Wood *et al.*, 1990) and is now widespread in Malaysia. Where resistance has developed, newer anticoagulants such as brodifacoum and bromadiolone have proved effective. With increasing labour costs, Chung and Balasubramaniam (2000) investigated alternatives to the replacement baiting method. They found that the replacement system remained the cheapest, even with high labour costs, but if sufficient labour was not available, then placing several baits per palm, or one large bait, in a single round was an effective alternative.

Recommendations for control of rats in Africa (IRHO, 1976) involved warfarin baiting on the same basis as described by Wood and Nicol (1972), together with wire-netting collars to protect young palms.

Biological control: In recent years there has been much interest in the barn owl, *Tyto alba*, for biological control of rats in oil palms in South-east Asia. Numbers of barn owls have increased enormously in Malaysia, following the expansion of the oil palm industry. In 1951, Glenister (1951) classified the species as 'very rare in Malaya', its having been recorded only three or four times. By the 1980s, Lenton (1985) described it as common. Lenton (1980) showed that numbers were limited by lack of nest sites, and designed a nest box; these have been used successfully to encourage breeding in plantations. By 1989, Smal (1990) found one owl per 17 ha in one oil palm plantation, and one breeding pair per 8.5 ha in another.

Duckett (1982) summarised work by Lenton, showing that barn owls consumed large numbers of rats, which could comprise as much as 98% of their diet. It was calculated that a breeding pair of owls and their young would consume 1200–1500 rats/year (see Duckett and Karuppiah, 1990). With one pair per 8.5 ha (see above), this is equivalent to about 160 rats/ha per year.

With an uncontrolled population of up to 600 rats/ha, there must be some doubt as to the degree of control that owls will exercise, and Wood (1985) noted that there is no well-documented example of a predator exercising continuing control over a vertebrate pest. Often, the predator population depends on the prey population, rather than vice versa; thus, snakes disappeared from oil palm plantations after rat control by intensive baiting started (Wood, 1985). We have already noted that rat populations stabilise at a certain level, despite having the potential to multiply exponentially. If a proportion of the population is removed by a predator, reproductive success may simply increase to restore the equilibrium population level. Alternatively, the population may stabilise at a lower level. Key questions then are: what is the equilibrium population level under owl predation, and is the amount of damage caused by that population economically acceptable?

Numerous authors have shown that owl numbers can be increased by providing nest boxes, but actual data on

control of rats are sparse, and those studies that have been done have not taken account of the large fluctuations in rat population that can occur in the absence of any control measures (Wood, 1984). Heru *et al.* (2000) estimated rat populations by trapping in plantations in Indonesia. Numbers trapped diminished from 100/ha in the year owls were introduced, to 20/ha 2 years later. They describe these figures as 'population density', but Smal (1990) estimated that in his study actual populations were about three times the numbers trapped. The relationship will, clearly, depend on the method and efficiency of trapping. However, if the rat population in Indonesian estates was reduced to as low as 60 rats/ha, that may be below the range of normal population fluctuations (Wood, 1984), suggesting that owls had an effect. In Malaysia, Smal (1990) found that rat numbers decreased after the owl population built up, but rat numbers also fell to a similar level in fields without nest boxes. This could have been because the owls hunt over a large range, well beyond the fields with nest boxes, but it could also have been a natural decline caused by some other factor. Chia *et al.* (1995) estimated populations of up to 400 rats/ha under owl predation in one estate, comparable to levels without control (see above).

Several comparisons of fresh damage levels before and after the introduction of owls have been made. It might be argued that the amount of damage is what matters, not the number of rats, but fresh damage is only a rough indicator of rat population, and is not the only damage done. Other rodents have been shown to change their habits when predators are about (e.g. Abramsky *et al.*, 1996), and it is possible that, when owls are present, rats spend more time in frond piles, consume more detached fruit and do less damage to bunches still on the palm. If feeding is mostly on detached fruit, then when considering the economics of rat control, one must ask whether such fruit would have been recovered if it had not been taken by rats (see Section 10.4).

Wood (1976b) considered that 5% fresh damage indicated an economically damaging population level. This has been interpreted as meaning that less than 5% damage is acceptable, but Wood used the 5% figure as an indication of a need for control by baiting. After baiting, damage should be reduced to zero, and will remain at that level for several months, so the average amount of damage over time would be well below 5%.

Duckett and Karuppiah (1990) found fresh damage on 15–20% of palms before owls were established and on 8–15% after establishment. Smal (1990) found that fresh damage was reduced to about 3% after establishment of owls in one estate, but remained above 7% on another. Ho and Teh (1997) found that damage in a 500 ha block of palms decreased to below 5% by the third year after establishment of owls, and remained low for the next 5 years, without baiting. Hoong H.K. (2000) found that, after the introduction of owls to Sabah, fresh damage in estates averaged 5%, compared with over 10% a decade earlier. In smallholdings, the comparable figures were 24% and 10%. In general, therefore, it appears that the amount of damage done when rats are controlled solely by owls may be less than without control, but is close to, and sometimes above, the threshold for baiting recommended by Wood (1976b). However, Adidharma (2002) claimed that fresh damage level was reduced from 30% to 0.14% after introduction of owls to a 14,000 ha plantation in Indonesia.

Smal (1990) and others have suggested that good control might be achieved by a combination of barn owls and limited baiting. If this is to be done, it is essential that owls eating poisoned, but still living rats should not be affected by the anticoagulant. There are various reports that owls are not affected by warfarin, but Lee (1995) found that warfarin and the second generation anticoagulants were all toxic to owls. The second generation anticoagulants were more toxic, but doses of warfarin taken by rats, and hence by owls, were higher. More work is needed if an integrated system using both owls and baiting is to function effectively, particularly on the choice of anticoagulant where warfarin resistance occurs.

Conclusion: Control of rats with anticoagulant baits is well established and cost-effective. However, as Chia *et al.* (1995) noted, the fact that planters will abandon a proven method in favour of barn owls, which are 'at best unproven', is a clear indication of the attraction of biological control. Owl populations are easily built up by provision of nest boxes, and they consume large numbers of rats. It appears that the equilibrium rat population in the presence of owls may be lower than in their absence, but the rats still do some damage. Smal (1990) calculated that construction of nest boxes was much cheaper than baiting, but noted that owls could not eliminate rats completely. In most studies, the amount of fresh damage has remained close to the 5% level that Wood (1976b) considered to indicate the need for baiting. For a proper comparison, the cost of this residual damage must be included in the costs of rat control by owls. Reliable trials would need to cover large areas, because of the hunting range of the owls, and would have to include an uncontrolled area, to show natural population fluctuations. Until such trials are done, the effectiveness and the economics of biological control of rats by owls remain uncertain.

12.3.2 Other mammals

The 'cutting grass', *Thryonomys swinderianus*, is common in Africa, and young areas planted near to the forest are particularly at risk from its devastating attacks. Protection against this pest using wire collars is described in Section 9.1.4.3. Porcupines (*Hystrix brachyura*) attack young palms on forest margins, gnawing through to the bud. Wire collars are not effective; zinc phosphide baits with palm oil in cassava root (Wood, 1968a) and chemical repellants (Chandrasekharan and Edmunds, 1976) have been employed.

Elephants have done great damage to young plantings in South-east Asia, systematically uprooting rows of newly planted seedlings. A ditch, 2.5 m deep and wide, may be an effective deterrent; though expensive, the cost is easily justified if there is a known risk of elephant incursion (Wood, 1977). Wild pigs damage or kill young palms, and monkeys occasionally pull up seedlings. Liaw (1983) described trapping methods used in Sabah for the control of these pests. In Indonesia, electric fences have proved effective for excluding pigs (Schmidt, 1986).

Squirrels (*Callosciurus* spp.) are occasionally troublesome in Asia, eating the mesocarp and sometimes attacking nursery plants.

12.3.3 Birds

The long-tailed parakeet (*Psittacula longicauda*), the blue-rumped parrot (*Psittinus cyanurus*) and the Malay lorikeet (*Loriculus galgulus*) have all been troublesome in Malaysia. Most destructive is the long-tailed parakeet, which feeds in flocks of up to 30 birds, carries away ripe fruit from the bunch and tends to scatter it about half-eaten. Such damage can be distinguished from rodent damage by the single beak groove in the fruit. The other species feed close to the bunch and do not scatter the fruit. Shooting is the only control known and with the long-tailed parakeet this does not seem to have been very effective (Wood, 1968a). However, with the expansion of the area under oil palms, most estates are now contiguous with other cultivated land, rather than adjacent to the parakeet's forest habitat, so their importance as a pest has diminished (B.J. Wood, pers. comm., 2001).

The American black vulture (*Coragyps atratus*) has become a serious pest in Brazil, Colombia, Honduras and elsewhere. In some countries these birds are protected by law as useful scavengers, and special permission must be obtained to shoot them. This course has been adopted in Colombia. In India, Dhileepan (1990) estimated that birds consumed up to 2.8 t FFB/ha per year. He suggested that cages could be used to protect bunches.

In West Africa the village weaver (*Ploceus cuculatus*) may be locally troublesome, stripping the leaflet laminae from a wide area to make nests in adjoining trees. It is usually necessary to fell the nesting trees to disperse the birds.

12.4 INSECT VECTORS OF DISEASES

As well as causing direct damage, some insects play an important role as vectors of disease. *Leptopharsa gibbicarina* (Hemiptera: Tingidae) appears to be the vector of *Pestalotiopsis* in leaf wither, and control of this insect has checked the spread of the disease (Section 12.1.5.2). A bug, *Recilia mica* (Delphacidae), has been implicated in the transmission of blast disease (Section 12.1.4). The weevils *Rhynchophorus palmarum* and *Metamasius hemipterus* are vectors of the nematode that causes red ring disease (Section 12.1.6.6). Two species of *Sogatella* (Homoptera: Delphacidae) have been shown to transmit a coconut disease similar to dry bud rot (Julia and Mariau, 1982).

Several insects have been associated with sudden wither (Section 12.1.6.4). *Sagalassa valida* was first suggested, then the hemipteran *Myndus crudus* (*Haplaxius pallidus*), but *Lincus lethifer* and *L. tumidifrons* (Hemiptera: Pentatomidae) now appear the most likely candidates.

12.5 PESTS OF OTHER COMPONENTS OF THE OIL PALM AGROECOSYSTEM

12.5.1 Pests attacking pollinating weevils

Since its introduction to oil palm-growing areas outside Africa, the pollinating weevil *Elaeidobius kamerunicus* (discussed further in Section 2.2.2.5) appears generally to have thrived. There have been occasional suggestions that poor pollination was due to pest or disease attack, but there is no convincing evidence for such effects. Liau (1985) reviewed what was known at that time, and little seems to have been added since.

The main predators on the weevil in the Far East are undoubtedly rats. These consume large numbers of larvae, destroying the old male inflorescences in the process, and Liau (1985) showed that rats grew more rapidly on a diet supplemented with weevil larvae. Basri Wahid and Halim Hassan (1985) considered that rat populations, and the amount of damage done, had increased since the introduction of the weevil. Chiu *et al*. (1985) estimated that up to 80% of weevil

larvae might be eaten by rats, but noted that the weevil population remained high enough to ensure good fruit set.

Kang and Zam (1982) detected, and eradicated, two species of parasitic nematodes in weevils imported to Malaysia. There have been more recent reports of weevils parasitised by nematodes in Malaysia, though (R.A. Syed, unpub.; Rao and Law, 1998), and Poinar *et al.* (2002) described a new species, *Elaeolenchus parthenonema*, which reproduces asexually and is an internal parasite of *E. kamerunicus*. Rao and Law showed that parasitised weevils had shorter life expectancy and lower reproductive rates than unparasitised. They considered that these effects, combined with low numbers of male inflorescences (the weevil breeding sites) during periods of high oil palm sex ratio, could lead to the poor fruit set which has sometimes been observed in parts of East Malaysia.

12.5.2 Pests attacking legume cover crops

Wood (1976a) and Liau (1979) reported that leaf-eating caterpillars, grasshoppers and cockchafers may do considerable damage to legume cover crops. Perhaps equally importantly, though, Wood also noted the existence of 'chronic' pests, particularly the bug *Chauliops bisontula*. The occurrence of this pest in Malaysia, and the debilitation that it can cause, may explain why cover crop growth is often very weak in that environment. Liau (1979) reported a trial in which cover crop pests were controlled by insecticide spraying. The planted legume species made up a consistently greater proportion of the total ground cover biomass in the sprayed than in the unsprayed plots, indicating that the pests were reducing the vigour of the legumes. In the latter, more than half of the biomass consisted of weeds by 11 months after sowing.

Liau did not recommend insecticide spraying of the cover crop as a practical measure; spot spraying of weeds with herbicide is clearly more environmentally benign. However, the trial did help to explain why so much time and effort has to be spent on managing and maintaining the cover crop in Malaysia, whereas in most countries *Pueraria phaseoloides*, and the other leguminous species used, grow strongly in young palm plantings, easily suppressing most weeds.

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R.H.V. Corley, P.B. Tinker

Chapter 13
The Products of the Oil Palm and their Extraction

13.1 PALM OIL PRODUCTS AND THEIR CHEMICAL STRUCTURE

The properties and uses of, and extraction processes for, the main oil palm products, palm oil, palm kernel oil and palm kernel cake, all depend on their chemical structure, so this is briefly discussed here.

13.1.1 Palm oil composition

Palm oil is a lipid, meaning it will not dissolve in water, but will do so in a wide range of organic solvents. It is a mixture of triglycerides, compounds with the general composition shown in Fig. 13.1a. The groups labelled R are always long-chain fatty acids, with chains of varying numbers of carbon atoms (e.g. Fig. 13.1b). These are combined with glycerol (Fig. 13.1c) to form esters, in which the fatty acid residues can be the same or different. This esterification reaction can be reversed, to give glycerol and fatty acids, as explained below. Some of the fatty acids have only single chemical bonds between the carbon atoms, while other fatty acids have double bonds between carbon atoms in one, two or three positions. This difference is important for their chemistry, physical properties and nutritional value. Fatty acids or fats containing double bonds are called unsaturated, oleic acid, with one double bond (Fig. 13.1d), is known as monounsaturated, while linoleic acid, with two double bonds (Fig. 13.1f), is polyunsaturated.

The presence of at least one double bond introduces a complication, because a carbon atom can rotate easily around its single bond to its neighbour, but a double bond fixes the positions of the two carbons that it links. Such compounds can then occur in two different forms, called steric isomers, with a *cis* or a *trans* form (Fig. 13.1e), depending on the relative positions in space of the groups linked to them.

There are five important reactions that may be undergone by many or all fatty acid groups within a triglyceride molecule. The first is hydrolysis (Fig. 13.2a), the reverse of esterification, so that the fat molecule is split, and the elements of water (H and OH) are added to the broken bonds, to produce glycerol and fatty acid(s). Measurement of the free fatty acid (FFA) content of palm oil is reviewed by Siew (2000a). When water is present, the reaction can be autocatalytic, or catalysed by some metals or by the enzyme lipase, which is widely found in living organisms and is also present in oil palm mesocarp. This hydrolysis can be undesirable, such as when palm oil still within the detached fruit begins to react, producing free FFA and diglycerides (Section 13.3.3), and it must be minimised during the whole extraction, purification and transport chain. Industrial hydrolysis is intentional, and involves reaction with an alkali such as sodium hydroxide. This produces glycerol, for which there are many uses, and soap, the sodium or potassium salt of a fatty acid.

The second reaction is oxidation, which is almost always undesirable. Free oxygen, especially in the presence of traces of metal and light, can attack the double bonds in an unsaturated fat or oil, forming hydroperoxides. Subsequently, these break down, with splitting of the carbon chain, to compounds that cause undesirable flavours or colours and reduce the value of the oil. The degree of peroxidation can be measured to give the peroxide value (PV), while the anisidine value (AV) gives a measure of the secondary breakdown (Section 13.4.5.2).

The third reaction is hydrogenation (Fig. 13.2b), by which a molecule of hydrogen attacks a double bond and produces a single bond, the hydrogen atoms adding to the two spare bonds. The reaction is catalysed by various metals. Hydrogenation allows the degree of unsaturation of an oil to be controlled, and this gives a great degree of flexibility to the industrial uses of oils (see Section 14.3.3.2). During hydrogenation there is significant isomerisation, so that some *cis*-type isomers may change to *trans*-type.

The fourth reaction is transesterification, in which the acids are rearranged among the three positions on the glycerol molecules, with the aid of a catalyst,

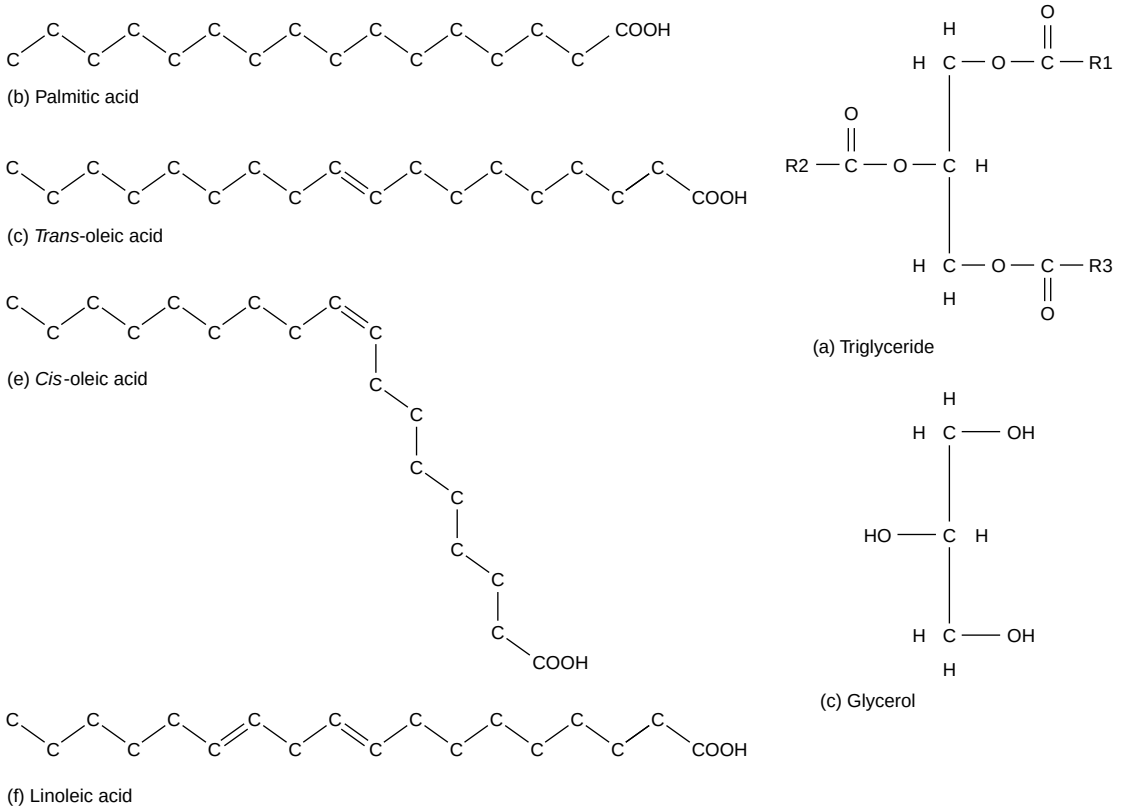

Fig. 13.1 Chemical structure of fatty acids, glycerol and triglycerides. Each carbon atom in a fatty acid chain carries two hydrogen atoms, or one in the case of double bonds (these are omitted for clarity).

producing a fat with different properties. Interesterification is similar, but involves redistribution of fatty acids between triglyceride molecules (see Section 14.3.3.3).

The fifth reaction is halogen addition, in which a molecule of iodine adds on to a double bond (Fig. 13.2d). This is the basis of the measurement of unsaturation, given by the iodine value (IV) (Siew, 2000a). High iodine values indicate a greater degree of unsaturation. Direct measurement of the iodine value is a long-established technique, but it can also be calculated from fatty acid composition measured by gas–liquid chromatography (GLC). A pure monounsaturated fat has an IV of 90, and a di-unsaturated fat 180. Thus, a fat with 40% oleic and 10% linoleic acids would have an IV of $(90 \times 0.4) + (180 \times 0.1) = 54$.

The physical properties of oils used in commerce are extremely important. Colloquially, 'fats' refers to solid material and 'oils' to liquids; this is not a scientific distinction, but the melting or softening points have to be precisely specified for use in industrial processes and domestic usage; methods of measurement are discussed by Siew (2000a). This is a complex topic because palm oil (like other oils) is a mixture of many different triglycerides, with different fatty acids combined in different positions within the same molecule. There is consequently no single clear melting point of this mixture. At ambient temperature palm oil is usually a mixture of solid and liquid phases, the solid fat often settling out under supernatant oil. The physical fractionating of this mixture, to produce materials with different melting points and behaviour, is described in Chapter 14.

13.1.2 Fatty acid composition and structure

The fatty acid composition of typical Malaysian palm oil, and of some of the fractionated products, is shown in Table 13.1; much more detail is given by Tang (2000).

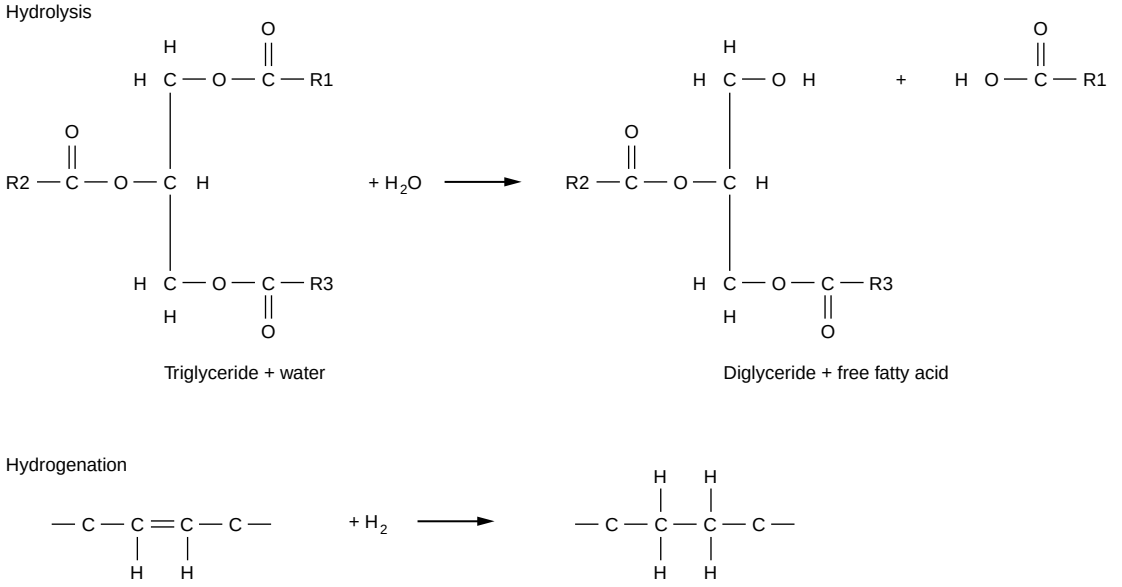

Fig. 13.2 Reactions which fatty acids may undergo. For the hydrogenation reaction, only the hydrogen atoms attached to the two carbons concerned are shown.

Table 13.1 Fatty acid composition and other properties of Malaysian palm oil and fractionated products

Fatty acid	Palm oil mean	Range for palm oil	Standard palm olein	Special palm olein	Typical palm stearin	Range for palm stearin
C14:0 Myristic	1.1	0.9–1.5	1.0	1.1	1.3	1.1–1.9
C16:0 Palmitic	43.5	39.2–45.8	39.8	31.5	54.0	47.2–73.8
C18:0 Stearic	4.3	3.7–5.1	4.4	3.2	4.7	4.4–5.6
C18:1 Oleic	39.8	37.4–44.1	42.5	49.2	32.3	15.6–37.0
C18:2 Linoleic	10.2	8.7–12.5	11.2	13.7	7.0	3.2–9.8
C18:3 Linolenic	0.3	0.0–0.6	0.4	0.3	0.1	0.1–0.6
Iodine value	53.0	51.0–55.3	58.0	66.4	39.9	21.6–49.4
Slip melting point (°C)	36.0	32.3–39.0	21.6	12.0	51.3	44.5–56.2
Cloud point (°C)	–	–	8.8	2.2	–	–

From Sambanthamurthi *et al.* (2000b), Berger (1996a) and Tang (2000).

The palmitic and stearic acids are saturated, and confer a high melting point. Oleic, linoleic and linolenic acids, with 1, 2 and 3 double bonds, respectively, are unsaturated, and confer lower melting points. Increasing the saturation by hydrogenation alters the melting point, but with acids that are already saturated, there is no simple way in which they can be made unsaturated. Consequently, there might be an advantage if palm oil contained more unsaturated acids, although standard palm oil has many uses.

There is no evidence that environmental factors affect oil composition, although ambient temperature does affect composition in other crops, with more saturated fats being produced at higher temperatures (e.g. Lehrian *et al.*, 1980). Loncin and Jacobsberg (1963, 1965) found no differences on average between grove palms and plantation palms in Congo. However, there may be some geographical differences, perhaps related to genetic differences (see Section 5.5.7). Hartley (1988, p. 677) reviewed the evidence that oil from palms in the western part of the palm belt in West Africa had a higher unsaturation than elsewhere, and that Deli palms had slightly lower unsaturation than palms from African origins.

There is much variation from palm to palm in oil composition, and the possibility of changing composition by breeding is discussed in Section 5.3.7. A large biotechnology programme at the Malaysian Palm Oil Board (MPOB) aims to produce a genetically modified palm with a significantly increased proportion of unsaturated acids in the oil (see Section 6.6.2).

13.1.3 Triglyceride composition and structure

The different fatty acids occur in different triglyceride molecules in a fairly random way, although with a preponderance of unsaturated acids in the 2-position on the glycerol molecule (Table 13.2). The distribution of saturated or unsaturated acids in the 2-position may be important in relation to heart disease (Goh, 1998; see also Section 14.4). In samples from Congo, about 6% of triglycerides contained only saturated fatty acids, 48% two saturated to one unsaturated, 43% one saturated to two unsaturated, and about 3% with only unsaturated fatty acids (Loncin and Jacobsberg, 1963). The comparable figures for Malaysian palm oil, from Jacobsberg (1975), were 8%, 49%, 36% and 7%.

Triglycerides have also been analysed in terms of total carbon atom number in the fatty acids. Mean figures for 100 Malaysian samples were: C46 0.7%, C48 8.5%, C50 42.9%, C52 39.0%, C54 8.6% and C56 0.5% (Tang, 2000).

13.1.4 Non-triglyceride constituents

All components of palm oil are oil soluble, and hence they are lipids. However, there are very small quantities of lipids that are not triglycerides, the importance of which is increasing (Goh, 1998). These include carotenes, tocopherols, sterols and terpenoids. These compounds are largely concentrated in the olein fraction of palm oil after fractionation. The main compounds are listed in Table 13.3.

Table 13.2 Triglyceride composition of Malaysian palm oil.
M: myristic; P: palmitic (but see below); S: stearic; O: oleic; L: linoleic

0 double bonds			1 double bond			2 double bonds			3 double bonds			4 double bonds		
FAs	%		FAs	%		FAs	%		FAs	%		FAs	%	
	1	2		1	2		1	2		1	2		1	2
PPP	4.8	9.0	POP	28.7	30.6	POO	19.6	21.5	POL	5.5	4.8	LOO	1.9	1.7
PSP	1.2	–	POS	4.7	–	PLP	6.9	9.3	PLO	4.8	6.5	PLL	1.4	1.5
Others	1.9	–	PPO	3.5	6.3	SOO	1.8	–	OOO	3.3	3.8	OLO	0.8	1.1
			MOP	0.9	–	PLS	1.2	–	Others	1.2	0.0	Others	1.0	0.1
			Others	1.9	0.0	PPL	0.9	1.4						
						Others	2.1	1.1						
Total	7.9	9.0	Total	39.7	36.9	Total	32.4	33.3	Total	14.8	15.1	Total	5.1	4.4

References: 1: Jacobsberg (1975); 2: Berger *et al.* (1978); in these figures, P includes all saturated fatty acids.

Table 13.3 Minor constituents of palm oil

Carotenes	%	Sterols	%	Tocopherols	%
Phytoene	1	β-Sitosterol	60	α-Tocopherol	21
β-Carotene	56	Campesterol	13	α-Tocotrienol	23
α-Carotene	35	Stigmasterol	24	γ-Tocotrienol	45
cis-α-Carotene	2	Cholesterol	3	δ-Tocotrienol	11
Lycopene	1				
Others	4				
Total (ppm)	500–700		250–620		600–1000

From Jalani and Rajanaidu (2000).

13.1.4.1 *Carotenoids*

These are strongly coloured, usually red or brown, compounds containing numerous alternating double bonds, some of which have the important property of splitting and forming vitamin A. They are thus known as pro-vitamin A compounds, with β-carotene being the most important (Sundram and Chandrasekharan, 2000). The concentration in palm oil is variable, but commercial oil will usually contain 500–600 ppm. The non-vitamin A precursor carotenoids are more stable than the precursors, and so may be able to maintain an antioxidant level for longer (Goh, 1998). The concentration of carotenes varies widely, as would be expected from the varied colours of oil palm fruits, and varies even within a bunch, and from bunch to bunch on the same palm. In general, Deli palms produce a less coloured oil than African palms do, and among the latter, oil from West Africa has the highest carotene content.

13.1.4.2 *Other minor compounds*

Compared with most of the edible vegetable oils, palm oil has a high level of tocotrienols and tocopherol, which are components of vitamin E (Table 13.3). These compounds are strong antioxidants, and have various helpful activities in relation to heart disease, e.g. inhibition of cholesterol plaques. The tocopherol concentration may be higher in plantation palm oil than in oil from grove palms (Hartley, 1988), perhaps because of more careful processing.

Sterols are usually present in palm oil to 300–500 ppm (Table 13.3). These sterols can be removed by physical refining, or left in the oil. They are believed to have anti-cholesterol activity, but their activity in the body is far from clear. Cholesterol is largely an animal product; palm oil contains only about 9 ppm (Tang, 2000).

13.2 NUT COMPOSITION

13.2.1 Kernel composition and structure

The structure of the nut, including the shell, is discussed in Section 2.2.1.1. The shell is important as a fuel in the extraction mill. The kernel is the true seed, and consists mostly of an oily, dull white endosperm. This is crushed to produce palm kernel oil, and a press cake that is used for animal feed. The average composition of palm kernels is 47–52% oil, 6–8% moisture, 7.5–9% protein, 23–24% extractable non-nitrogen (mainly carbohydrates), 5% cellulose and 2% ash (Hartley, 1988). The moisture content is variable, as the kernels eventually reach an equilibrium with the relative humidity in which they are stored. Kernel cake, after extraction of the oil, is composed of about 48% carbohydrate, 5% residual oil, 19% proteins, 13% fibre, 4% ash and 11% water. It is a source of useful additional income, although it is far less important to the palm oil plantation than soyabean press cake is to a soyabean farmer (Section 14.2.2). It has a lower protein content than soya meal, and is less valuable to animal feed compounders for that reason. The protein is high in argenine and glutamic acid.

13.2.2 Kernel oil composition and chemical structure

Palm kernel oil (PKO) is similar in fatty acid composition to coconut oil, both being known as 'lauric oils' because of the high proportion of lauric acid (about 50% in PKO). It contains a smaller proportion of unsaturated fatty acids than palm oil, and consists predominantly of acids with shorter chain-lengths (Table 13.4). There are small quantities of C6 and C20 (caproic and arachidic) saturated acids, and of the unsaturated acids C16:1 and C18:3 (palmitoleic and linolenic). With the low content of unsaturated fatty acids the iodine value is only about 17. The melting range is also smaller than for palm oil, at 27–30°C, and the mean slip melting point is 27.3°C. Kernel oil is pale yellow, containing only about 7 ppm carotene (Yusoff, 2000).

13.3 OIL SYNTHESIS AND BREAKDOWN IN THE FRUIT

The physical changes accompanying ripening have been described in Chapters 2 and 10. Development of fats in the kernel precedes that in the mesocarp. Some data from the work of Crombie (1956) and Oo *et al.* (1986) are given in Table 13.5.

13.3.1 Kernel oil formation

At 8 weeks from pollination the content of the seed is liquid; by 10 weeks it becomes semi-gelatinous, and it is not really hard until the 15th week. At 10 weeks from pollination the amount of lipid is very small, consisting of membrane and other structural lipids; unsaturated fatty acids preponderate, as indicated by the iodine value of about 85 (Crombie, 1956). From this stage there

Table 13.4 Composition of palm kernel oil and fractionated products

Fatty acid	Palm kernel oil[a]		PK Olein[b]	PK Stearin[b]
	Turrel (1985)	Tang (2000)		
C8:0 Caprylic	3.3 (2.5–4.7)	4.2 (3.4–5.9)	4.3	1.9
C10:0 Capric	3.5 (2.8–4.5)	3.7 (3.3–4.4)	3.6	2.7
C12:0 Lauric	47.5 (43.6–51.4)	48.7 (46.3–51.1)	44.7	56.6
C14:0 Myristic	16.4 (15.3–17.2)	15.6 (14.3–16.8)	14.0	22.4
C16:0 Palmitic	8.5 (7.2–10.0)	7.5 (6.5–8.9)	8.3	8.0
C18:0 Stearic	2.4 (1.9–3.0)	1.8 (1.6–2.6)	2.3	1.8
C18:1 Oleic	15.3 (11.9–18.5)	14.8 (13.2–16.4)	19.2	5.6
C18:2 Linoleic	2.4 (1.4–3.3)	2.6 (2.2–3.4)	3.3	0.8
Iodine value	–	17.9 (16.2–19.2)	23.0	7.0

Turrell (1985): data for 54 samples from 16 countries.
Tang (2000): data for 118 samples of PKO, 52 samples of olein and 49 samples of stearin from Malaysia.
[a]Mean (range); [b]mean values.

Table 13.5 Changes in weight and composition of developing fruit

(a) Kernel

Weeks after pollination	Dry wt (g/nut)	Oil[a] (g/nut)	Saturated acids						Unsaturated acids	
			C6 + C8 (%)	C10 (%)	C12 (%)	C14 (%)	C16 (%)	C18 (%)	C18:1 (%)	C18:2 (%)
10	0.07	0.01	0.4	0.5	1.4	1.2	13.3	2.0	67.1	14.1
12	0.16	0.02	0.5	1.2	21.4	8.6	11.1	4.3	46.5	6.4
13	0.20	0.05	6.2	1.7	25.7	10.1	10.7	3.6	35.6	6.4
14	0.38	0.09	4.0	2.1	44.3	15.7	7.5	4.2	21.2	3.0
15	0.59	0.24	3.8	3.9	47.6	17.1	9.6	2.2	14.3	1.5
19	1.08	0.37	1.7	1.4	50.7	17.9	9.1	2.4	14.1	2.7
20	1.21	0.42	2.0	2.7	46.1	18.4	13.3	1.7	16.0	3.1

(b) Mesocarp

Weeks after pollination	Dry matter (%)	Oil[a] (% fresh weight)	Saturated acids					Unsaturated acids		
			C10 (%)	C12 (%)	C14 (%)	C16 (%)	C18 (%)	C18:1 (%)	C18:2 (%)	C18:3 (%)
8	12.2	0.09	4.2	3.1	1.0	27.5	4.4	22.2	24.0	13.6
12	11.6	0.14	1.4	1.5	1.0	27.0	4.5	22.7	23.9	18.0
16	18.5	6.4	0.1	1.7	0.4	35.2	5.4	42.6	13.9	0.8
20	62.5	47.8	0.4	5.5	1.1	40.8	5.0	35.9	11.3	0.0
Overripe	77.2	66.7	0.0	0.8	1.5	44.2	5.4	38.7	9.4	0.0

Kernel data from Crombie (1956); mesocarp from Oo *et al.* (1986).
[a]In the kernel analyses, weights are on a per nut basis. In mesocarp, oil is shown as per cent of dry weight.

is a slow accumulation of lipids until about the 12th to 13th week, when lipid formation becomes more rapid; the lipids laid down are largely saturated, principally lauric and myristic. The major accumulation occurs around the 14th to 16th week.

13.3.2 Palm oil formation

Fat formation in the mesocarp takes place late in fruit development (Crombie and Hardman, 1958; Thomas *et al.*, 1971). Up to about the 16th week after pollination, lipids

constitute less than 2% of the dry weight of the mesocarp, again consisting mainly of structural lipids. There is very little addition of any kind to the dry weight of the mesocarp from the 8th to the 16th week when, just prior to ripening, dry weight increases by 300–500% and fats come to constitute 70–75% of dry matter (Crombie and Hardman, 1958). During the long period of low oil content linoleic and linolenic acid levels are high; these are typical of membrane and chloroplast lipids. During the final weeks of ripening all of the fatty acids in combination increase, with oleic acid becoming second only to palmitic acid in quantity. The pathway of fatty acid synthesis is outlined in Section 6.6.2.1.

The process of oil accumulation in the fruit is important because of the need to determine the point at which harvesting is most profitable (Section 10.4.4). The very rapid build-up shortly before the fruits ripen and start to detach from the bunch means that quite small changes in harvesting procedure may have large effects on oil content. Once fruit start to detach, though, triglycerides start to break down, as discussed in the next section.

13.3.3 Lipase activity

It has long been assumed that palm mesocarp contains a highly active lipase, which releases FFA from triglycerides; the FFA content of crushed mesocarp may reach 30% within 5 min (Desassis, 1957). Tombs and Stubbs (1982) were unable to detect an endogenous lipase in surface-sterilised fruits, and suggested that all lipolytic activity was microbial, but other work has shown that there is an endogenous lipase (Abigor *et al.*, 1985; Henderson and Osborne, 1991). The latter authors suggested that the enzyme was inactivated by chilling, explaining why Tombs and Stubbs found no activity. However, Sambanthamurthi *et al.* (1995) showed that lipase activity could be inhibited by adding high levels of FFA, and suggested that the inhibition observed by Henderson and Osborne was due to feedback inhibition by FFA, and not to chilling. Similar experiments carried out by Henderson and Osborne (not reported in their paper) showed that the direct addition of these high levels of palmitic acid in the lipase assay could shift the pH sufficiently from the assay optimum for the result to appear as an FFA inhibition (D.J. Osborne, pers. comm., 2001). It is clear that further experimentation is still needed.

The function of the lipase remains uncertain. Henderson and Osborne (1991) found that activity developed at about the same time as oil synthesis commenced, and speculated that the lipase might play a part in triglyceride synthesis in the lipid-rich oleosomes of the mesocarp, although the accepted pathway for triglyceride formation *in vivo* involves glycerol-acyltransferase enzymes (Sambanthamurthi *et al.*, 2000b). Lipases do not normally have a synthetic function in nature, although industrially they can operate synthetically under non-aqueous conditions (see Lortie, 1997, for review).

Hydrolysis of triglycerides does not occur in undamaged fruit, presumably because the lipase is compartmentalised within the cell and only comes into contact with the oil if cell membranes are damaged. The first stage is a partial hydrolysis, the products being FFA and diglycerides (glycerol with two fatty acids attached). The FFA can be removed by neutralisation, but the diglycerides remain, and have significant, and undesirable, effects on fractionation behaviour (see Section 14.3). It is therefore essential to minimise bruising or damaging of the fresh fruit before it reaches the mill, where the enzyme, together with any microbial lipases, is inactivated by sterilisation.

13.4 EXTRACTION OF PALM PRODUCTS

13.4.1 The extraction process

Most of the stages in the process are essentially the same, whether in a 60 t/h mill or a small-scale village process. The stages are as follows (Maycock, 1990) (see Fig. 13.3).

1. Bunch sterilisation with high pressure steam; this loosens the fruit from the bunch, and inactivates the endogenous lipase, and any micro-organisms, so that FFA build-up does not occur (Section 13.3.3).
2. Bunch stripping, to separate fruit from bunch stalk and spikelets.
3. Fruit digestion to pulverise and disrupt the mesocarp, with heating to aid oil extraction.
4. Pressing or other treatment of the digested fruit to extract the oil.
5. Separating, clarifying and drying the oil.
6. Separating nuts from fibre.
7. Nut drying, grading and cracking.
8. Separating kernels from shell.
9. Kernel drying and packing.

Mills are typically powered by steam turbines, and a generator driving electric motors of appropriate sizes for the different pieces of equipment. The steam comes from boilers fed with shell and fibre; boiler operation, discussed by Cooper (1983), is an important aspect of mill management. Wood and Corley (1993) estimated that the energy output of a plantation (182 GJ in the oil

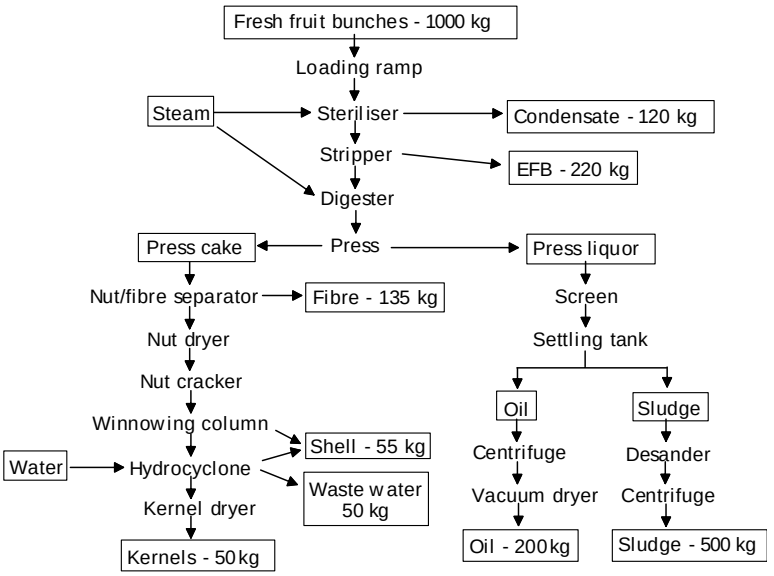

Fig. 13.3 Schematic flow diagram for palm oil and kernel extraction. Approximate mass of outputs shown, from 1 t of FFB, assuming 20% OER and 5% KER. (Based on Ma, 1999a, and Chan, 1999.)

and kernels from 20 t FFB/ha·yr) was over nine times the input energy (19.2 GJ/ha, of which fertilisers made up 59%, and fuel for transport 30%).

13.4.2 Extraction of palm oil and kernels by traditional methods

It is unlikely that any oil produced by these methods enters international trade now, but small-scale extraction still continues in Africa. A brief discussion follows; Hartley (1988) gives more detail. There are two methods, yielding 'soft oil' and 'hard oil'. For both methods, the fruit is allowed to ferment for a time (omitting stage 1, above). For soft oil, the fruit is then boiled for some hours and pounded into a pulp. The oil is separated by adding water and skimming it off; it is then heated to remove any residual water. The hard oil process is basically similar, except that initial fermentation is longer, there is no boiling, and the fermented fruit is trodden in a large container until it has formed a pulp. Again, water is added and the oil is skimmed off as it rises to the top. Both processes are inefficient, with 40–50% recovered by the soft oil process and 20–30% by the hard oil process (Maycock, 1990). The FFA values would be about 10% and 30–50%, respectively. It is hard to imagine procedures more at variance with modern plantation methods.

Various hand presses have been developed for village use; hand-operated centrifuges may also be used, with special sterilisers, or with boiling in drums as described above. The most successful press was a modified wine-press, which could give extraction efficiencies of up to 70% under the best conditions. Systems developed around this type of press could deal with some 700–800 kg of bunches/day. The FFA content of oil produced in these systems was much lower than in the traditional methods. In 1959 hydraulic hand-presses came into use that were much more efficient, handling around 0.75 t of bunches/h in continuous operation, and extracting some 95% of the oil in the boiled pulp. These are discussed further in Section 13.4.4.

13.4.3 The palm oil mill

A modern palm oil mill or factory (Plate 13.1) consists of a number of sections, each performing one of the stages listed in Section 13.4.1. The development and operation of the mill is briefly outlined in the following sections; more detail of the early methods can be found in Hartley (1988). The first mechanised mills were constructed in Africa around 1909, in Cameroon and in Benin; the first one in Asia started in Sumatra in 1919. The modern mill design had developed before the 1970s, and recent developments in milling technology have been fairly minor (Southworth, 1976; Maycock, 1990; Menon, 2001).

13.4.3.1 *Fruit reception*

Fruit is normally delivered to a raised ramp. Tipping lorries or trailers deliver the fruit into sloping hoppers,

Plate 13.1 A large mill of 60 tonnes per hour capacity serving 8000 hectares in Malaysia.

Plate 13.2 Horizontal bunch sterilisers with bayonet-type doors. (Gebr. Stork & Co.)

with hydraulic doors controlling the loading of the fruit into steriliser cages. The effects of fruit handling on quality are discussed in Section 13.4.6.1. Fruit may be stored for several hours on the ramp, until the mill is ready to process it, thus providing a buffer between fruit transport, which is usually a daytime activity, and milling, which may be a 24 h process during the peak season.

13.4.3.2 *Sterilisation*

Some small mills use vertical sterilisers, but the horizontal steriliser is now standard. The steriliser consists of a long, cylindrical pressure vessel, of about 1.8 m diameter, with rails running along the length of the interior (Plate 13.2). The fruit is loaded into 'cages', which are of approximately circular cross-section to fit inside the steriliser. These cages, each containing 1.5–2.5 t fruit, are pushed on the rails into the steriliser. Steriliser capacity depends on the length; a large steriliser would hold six or more cages, and a large mill would have several sterilisers. In some mills cages of up to 10 t capacity are used (Menon, 2001). Once the steriliser has been loaded and closed, steam is introduced. Pressure is built up to about 3 kg/cm^2, which

corresponds to a temperature just above 130°C, and held there for about 1 h. As already mentioned, sterilisation serves two main purposes: it prevents FFA build-up in the oil, and it loosens the fruit on the bunch to facilitate stripping. Maycock (1990) also mentioned softening of the pericarp for easier digestion, and preconditioning of nuts to reduce breakage in the press. In some mills, detached fruit are sterilised separately. A period of 12–15 min is sufficient for such material, the shorter time greatly reducing oil losses.

'Hard bunches', in which stripping is incomplete, are often a problem, particularly where fruit set is very high, or where bunches have been harvested underripe. Stripping of hard bunches is improved by double or triple peak sterilising, in which pressure is released, and then built up again, but this tends to increase oil losses on empty bunches and in steriliser condensate (Section 13.4.5.2).

In recent years, there have been minor improvements in control mechanisms and safety devices; microprocessor control of sterilisation is well established in the industry. Sivasothy and Rohaya (2000) investigated a system of bunch crushing before sterilisation. Crushing meant that sterilisation could be done with low-pressure steam, giving the possibility of a continuous sterilisation process. Complete stripping was easy, and provided that heating immediately followed crushing, there was little increase in FFA content, but the mesocarp was not sufficiently soft for good digestion.

13.4.3.3 *Stripping*

The aim of stripping is to separate the fruits from the empty bunch, consisting of the stalk and spikelets. Small mills have used a 'beater' stripper, but the drum stripper is standard in modern mills; Chooi (1983) gave details. This consists of a horizontal drum, made of bars spaced so that fruits can fall through, but the bunches remain inside the drum. Cages of sterilised fruit are lifted and tipped into a bunch feeder; bunches are fed from this into one end of the stripper drum, either manually or automatically, sometimes with a feedback control from the digester. The drum rotates at about 22 rpm. In one design, the central shaft on which the drum rotated was eliminated; instead, the drum moved on rollers (Maycock, 1990). This reduced breakdowns, and adding beater arms increased stripping efficiency.

Empty fruit bunches (EFB) from the stripper are conveyed either to an incinerator or, more commonly now, to an EFB hopper prior to transport back to the field for use as mulch (see Sections 10.1.3.2 and 11.7.2.1). The EFB conveyor is inspected continuously for hard or 'unstripped' bunches. These, which are usually more accurately described as partially stripped, are recycled for repeat sterilisation and stripping.

13.4.3.4 *Digestion*

Fruit from the stripper is carried by conveyor belt to the digester. The design of digesters has changed little over the years. There is a vertical cylinder, with rotating beater arms which pulverise the fruit, loosening the pulp from the nut. The mass of nuts and pulp is heated, before passing into the press, either by a heating jacket or by live steam injection. The latter is now the more common method (Maycock, 1990). Thorough digestion is critical for efficient pressing (Southworth, 1976).

13.4.3.5 *Pressing*

Oil extraction is the core of the mill operation, and press capacity normally determines the throughput of the mill. Centrifuges were used in many early mills, but hydraulic presses were introduced in the 1920s and gave greater extraction efficiencies (Hartley, 1988). Screw presses were first used in the 1950s (Maycock, 1990), and although there was much debate as to the relative merits of screw and hydraulic presses in the 1960s and early 1970s, screw presses are now universally used. The advantages of the screw press over the hydraulic press are (Maycock, 1990):

- continuous operation, and hence less labour required; the hydraulic press was a 'batch' process
- higher throughput, and hence less investment in buildings and machinery
- less power required for a given throughput
- nut/fibre separation is easier because of the lower oil content after pressing
- screw presses can handle a wide range of throughput rates.

A variety of different screw press designs is in use, with single screws or double screws, and throughputs of up to 20 t of fresh fruit bunches (FFB)/h (see Hartley, 1988, for more detail). The digested mixture of fibre, oil and nuts is forced through a perforated press cylinder by the rotation of the screw, or counter-rotating screws in the double screw press. Adjustable cones restrict the exit of the mass, so that pressure builds up in the press cylinder. In some designs, the pitch of the screw is gradually diminished, thus increasing the pressure.

Southworth (1983) gave information on factors affecting screw press performance.

Several alternatives to pressing have been investigated over the years. Maycock (1990) described the 'wet process' developed in Congo in the early part of the twentieth century. This involved the addition of hot water after digestion, to wash the oil out of the pulp. The method was further developed for small mills by Vandekerckhove of Belgium, who claimed 78–80% extraction using a fruit cooker and digester only, and 88–90% using a low-pressure (30 kg/cm^2) piston press, followed by warm water washing in a counter-current wet digester (Cornelius, 1983). These extraction processes had capacities of 0.7–2 t of bunches/h.

The Drupalm® process, based on methods of olive oil extraction (Noel *et al.*, 1997a, b) involves crushing sterilised and stripped fruit including the nuts, in a hammer mill, followed by digestion, and separation of the oil in a three-phase decanter. The process is claimed to be cheaper both to install and to run than a conventional mill, and to have a higher extraction efficiency. It produces a mixture of palm oil and kernel oil, which would be a disadvantage for some uses. Because the kernel content of present-day *tenera* fruit is low, the oil contains only 3% lauric acid, but even that amount would be enough to change the fractionation behaviour of the oil. Noel *et al.* (1997b) claimed that the olein yield was higher than from crude palm oil (CPO), but accepted that the product might not be suitable for some processes. The loss of the higher value PKO is also a disadvantage, but the cost savings are said to offset this.

Solvent extraction has been investigated (British Patent 1104577, 1968; Everaerts and Lubis, 1976), and Southworth (1976) considered that higher extraction efficiency than with pressing should be possible, but it does not appear to have been attempted on a commercial scale. Health and safety aspects would have to be considered, depending on the solvent used. The solvent extraction of residual oil from fibre after normal pressing has been suggested, but this oil is known to contain a high proportion of carotenoids and non-oil components such as waxes (Olie and Tjeng, 1974), which would introduce bleaching problems.

13.4.3.6 *Clarification, drying and storage*

The crude oil from the press consists of a mixture of oil, water and other 'non-oily solids' (NOS: mainly dirt and fibre). Exact composition depends on how much water was added prior to pressing; Velayuthan and Chan (1983) quoted 66% oil, 24% water and 10% NOS, but a survey of mills by Lim (1983) showed up to 50% water. Lim described the methods of separating of these components. Where the content of water and non-oily solids is low, simple physical settling is quite effective. In continuous settling tanks the oil/water mixture is fed into the middle of the tank, while separated oil is steadily removed from the top, and waste (sludge) from the bottom (Hartley, 1988). The oil and waste fractions are then centrifuged. More recently, decanters have been introduced, which can handle oil straight from the press, without the need for a settling tank (Kanapathy *et al.*, 1981; Roege *et al.*, 1983).

Finally, the oil must be dried, by the use of vapour extraction units or vacuum dryers, to prevent FFA formation by autocatalytic hydrolysis. Most mills in Asia achieve a water content of 0.1%, but Berger (1985) has suggested that it would be better to have a limit of 0.15%, as this would enhance the effect of antioxidants.

Storage is generally in welded steel tanks; the tanks contain heating coils, to prevent crystallisation and subsequent settling out of the solid phase. They may be filled with carbon dioxide or other inert gas above the oil, to prevent oxidation. The sensitivity of palm oil to higher temperatures is well established, and the temperature during storage and in transit is controlled to between 32 and 40°C, with loading and unloading temperatures between 50 and 55°C. Temperatures should be kept as low as possible, to minimise deterioration in quality during storage (Chong, 2000).

Berger (1985) published a draft code of practice for storage and transport, which in 1999 was adopted as the *Codex Alimentarius Code of practice for handling edible oils and fats* (Berger, 2000). In the latter paper, Berger described some of the contamination and quality deterioration which used to occur during shipping and pipe-line transfers in port, which the code of practice has eliminated.

13.4.3.7 *Kernel handling*

The cake coming from the presses consists of nuts and moist fibre, with some residual oil. To extract the kernels it is necessary to separate the nuts from the fibre, crack the nuts and separate the kernels from the cracked shells.

Fibre separation: This may be pneumatic, mechanical or hydraulic, but pneumatic fibre separators have become the standard in modern mills; Oh (1983) gives details. In the most commonly used type the fibre–nut mixture, partially dried, passes from a 'cake breaker' conveyor into a vertical airstream sufficient to carry the fibre upwards while the nuts fall into a smaller, lower rotating drum, where they are polished by friction. Some air also passes

through this drum, carrying any light particles upwards to join the main flow.

Purely mechanical fibre separators have been used for a long time, particularly in small mills where a low capital cost was imperative. One type consists of a screened drum which is rotated and allows the separated fibre to fall through the screen. A second type is a modification of a cotton ginning machine; a revolving shaft is fitted with studs which tease off the fibre. A third type has a rotary cage bounded by rollers, revolving in opposite directions in pairs, which remove the fibre to the outside of the cage but retain the nuts inside. Direct air separation columns are also used, in which the velocity of the upward current of unheated air which removes the fibre is adjustable.

Nut screening and cracking: The clean nuts may be dried in a nut silo or, if the drying during fibre separation has been sufficient, they may be conveyed straight to screens for grading by size before cracking. According to Maycock (1990), it is necessary to heat the nuts, to dry the kernels partially so that they shrink away from the shell, and then to cool them before cracking. Without this conditioning, kernel breakage is increased, and fragments of kernel adhere to the shell and are lost. If heating is excessive, though, kernel quality may suffer (Hartley, 1988).

In nut-cracking machines of the centrifugal type the nuts are fed through a central spindle, rotating at 1600–2200 rpm, and flung out against the wall of the cracker. A development has been the self-sorting nut-cracker which incorporates grading slots and pitching blades which grade the nuts and give them the correct speed for cracking; this makes prior nut screening unnecessary (Olie and Tjeng, 1974). Maycock (1990) mentioned the introduction of a ripple mill cracker, which has the advantage that prior nut conditioning is not required, and according to Menon (2001) this is now wildely used.

Kernel and shell separation: In the early days the shell and kernel mixture was placed in a salt bath, of specific gravity such that the shells sank while the kernels floated, and could be skimmed off, washed and dried. Later a mixture of water and clay was found more suitable. Shell has a specific gravity of 1.3, and kernels 1.1 (Akubuo & Eje, 2002), and according to Hartley (1988), a clay bath SG of 1.17 was used. Maycock (1990) quoted SG figures of 1.17 for shell, 1.07 for kernels, and 1.12 for the clay bath.

Modern mills almost exclusively use hydrocyclones for separation, although the clay bath was cheaper. The mixture is fed into a rotating vortex of water, and the heavier shell particles settle, while the kernels are carried off upwards. The shell is sent to the boiler house for fuel. The kernels should contain no more than 2.75% shell and other foreign matter (Turner & Gillbanks, 1974). Akubuo and Eje (2002) described a simple mechanical separator for use in small mills, but this gave kernels with about 20% shell, uncracked nuts and other impurities.

Kernel drying: Fresh kernels have a moisture content of about 20% and cannot be stored without deterioration. If the moisture content is much above 7%, hydrolysis of the oil in the kernel can proceed, both by autocatalytic hydrolysis and by lipolytic micro-organisms. Details of the latter are given by Hartley (1988), including some which are thermophilic and appear if a stack of kernel bags heats up to 50–60°C, as can happen occasionally. Hydrolysis is increased in proportion to the fraction of broken and damaged kernels. Drying is usually done in a silo: the fresh kernels are fed in at the top, warm air is blown upwards from below and dry kernels (7% moisture) are removed at the base. Menon (2001) described an experimental tray drier. The kernels may be steam-sterilised for 5–6 min before drying (Bek-Nielsen, 1969), and FFA of the kernel oil will then remain below 1% after storage for 6 months or more (Maycock, 1990).

Kernel oil extraction: In most mills, palm kernels are the final product, the crushing being done elsewhere (Section 13.5.2), but sometimes kernel oil is extracted in the mill, by pressing. This has the advantage of using the same power supply, derived from shell and fibre, as the rest of the mill.

13.4.4 Small-scale mills

For a long time palm oil production was considered either as a very large-scale business or as a small-scale peasant undertaking. For this reason there was much technical progress in the installation of very large mills and, at the same time, attention was given to providing for the non-mechanical needs of the small producer. However, in some parts of the world, notably America, the planting of small or medium-sized holdings of a few hundred hectares or less became common, and this engendered an interest in small mills of high efficiency. Such mills need to have a capacity of between 1 and 3 t of bunches/h and a low installation cost. The first small-scale or mini-mill was erected at the Central Experiment Station at Serdang, Malaysia, in the 1920s, and had both a small centrifuge and a small hydraulic press, but the first widely used such mill was the centrifuge-based 'Pioneer', which was introduced in Nigeria and other African countries in the 1940s. When wages rose steeply, these Pioneer mills became uneconomic in

Plate 13.3 Bunch stripper or thresher for the hand press mill.

comparison with small village curb-press businesses; Hartley (1988) gives details of the latter.

Small-scale mills now are of two kinds: they may be based on a hydraulic hand-press, or they may be fully mechanised but of low throughput and simple design. Mills of the first kind were developed at the Nigerian Institute for Oil Palm Research (NIFOR) (Nwanze, 1965), but Blaak (1979) found that the system was unpopular because of the high labour requirement for manual bunch stripping, pounding and reheating of the mashed fruit (Plates 13.3, 13.4). He constructed a village mill in Cameroon which allowed for the mechanisation of heavy work while retaining low-cost, simple apparatus. A small boiler provided steam for fruit sterilisation and nut drying, while diesel engines operated a digester, nutcracker and water pump. Production could reach 1 t of palm oil in an 8 h shift, equivalent to 0.625 t of *tenera* bunches/h. This type of mill is most suited to the traditional oil palm peasant agriculture of Africa and is unlikely to attract growers elsewhere. Some of its features were adopted by workers at the NIFOR/FAO (Food and Agriculture Organisation of the United Nations) Engineering and Development Unit in Nigeria (Hadcock, 1983; Badmus, 1993) with the same objectives in view. Baryeh (2001) studied the effects of processing conditions on palm oil yield from a hydraulic hand-press. The optimal duration of fruit cooking was 20 min, at 100°C. The yield was greatest with an extraction pressure of 25 MN/m^2, applied for up to 10 min.

The Kramer process developed in Ghana, described by Blaak (1989), involved bunch stripping and fruit cooking in the village, with hot fruit delivered by the farmer to a simple mill using a horizontal digester and hydraulic hand-presses. The press cake was returned to the farmer, who separated the nuts and dried the fibre

Plate 13.4 Pounding sterilised fruit.

before a second pressing. The oil produced was almost dry, so there was no liquid effluent from the process. The equipment was very cheap, but extraction efficiency was only about 82%.

Mills of the second kind with a capacity of 0.75–3 t/h have been installed in several parts of Africa and America. In the latter continent many of these mills have been locally designed and incorporate short horizontal bunch sterilisers with a compact rail system which enables the sterilised bunches to be moved easily from the sterilisers to the stripper (Plate 13.5). In many cases the mills have been constructed on a slope so that gravity can be used for moving the bunches to the sterilisers and to the strippers, and the fruit to the digesters.

Plate 13.5 Small cages, rails and weighing scales for short horizontal bunch sterilisers in a small, locally designed mill in Columbia.

Table 13.6 Typical oil losses

	Cause of loss							
	Steriliser condensate	EFB	Hard bunches	Fibre	Sludge	Nuts	Total	Ref.
Product as % FFB	14.7	18.9	2.62	13.3	42	–	–	1
Oil in product (%)	0.47	2.86	23.8	6.2	0.72	–	–	
Oil loss as % FFB	0.07	0.55	0.60	0.84	0.32	–	2.39	
Oil in product (%)	–	–	–	5.3	–	–	–	2a
Oil loss as % FFB	–	0.42	–	0.64	0.43	0.10	1.59	
Oil in product (%)	–	–	–	5.7	–	–	–	2b
Oil loss as % FFB	–	0.61	0.10	0.63	0.39	0.12	1.85	
Oil in product (%)	0.36	–	–	14.7	1.66	–	–	3
Oil loss as % FFB	0.07	–	–	0.9	0.68	–	–	

EFB: empty fruit bunch; FFB: fresh fruit bunch.
References: 1: Wood *et al.* (1985b) (data for seven 200 t batches of fruit, harvested to different ripeness standards; hard bunches recorded before recycling; figure = loss in fruit from such bunches if not recycled, measured after removal; bunch stalks of hard bunches included under EFB); 2: Velayuthan (1985) (a: mean for two mills, over 2 years before introduction of weevil; b: same mills for 2 years after introduction; hard bunches stated to be negligible before introduction; figure = losses persisting after recycling); 3: Sundaresan *et al.* (1990) (data from 1 t/h mini-mill; no figures given for loss on EFB).

Sundaresan *et al.* (1990) described a small mill constructed in India, with a capacity of 1 t FFB/h. This gave an oil extraction ratio (OER) of 19% with *tenera* fruit; some data for processing losses are given in Table 13.6.

In Nigeria, a horizontal digester and a single-screw press have been combined into one machine (Plate IIIC, D), driven by a diesel engine, with a capacity of at least 1.3 t FFB/h. Owolarafe *et al.* (2002) compared the new machine with a hydraulic hand press: extraction efficiency was greater (89% compared to 79% for the hand press), clarification was faster, and labour requirement was lower.

The main problem with mini-mills is ensuring adequate supervision and recording of both quantities and quality (Hartley, 1988). Weigh-bridges or other means of bunch weighing are often not provided as standard equipment, and the owners may not know either the extraction rates or efficiencies being obtained.

13.4.5 Mill operation

13.4.5.1 *Siting of the mill*

For an estate of 1000–2000 ha, some 4 ha of land will be needed for a mill and accompanying buildings. The following factors should be taken into account in siting a new mill.

- There must be a good supply of reasonably pure water. If necessary, a purification plant must be installed.
- The usual construction requirements for a large building must be met: the soil must have a reasonable bearing strength to prevent the need for extensive piling, and there should be no flood danger.
- The position should be central to the estate(s) from which fruit will be brought.
- There must be some permissible way to dispose of the effluent, with or without prior purification.
- With a suitable slope, and careful design, it may be possible to avoid the building of ramps and elevators.

13.4.5.2 *Process control*

Oil and kernel extraction ratios (OER and KER) are calculated from the tonnage of FFB coming into the mill, and the weights of oil and kernels produced. To manage the process, it is necessary to understand the possible errors in calculation of these ratios, and to measure the losses in the extraction process. These aspects are discussed below; more details are given by Velayuthan (1975, 1985), Velayuthan and Chan (1983) and Southworth (1977). Factory efficiency is calculated as:

$$\text{Oil produced}/(\text{Oil produced} + \text{Known losses})$$

Some of the sources of oil loss in the factory are regularly monitored, while others are assumed to be constant or not measured at all. Velayuthan and Chan (1983) grouped oil losses into 'known' (losses on fibre, bunch stalks, nuts and waste water), 'known but not recorded' (steriliser condensate, unstripped bunches, fruit spillage) and 'unknown' (errors in FFB weight or oil production, fraud). Some typical loss figures are shown in Table 13.6. Noel *et al.* (1997b) pointed out that the true efficiency of a mill was always lower than the 92–93% claimed, because not all losses were accounted for.

Measurement of FFB and oil: The measurement of incoming FFB depends on weigh-bridge accuracy. Oil is usually measured by volume in the daily production tank, volume being converted to weight, with a correction for temperature from standard tables. Provided that calibration errors are avoided, these measurements give accurate estimates of OER. Wood *et al.* (1987) recommended comparing these figures with expected OER, calculated from bunch analysis data with allowance for known processing losses. Bunch analysis was used to estimate potential OER on representative batches of fruit from the various palm ages and planting material sources feeding into the mill. A daily figure for expected OER could then be calculated from the weights of different sources of fruit processed. This method was shown to give good prediction of actual OER, provided that harvesting was well controlled. Deviations below prediction would indicate processing faults or, more probably, harvesting or fruit-set problems. Rao *et al.* (2001) listed the changes in OER and KER that may follow from changes in fruit set or in harvesting standards. Possible processing losses are discussed below.

Steriliser waste or 'condensate': The quantity of steriliser waste can be measured, and samples, taken at regular intervals, analysed for oil; hence, the total quantity of oil lost over a period can be estimated. Sampling is usually infrequent, perhaps only weekly. This oil loss is usually small (Table 13.6), and the oil in the condensate is of poor quality, so in many mills the loss is excluded from the calculation of efficiency. However, the loss does vary depending on the sterilisation cycle (Velayuthan, 1985).

Bunch refuse: The weight of bunch refuse can be estimated by weighing a sample of the loads of EFB going to the incinerator or field, or measured directly with a weighing machine in the conveyer line. Sometimes it is not weighed, but assumed to be a constant fraction of incoming FFB. The EFB can be sampled and analysed for (a) unstripped fruit, and (b) oil absorbed by the stalk and empty spikelets. Chan K.S. (1977) found there was more oil in the stalks of overripe than under-ripe bunches.

The percentage of unstripped or 'hard' bunches is more difficult to measure reliably. Their number tended to increase in the Far East after the introduction of the pollinating weevil led to improved fruit set and more inner fruit in the bunch (see Section 4.4.7.1). The resulting milling problems were discussed in detail in a symposium (PORIM, 1985). Triple peak sterilisation, or splitting of bunches in half before sterilisation, was shown to reduce the incidence of unstripped bunches (Ismail *et al.*, 1985a; Velayuthan, 1985). Underripe harvesting also leads to an increase in unstripped bunches; as noted in Section 13.4.3.3, these should be recycled for further sterilisation. Provided that the recycling is efficient, the weight of bunches is easily determined, and if they are adequately stripped at the second attempt, the only loss should be a small increase in the oil loss in EFB (Wood *et al.*, 1985b). However, if inspection

of EFB on the conveyor is inefficient, not all bunches will be recycled. The loss if there is no recycling may be considerable (Table 13.6); in some batches of fruit, the oil loss in hard bunches, if not recycled, amounted to over 1% of FFB weight, or 5% of total oil (Wood *et al.*, 1987).

Fibre: The oil content of dry fibre is simple to estimate by solvent extraction; samples are perhaps best taken at the fibre cyclone. The total quantity of fibre must also be known. The simplest method of estimating this is to determine, by sampling, the ratio of dry fibre to nuts in the press cake; the total fibre is then calculated from the known tonnages of nuts produced (Velayuthan, 1975).

The figure of oil to dry fibre, being the largest among the accounted losses (Table 13.6) and this loss being obvious to the eye and touch, has received a great deal of attention. Gradual improvements in digestion and extraction methods have reduced the average figures over the years from nearly 20% oil to fibre to well under 6%, although losses in mini-mills may be higher (Sundaresan *et al.,* 1990).

Sludge: The tonnage of sludge (clarification waste) emitted for disposal and treatment is determined by using a basculator at the exit of the final sludge centrifuge or, if tanks are used, by counting the number filled and discharged. The ratio of sludge to bunches processed is then determined. Samples are analysed for oil and for 'solids not fat'. The same procedures can be applied to decanter cake, where a decanter is used. The losses in sludge are quite significant (Table 13.6).

Oil loss on nuts: This is easily estimated, provided that the weight of nuts is measured. The loss is usually small (Table 13.6).

Kernel extraction efficiency: Kernels may be lost in unstripped bunches, as small nuts remaining among the fibre, or with the shell. The first two can be estimated at the same time as oil losses on fibre are estimated. For the last, samples of shell must be analysed, and related to the total quantity of shell or nuts. Total losses are typically about 5% of total kernel production (Velayuthan, 1985).

13.4.5.3 *Economics of a palm oil mill*

The costs of milling are an important part of the total plantation operation. Davidson (1993) showed that productivity in the mill had increased from 33 t oil/worker per year in 1951 to 537 t/worker in 1991, representing an annual gain of 7.2%/year over 40 years. This arose from the replacement of centrifuges by screw presses, triple peak sterilisation, automation at the loading ramps, boilers and digesters, and a variety of other labour-saving changes. The increase in productivity in the mill was greater than that in the field: in 1951, 17% of labour was employed in the mill, but by 1991, this was down to only 6%.

Mohd Arif and Mohd Nasir (1997) studied the costs of milling over 4 years in Malaysia. Increasing labour costs were offset by increasing throughput, so that cost per tonne of FFB remained stable. However, cost per tonne of oil increased, because of declining OER; the general decline in OER in Malaysia is discussed in Section 10.4. An important factor affecting profit per tonne of oil is the loss of oil and kernels during processing, discussed above (see also Menon, 2000).

13.4.6 Quality control

Good quality palm oil must have the following characteristics: low FFA content, low contamination with water and other impurities, and good bleachability. The standard tests for quality are reviewed by Siew (2000a). The characteristics interact; for example, a high water level is likely to lead to increased FFA. FFA can be removed, but a higher FFA level leads to a proportionately lower oil yield after neutralisation. This can be allowed for in the price, but a high FFA level can have a large effect on throughput of the refinery (Section 13.5.1). It also indicates a high diglyceride content, which affects the fractionation properties of the oil (Siew, 2000b). Oxidation affects the bleachability of the oil.

13.4.6.1 *Free fatty acids*

The FFA in bruised mesocarp increases rapidly (Section 13.3.3), so the first step towards avoiding high FFA is to handle the fruit carefully in both field and mill. Clegg (1973) classified the impacts to which a bunch may be subjected in harvesting, loading and unloading according to the resultant FFA increase. Each severe impact, such as from harvesting a tall palm or unloading onto the ramp, caused an FFA increase of about 0.2%. The most widely used ramp handling system, with tipping lorries and dropping from the ramp into steriliser cages, caused an overall increase between palm and steriliser of about 1.3% FFA. The best system was one where the steriliser cages were taken to the field and loaded immediately after harvesting, with no further handling, but this is now little used.

Once the bunch has been harvested, micro-organisms start to attack the fruit surface, through wounds or breaks on the surface, and the base of detached fruits. Most of these organisms have lipolytic activity, and will cause further FFA increase. Sterilisation kills

the micro-organisms and inactivates the endogenous lipase, but any delay in processing after the fruit has arrived at the mill will result in a higher FFA level. After extraction, the oil must be dried. In oil saturated with water (0.4% moisture), autocatalytic hydrolysis of triglycerides occurs, stimulated by FFA, but this reaction is negligible at 0.1% moisture (de Graaf, 1976; Berger, 1983; Chong, 2000).

The FFA limit is traditionally 5%; a premium may be paid for oil with lower FFA, although this has not been the case in recent years in Malaysia, where demand by the refining industry has outstripped supply. Special quality oils have sometimes been produced, where buyers were prepared to pay a suitable premium (Section 13.4.6.3). Hartley (1988) believed that attempts to produce such oils could be counterproductive, in that they encouraged managers to harvest underripe fruit and so lose production, but this may be justified if the premium paid for the special quality oil is large enough.

13.4.6.2 *Oxidation and bleachability*

The 'bleachability' of an oil sample can be measured directly as residual colour after bleaching (Olie, 1969). Bleachability depends on the carotene content, but is more affected by the oxidation state of the oil, the level of antioxidants and the contaminants present. The acceptable level of residual colour depends on the intended use for the oil, and is higher for margarines than for white fats or shortenings. A variety of tests for oxidation have been developed, of which the peroxide value (PV) is the most widely used. Benzidine or anisidine (AV) values may also be measured. The 'Totox' value is calculated as AV + 2 × PV (Jacobsberg and Jacqmain, 1973), but these authors considered that AV and absorbance of UV light at 233 nm gave an adequate measure of oxidation. If these were recorded, then PV did not give additional information.

Oxidation can occur at all stages during processing. Overripe and rotting fruit have poor bleachability (Olie, 1969). A moisture content above 0.2% suppresses oxidation during storage (Berger, 1983), but this conflicts with the requirement for low FFA (see above). High FFA also reduces bleachability (Parakh and Pathak, 2000). Copper and iron are catalysts for oxidation reactions, so contamination with these metals during processing and storage must be avoided. The copper content of the oil should be below 0.5 ppm, and iron content below 10 ppm. High FFA oil dissolves copper from brass fittings (Chong, 2000), and some mills use stainless-steel piping and fittings to minimise contamination.

Table 13.7 Special quality palm oils available in the past

Name	Source	Specifications
SPB (special prime bleachable)	Congo	FFA < 2.5%, good bleachability
SQ (special quality)	Malaysia	FFA < 2% at time of shipment
LOTOX (low total oxidation)	Malaysia	FFA < 2.5%, PV < 3 meq/kg, AV < 4 UV abs. at 233 nm < 1.5 Fe < 3 ppm, Cu < 0.2 ppm

From de Graaf (1976).
FFA: free fatty acids; PV: peroxide value; AV: anisidine value; UV abs.: ultraviolet absorbance.

High temperatures encourage oxidation, and should be avoided as far as is compatible with storage and shipping requirements (Section 13.4.3.6). Tocopherols play an important antioxidant role in palm oil (Jacobsberg *et al.,* 1978). Oxidation is a greater problem with refined oils, as the content of tocopherols is reduced during refining (Chong, 2000).

13.4.6.3 *Technical standards for palm oil and palm kernels*

In the past the standard for palm oil was defined in terms of FFA (below 5%), dirt and moisture. Special quality oils have been produced at various times (Table 13.7). There is now a wide range of palm oil-derived materials available in Malaysia, with standard specifications; most of these are listed in Table 14.2.

The FFA (expressed as lauric acid) in PKO is about 0.5% immediately after pressing, but this rises to 1.5% after drying, and after more prolonged storage up to anything between 2 and 10% owing to the action of microbial lipases (Loncin and Jacobsberg, 1964). Sterilisation of the kernels before pressing helps to control this process (Section 13.4.3.7), and may allow the FFA to be kept below 1.5% during storage for 6 months or more (Maycock, 1990). Typical contract specifications for PKO demand less than 5.5% FFA and 0.5% moisture and impurities (Hargreaves, 1985).

13.4.7 Extraction of minor components

Parakh and Pathak (2000) state that the value of the minor components, such as carotenes and tocopherols, is greater than the value of the palm oil itself.

Such statements can be misleading: if commercial extraction from palm oil were routine, supplies would be increased, and prices would be reduced accordingly. None the less, development work on extraction methods is clearly justified. Miyawaki (1998) described a commercial method of extracting the carotenes. This involves converting palm oil to fatty acid methyl esters. These can be differentially extracted into a methyl alcohol/water mixture, separating carotene from decolourised methyl esters. The carotene is then further purified and possibly fractionated. The methyl esters are used as feedstock for various oleochemical products.

13.4.8 Waste products

13.4.8.1 *Liquid effluent*

There are several sources of liquid effluent from a mill:

- condensate from bunch sterilising (0.6 t/t palm oil produced)
- the water phase or sludge from clarification centrifuges (up to 2.5 t/t palm oil)
- water from the hydrocyclone (0.25 t/t palm oil).

Palm oil mill effluent (POME) consists of a mixture of these liquid wastes. Kanapathy *et al.* (1981) described the use of a decanter–drier system, in which the water from the clarification stage was evaporated using exhaust heat from the boiler, but in most mills the entire liquid waste is combined for disposal.

Most palm oil-producing countries now have regulations governing discharge of effluent from mills. The progressive increase in the stringency of Malaysia's limits for discharge of effluent into a watercourse is shown in Table 13.8. The limits for land application are rather less stringent, that for biological oxygen demand (BOD) being 5000 mg/l. To meet these standards, the treatment of the effluent is a vital part of the mill operations. The various systems available were reviewed by Ma (1999a).

First, there is separate settling treatment of steriliser condensate and clarifier waste, to remove residual oil; this is of poor quality and is used by the oleochemical industry. The mixed POME is a thick, brownish, colloidal slurry of water, oil and cellulosic residues from the bunches and fruit, the composition of which is shown in Table 11.28. This material is biodegraded by populations of micro-organisms, in processes that can be anaerobic, aerobic or facultative; often all three are applied sequentially in cleaning up POME. The anaerobic process produces methane, carbon dioxide and traces of hydrogen sulfide, while the aerobic process produces only carbon dioxide. Both also produce residual solid material. The anaerobic stage is a two-stage process, in which the first stage produces organic acids. These must be broken down by the second stage quickly enough to prevent the development of an extremely low pH.

Table 13.8 Malaysian limits for watercourse discharge for palm oil mill effluent

	Dates of application					
	1.7.78–30.6.79	1.7.79–30.6.80	1.7.80–30.6.81	1.7.81–30.6.82	1.7.82–31.12.83	1.1.84 and thereafter
BOD (3-day, 30°C; mg/l)	5,000	2,000	1,000	500	250	100
COD (mg/l)	10,000	4,000	2,000	1,000	–	–
Total solids (mg/l)	4,000	2,500	2,000	1,500	–	–
Suspended solids (mg/l)	1,200	800	600	400	400	400
Oil and grease (mg/l)	150	100	75	50	50	50
Ammoniacal nitrogen (mg/l)	25	15	15	10	150[a]	150[a]
Total nitrogen (mg/l)	200	100	75	50	300[a]	200[a]
pH	5.0–9.0	5.0–9.0	5.0–9.0	5.0–9.0	5.0–9.0	5.0–9.0
Temperature (°C)	45	45	45	45	45	45[a]

Based on *Environmental Quality (Prescribed premises) (Crude palm oil) Regulations, 1977*, Department of Environment, Malaysia (from Mariana, 1999).
[a]Value of filtered sample.
BOD: biological oxygen demand; COD: chemical oxygen demand.

The great majority of mills use the ponding system (Fig. 13.4). This is a very simple system, in which pumps to move the liquid forward are the only machinery (gravity may also be used, depending on site layout). It needs careful control, to prevent a sticky scum forming on top of the liquid and solids accumulating on the bottom, thus decreasing the effective volume of the pond. This system loses the biogas methane that is produced. Trials have been done using large steel tanks as closed digesters, in which biogas is collected and recirculated to ensure good mixing, and these allow collection and use of the biogas. A 1200 t/day mill can produce 20,000 m^3 biogas/day, with an energy content of 5300 kcal/m^3 (Quah and Gillies, 1981). However, it appears that costs are not competitive with those for fossil fuel at present, and so far as we are aware, the process is not being used on a significant scale.

13.4.8.2 *Solid wastes*

The solid wastes from a mill may include any of the following.

- *Empty fruit bunches*: In the past, this material was incinerated, and the ash used as fertiliser. However, as a result of a combination of clean air regulations (Mariana, 1999) and realisation of the value of organic matter as mulch, it is now much more commonly returned to the field *in toto* (Gurmit *et al*., 1999b). Other possible uses for this material are discussed in Section 13.6.1.
- *Surplus shell and fibre, not required as fuel*: Where there is a surplus, most mills will use the fibre as fuel, as this is harder to dispose of in other ways. Husain *et al*. (2002) described fuel briquettes made from fibre and shell, with starch as a binder. These had a density of 1100–1200 kg/m^3, and a calorific value of 16.4 MJ/kg. Shell makes a good road metal for estate roads. It can also be used to produce activated carbon (Cheah and Hoi, 1999), but so far as we know this is not being done on an industrial scale.
- *Decanter cake*: This is most commonly returned to the field to recycle the nutrients that it contains. It may also be dried, for easier handling. Gurmit and Toh (2000) describe a system in which inorganic fertilisers are mixed with the cake before drying to make granulated 'compound' fertilisers. The dried cake may also be used as animal feed.
- *Solids from effluent ponds*: Regular desludging of ponds is recommended (Ma, 1999a), with the solids being recycled to the field.

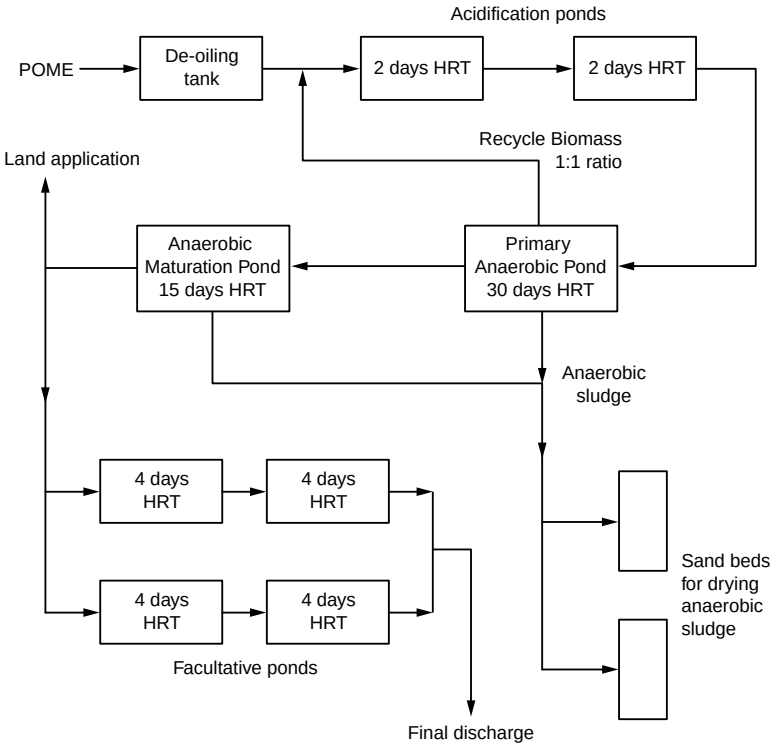

Fig. 13.4 Schematic flow diagram for a ponding system for effluent treatment. HRT: hydraulic retention time. (From Ma, 1999a.)

13.5 PROCESSING OF OIL PALM PRODUCTS

Until the 1970s, refining and fractionation of palm oil was done in consuming countries, but in 1974 the first refineries opened in Malaysia, and less than 5% of Malaysia's production is now exported as crude oil (Maycock, 1990). Both refineries and fractionation facilities are now often grouped with large oil mill complexes. Refining is described below, and fractionation in Chapter 14.

13.5.1 Refining of palm oil

Refining is necessary to remove FFA, coloured pigments, phospholipids and other compounds that could affect appearance, flavour or functionality in end-product manufacture. Much refining is now done in producing countries, particularly in Malaysia, but there remains a considerable international trade in CPO.

Initially, alkali refining was used to remove FFA, with the acids extracted into alkali. Later, physical refining was introduced, and is the standard method now: in 1989, 95% of Malaysia's refining capacity used the physical method (Maycock, 1990). According to Yusoff (2000), alkali refining is two to three times more expensive. The following stages are involved in physical refining.

1. Treatment with 0.1–0.4% phosphoric acid at 90–110°C, to remove gums (degumming).
2. Treatment with 1–2% bleaching earth, held at 95°C for 30 min, under a vacuum of 20–25 mmHg, to remove pigments (bleaching).
3. Cooling to 60–70°C, and filtering to remove bleaching earth.
4. Steam-stripping at 240–270°C, under a vacuum of 2–5 mmHg, to remove FFA and volatile compounds (neutralising and deodorising).

The final product is described as 'refined, bleached, deodorised' (RBD) palm oil. Parakh and Pathak (2000) and Yusoff (2000) give details of recent technical improvements in this core process in the oil palm industry. The individual processes may be separated, and a range of products exists, such as neutralised palm oil, neutralised and bleached palm oil, and so on (see Table 14.2). Refined, deodorised (RD) palm oil, produced by a mild alkali process and retaining about 70% of the carotenoids (Yusoff, 2000), is now a standard grade, sold for its content of provitamin A.

Refinery throughput is reduced by the need to handle high FFA oils (Parakh and Pathak, 2000); an increase of FFA from 4 to 6.5% can reduce the throughput to 60% of the original level if the end-product quality is to be maintained.

13.5.2 Processing of kernels

PKO is extracted from the kernels, leaving palm kernel cake (Section 13.2.1). Where the end-products are for export, as in countries such as Malaysia which produce a large volume, this 'crushing' is usually done in large, centralised plants, often near to a port. This gives economies of scale and easy bulk handling. Such large crushing plants usually use solvent (hexane) extraction, which gives kernel cake with about 2% oil. In smaller markets, where the PKO and cake are for local consumption, crushing may be done in the mill on the plantation. In such cases, screw presses are usually used; these give a cake with 8–13% residual oil, but are cheaper and simpler to operate than the solvent process (J.H. Clendon, pers. comm., 2001).

The quality of the oil and cake is very dependent on the quality of the kernels from which they come. The cake should be light coloured, and contain normal levels of proteins and constituent amino acids. Cake quality is reduced if the kernels are contaminated with shell.

Good quality PKO has low FFA, is a light yellow colour and should be easily bleached to a colourless state. Sterilisation of the kernels before pressing is necessary to prevent FFA build-up in the oil, but any heating, either during sterilisation or under inappropriate storage conditions, will cause some discoloration. This browning of the kernels affects the colour of both the cake and the oil after pressing.

13.6 OTHER OIL PALM PRODUCTS

There is a continuing drive to obtain more high-value products from the oil palm, without losing or damaging the markets for the traditional products. Products from the oils are discussed in Chapter 14. Many papers at PORIM conferences have been devoted to potential uses for by-products or co-products; some of the more interesting ones are listed below (see also Section 13.4.8.2).

13.6.1 Biomass

Mature oil palms will produce 20–30 t/ha per year of above-ground biomass, or plant dry matter (see Section 4.1.2). The main sources that can potentially be removed and used, in addition to the oil and kernels,

are EFB and pruned leaves, and the trunks and crowns of palms that are felled before replanting. The total dry matter production over a 25-year planting cycle will be well over 400 t/ha. The idea of using some of this material for new products has been considered for at least 20 years (see papers quoted by references here). At present, the oil palm ecosystem works on the basis of recycling most of these biomass materials (see Section 11.7), but there is enough experience of fields in which EFB has not been returned to conclude that exporting this material would be acceptable, despite the undoubted advantages to the palms of recycling. (EFB is almost never recycled into fertiliser trial areas, unless it is one of the treatments in the trial.) There is much less experience of removing all three sources of biomass, and this would need field experiments over several years to test its sustainability (Fairhurst and Mutert, 1997). Khalid *et al.* (1996a) detected no effect on yield from removal of petioles over a 6-year period, but Hashim and Yeow (1987) found that FFB yield, leaf nitrogen, phosphorus and potassium contents, leaf area and petiole cross-section were all depressed by 5 years of complete frond removal. Results will depend on the extent to which nutrients removed are replaced by additional fertiliser inputs.

13.6.1.1 *Paper and board*

Much of the available biomass has no large-scale inherent strength or structural properties, so must be broken up. It can then be used for paper or board (H. Kamarudin *et al.*, 1999), and many tests have been conducted of various methods of pulping oil palm trunks, oil palm fronds and EFB. Kamarudin *et al.* (1999) concluded that the most promising material was EFB, although a paper mill of reasonable capacity would need the output from 40 average oil mills. All of these would have to be within 150 km for the transport costs to be acceptable, so siting of the paper mill would need care. The situation is analogous to that in western Europe, where repeated attempts have been made to use straw for paper making. So far, these have been defeated by the transport costs needed to gather large tonnages of straw together, and the fact that present paper mills are organised to use softwood and see little advantage in undergoing major change. It is to be hoped that the Malaysian experience will be more profitable.

13.6.1.2 *Structural and building uses*

Another main use of biomass is as structural and building materials. Parts of the oil palm trunk can be used for plywood, and as the basis for blockboard and fibreboard (MDF). Trunks, fronds and EFB can be used as material for one- and three-layer particle board, bonded with a resin. The denser material from the base of the trunk, treated with a suitable resin, can be used to make furniture. Several of these uses have been tested successfully (Koh *et al.*, 1999), in the sense that usable materials have been produced. Most uses need a good-sized factory to give commercial economies of scale, and it is not clear yet whether the capital costs will be justified.

13.6.1.3 *Microbial processing*

It is theoretically possible to convert biomass into many other useful materials by microbiological processing (Cheah and Hoi, 1999). The use as a material for growing mushrooms seems feasible. Single-cell protein manufacture seems less promising, on the basis that it has been tried many times and rarely been found to be economic. As with so many processes of this nature, they are possible, but not profitable. The profitable discoveries are rare, but they must certainly be searched for. It is essential that there is a hard-headed and economically experienced manager in charge of such programmes.

13.6.1.4 *Traditional uses*

In some parts of Africa, annual pruning is done to provide leaves for thatching, wall construction and other purposes. Sly (1968) mentions the use of rachises as multipurpose poles, rope made from strips of midrib twisted together and brooms made from bunches of midribs. The alkaline ash from incinerated EFB is traditionally used for soap making (Taiwo and Osinwo, 2001).

13.6.2 Palm wine

In Africa, palm wine is quite a valuable and well-known product where it can be produced within easy range of a market. Details can be found in Hartley (1988). The sap is obtained by tapping a male inflorescence, or alternatively by tapping the growing point of a felled palm, after which the sap ferments naturally. In Nigeria, at one time, the income from tapping male inflorescences for palm wine was said to be greater than that from the palm oil and palm kernels (Hartley, 1988). Felling the palm simply for the wine is clearly very wasteful, but where felling for replanting is in progress it causes no difficulty. In parts of West Africa a significant 'cottage industry' has developed, and the income from selling felled palms for tapping can cover a considerable part

of replanting costs. Cheyns *et al.* (2001) quoted a figure of over US$500/ha.

13.6.3 Animal feed

Dried mill effluent has a protein level of about 12%, and extensive trials were done in Malaysia in the 1970s on using POME for animal feed. The product has a rather low energy content and is not very digestible, and most ruminants cannot tolerate a very high proportion in the diet (Hutagalung *et al.*, 1982). Dalzell (1977, 1978) found that water buffalo, which are well adapted to a very coarse diet, could take no more than one-third of the diet as undried effluent. However, if the water content was reduced to 75%, effluent could provide up to 85% of daily nutrient requirement, and effluent plus press fibre up to 95%. Energy needed to dry partially the effluent was a limitation, but this might be overcome with a decanter, which can produce an effluent with only 70% moisture (Roege *et al.*, 1983). The decanter–drier system of Kanapathy *et al.* (1981) produced a product with 10% moisture, and trials of this as animal feed were mentioned by Gurmit and Toh (2000).

Other by-products have been suggested as a basis for animal feed. Goats can be fed successfully on a diet with 50% fresh or ensiled leaflets (Dahlan *et al.*, 2000). Cattle can be raised on a diet of peletised leaflets, palm kernel cake and mill effluent, supplemented with tapioca waste and rice bran (Kawamoto *et al.*, 2001). Other products (EFB, press fibre) have a value only as roughage, equivalent to rice straw, with negligible protein content. One possibility is to break up the tissues so that the cellulosic materials with little feed value are used for particle board, while the parenchymatous tissues are used for animal feed.

A difficulty that appears to have discouraged work on effluent as animal feed is the irregularity of supply, which fluctuates seasonally in line with the FFB input to the mill. The material cannot be stored, so the animal herd must be matched to the lowest output. The surplus at peak periods then has to be disposed of in the normal way. However, if the material is regarded as a source of nutrients, rather than simply as a waste product, then a system might be devised which combined animal feeding with recycling to the field of both dung and peak season decanter solids.

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Chapter 14
Marketing, Economics, End Use and Human Health

Our intention in this chapter is to give a broad but brief outline of the fate of palm oil and palm kernel oil after they leave the palm oil mill or the refinery, which we hope will be useful to growers and agricultural researchers. We have not attempted to give a comprehensive review of current research on these subjects, and readers requiring detailed information will have to consult more specialised works.

14.1 PALM OIL MARKETING

Palm oil is grown for two quite distinct types of market: oil for local consumption, and oil as an exportable commodity. These two types of market are considered separately below.

14.1.1 International trade

As noted in Section 1.4, larger volumes of palm oil enter international trade than of any other vegetable oil. As a result, a sophisticated market for the commodity has developed.

Historically, palm oil was imported to Europe from Africa, and later Indonesia, and was traded after arrival in Europe. The Liverpool price was the standard up to World War II; thereafter, the Rotterdam price became the standard. Voituriez (1998) studied monthly prices over 180 years, from 1818 to 1998. The Rotterdam price is a 'spot' price, for immediate delivery of 'physical' batches of oil. However, both producers and buyers of commodities wish to be able to fix future prices, and thus to reduce their exposure to market fluctuations. Forward selling and futures are the two main mechanisms for this. Forward selling is the simpler approach: producer and buyer agree a contract for delivery at a fixed price and on a specified date in the future. The price agreed will depend in part on the current spot price, and on expectations for future supply and demand. Problems can arise if a large movement in the spot price occurs before delivery on the forward contract. For example, if a producer sells forward, and a drought then causes a production shortfall and a rise in the spot price, he may have to buy in palm oil to cover the shortfall on the contract, at a price higher than he has agreed to sell it for. Conversely, if the price falls, the buyer will be at a disadvantage to his competitors who did not buy forward.

A 'future' is essentially a forward contract, but the contract itself is a tradable commodity, rather than an agreement between a particular buyer and seller. The price of the future is only a fraction (typically 10%) of the value of the oil it represents. This 'gearing' encourages speculators to come into the market, providing liquidity and assuming risks which would otherwise be borne by buyers or producers. In the above example, the producer selling forward could 'hedge' (insure against the risk) by buying a matching future. If prices rise because of a production shortfall, the value of the future will also rise, covering the loss he would otherwise have made.

Trading in palm oil futures on the Kuala Lumpur Commodity Exchange (KLCE, now known as the Commodity and Monetary Exchange of Malaysia) commenced in 1980. The intentions were to provide 'an efficient price discovery mechanism' and to provide hedging facilities against market fluctuations (Fatimah Arshad and Zainal Abidin, 1993). Previously, palm oil traders had relied on soya bean futures for hedging. The early performance of KLCE crude palm oil (CPO) futures was reviewed by Shahabudin (1993). By 1995, the total volume traded on the KLCE was equivalent to over 13 million tonnes (Nasir Amiruddin and Abdullah, 2000).

A crucial factor in the market is the fact that palm oil is seen largely as a general-purpose oil, and for many uses is interchangeable with other oils, particularly soya and rapeseed (known as canola in North America). Thus, the palm oil and soya bean oil prices are highly correlated; for example, the correlation of monthly prices between 1984 and 1988 was 0.93 (Bastin, 1990). Soya bean is an annual crop (as are most other vegetable oils), so total production may vary considerably from

year to year, depending on the area planted. This is affected by price expectations at the time of sowing, and by competing demands for land for other crops. For example, high prices for maize will lead to reduced soya bean planting. There is a further complication, in that oil is essentially a by-product of soya bean growing. Soya bean meal constitutes about 80% of the weight of the bean, so the demand for meal for animal feed has a large influence on soya bean planting, and thus indirectly on the palm oil price. The weather in the mid-western soya bean-growing area of the USA will affect expectations of soya bean yields, and hence future palm oil prices.

14.1.2 Local consumption

In large parts of Africa palm oil is the main traditional cooking oil. Much of the oil for this market comes from semi-wild groves or village palms, but plantations in Africa also market CPO for immediate local consumption. Palm oil is also grown industrially for local manufacture of margarine, soap and other products. This is important in countries where production costs are too high for competitive exports, but where shipping costs are also high, so that imports would be more expensive than local production.

14.1.3 Factors causing distortions of markets

A range of factors can cause distortions of international trade in vegetable oils (and many other commodities). Most aspects were reviewed in the *1989 PORIM Conference on Chemistry, Technology and Marketing*, but the situation is continuously changing. We will not go into detail, but will briefly list the most important factors relevant to palm oil trade, and their effects on the free market or world price.

- Subsidies, support prices, deficiency payments and intervention buying can encourage production of oils regardless of demand, and in areas where production might otherwise be uneconomic. Thus, surpluses may accumulate, and prices will be depressed when these are 'dumped' on the market, and may be depressed in anticipation of such dumping. Such government support is susceptible to political pressures.
- Import duties are charged by many countries, often to protect a local industry from competition by lower cost producers. This will tend to depress prices outside the tariff barrier, although the effect will be small unless a very large industry, such as rapeseed in Europe, is being protected. High tariffs also encourage smuggling, which may negate the intended benefit to local producers.
- Export duties are charged by some producing countries, sometimes with exemptions for certain products. Malaysia has an export duty on CPO and lower rates of duty on refined products; the structure is very complex, and was described by Nasir Amiruddin and Abdullah (2000). The intention when the duty was introduced was to encourage local refining. The measure was very successful, and little CPO is now exported; in 1997, CPO made up less than 0.5% of Malaysia's total palm oil exports (Nasir Amiruddin and Abdullah, 2000). However, a demand for CPO still exists (now met largely from Indonesia), and for some years there was a thriving business outside Malaysia reconstituting 'crude palm oil' from olein and stearin, often with an excess of the cheaper stearin fraction.
- In some countries a marketing board was established, which set a fixed price for commodities. The stated aim was usually to stabilise prices, but the price set was sometimes well below the world price, with the result that growers could not produce economically, and stopped producing or moved into other crops. In the 1960s, while Malaysian companies were converting rubber plantations to oil palm, some oil palm plantations in Nigeria were converted to rubber, because the palm oil price was controlled, but not the rubber price.

With so many factors in play, future palm oil prices are almost impossible to predict, and even past price changes may be difficult to explain. One observer may attribute a price drop to excess palm oil stocks overhanging the market, and expected high yields because of good weather last year in Malaysia, while another refers to favourable weather in the mid-west of the USA and a strong demand for soya meal. However, as noted in Section 1.4.2.1, average palm oil prices, in common with most commodities, have been declining steadily for several decades. There is much fluctuation around the trend line, but since the early 1960s, prices have declined by an average of about 3% per year (Fry, 1998). In the long term, demand for vegetable oils will continue to increase: fat consumption tends to increase as incomes rise, and a large part of the world's population still consumes less fat per annum than the 12 kg per person recommended by the World Health Organisation (WHO). It should not be thought that this will break the trend of declining prices, though. Consumption has

increased enormously since the 1950s, owing to both increasing population and increasing wealth, but this has not stopped prices from falling.

14.2 PRODUCTION COSTS

14.2.1 Palm oil production costs

Costs of palm oil production vary greatly from one producing country to another, for two main reasons. First, yields vary, mainly because of the effects of climate (see Chapter 3); some costs are essentially constant per hectare, and thus are inversely proportional to yield when expressed on a per tonne basis. Secondly, palm oil growing is labour intensive, and labour costs differ widely between different countries, as does labour productivity. Labour requirements for the main operations are given in Chapters 8–10. Differences in labour use between countries are partly a result of differences in labour cost; where this is high, there is an incentive to increase productivity and reduce numbers.

Davidson (1993) analysed changes in production costs over 40 years in Malaysia. Overall, production cost per tonne of oil had decreased at an annual rate of 2.6% (after adjustment for inflation). This had kept pace with the declining palm oil price, allowing the business to remain profitable. The cost reduction was attributable in part to a four-fold yield increase, from both breeding and agronomic improvements (see Section 5.5.2), and in part to increased labour productivity. In 1951 there was one worker per 4 ha, producing 5.7 t of palm oil per year; by 1991, one worker covered 7.5 ha, and produced 30 t of palm oil.

There have been few direct comparisons of production costs between countries; precise figures vary with wages rates and exchange rates, and also with accounting practices, and numerous assumptions have to be made. Some cost comparisons are summarised in Table 14.1, but these can only indicate general trends. Production costs in the Far East are clearly much lower than in Africa, because of the higher yields in the former. Costs in Indonesia are in general lower than in Malaysia, because of the lower wage costs in Indonesia. Labour use is least in Malaysia, because high costs have driven producers towards mechanisation.

14.2.2 Production costs of competing oils

The important influence on the palm oil market of other vegetable oils, which are more or less interchangeable with palm oil, has already been mentioned. True production costs are difficult to arrive at, particularly for soya bean, because the main product of that crop is the meal, not the oil. Stringfellow (2000) estimated that during the 1990s, the oil varied between 30 and 44% of the total soya bean product value.

In 1998, Stringfellow (2000) estimated that soya bean oil production costs in the USA, Brazil and Argentina were 2.2–3 times palm oil costs in Malaysia, and 2.7–4.6 times those in Indonesia. However, the Malaysian and Indonesian currencies were unusually weak in 1998, which would have distorted this comparison. Fry (1996) estimated that soya bean oil production costs from 1985 to 1992 were about 50% higher than Malaysian and Indonesian palm oil costs. In 1991, Davidson (1993) estimated that the cost of rapeseed oil production in Europe was about 3.2 times the cost of palm oil production in Malaysia, but Bastin (1990) gave figures of 1.5–2.6 times.

Palm oil is much more productive per unit land area than other oil crops, and at present that leads to highly

Table 14.1 Palm oil production cost comparisons between countries. All figures expressed as percentages of the reference country, usually Indonesia

Year	Malaysia	Indonesia	Africa	America	Other	Ref.
1998	100–120	67–100	–	138 Colombia	–	1
1998	132	100	–	–	–	2
1993–94	116	100	–	–	–	2
1992	170	100	336 Ivory Coast	247 Colombia	197 PNG	3
1989	155–179	100	390 Ivory Coast	–	–	4
			520 Cameroon	–	–	4

References: 1: Stringfellow (2000), Fedepalma (2000); 2: Fry (1998); 3: Gray and Siggs (1994); 4: Nasir Amiruddin and Basiron (1993).

competitive production costs. In the long term, though, costs will increase as labour expectations rise, and the high labour requirement for palm oil production must become a major disadvantage. Gan and Ho (1994) estimated that the palm oil industry could absorb an expected four-fold increase in cost per man-day between then and 2020, but the discrepancy in labour requirements between palm oil and other oils is much greater than a factor of four. Stringfellow (2000) calculated that it takes 0.07 man-days to harvest 1 t of soya bean oil, compared with 2 man-days for 1 t of palm oil, 30 times more. In Brazil, Fearnside (2001) estimated that there was one worker to 160–200 ha of soya beans, whereas for oil palm a typical figure is less than 10 ha per worker. Mechanisation is discussed elsewhere (particularly in Section 10.2), but it should be clear that further major improvements in labour productivity will be needed if palm oil is to remain competitive with other oils in the long term.

Fry (2002) pointed out that soya bean and rapeseed yields had been increasing faster over the previous 25 years (1.3% and 2.4% per annum respectively) than oil palm yield (0.9% per annum). He predicted that, unless labour productivity could be improved, by 2010 Malaysian palm oil might have a higher production cost than Brazilian and Argentinian soya bean oil.

14.3 USES OF PALM OIL AND PALM KERNEL OIL

Oils and fats serve a number of functions in cooking, summarised by Berger (1996a). In frying, the high temperature and intimate contact between the oil and the food result in rapid cooking. In baking pastry, the fat prevents the hydration and toughening of wheat proteins, while in cakes the incorporation of air bubbles in the fat gives the desired crumb structure.

14.3.1 Importance of oil composition

The melting and crystallisation behaviour of fats is critical in determining their suitability for particular uses. These characteristics depend on the fatty acid and triglyceride composition (see Section 13.1 for palm oil composition data). The crystallisation behaviour of palm oil was reviewed by Timms (1990). The measurement of these characteristics is complicated, and modern physical methods may be used, including differential scanning calorimetry, nuclear magnetic resonance and X-ray techniques (Siew, 2000a).

Because fats are a mixture of different triglycerides, and not single, pure compounds, they have a melting range, rather than a specific melting point. When a figure for a melting point is quoted, it usually refers to 'slip point', the temperature at which melting starts. The melting behaviour of some palm oil products is shown in Fig. 14.1.

The importance of the melting range is exemplified by cocoa butter. This contains over 70% solid fat at temperatures up to 20°C, but melts over a relatively narrow range and has no solid fat content above 35°C. In contrast, palm oil has only 50% solid fat at 10°C, 25% at 20°C and 10% at 30°C. The narrow melting range of cocoa butter, slightly below body temperature, means that it is solid at room temperature, but melts rapidly in the mouth, giving it a pleasant, fresh and non-greasy taste. The melting behaviour of cocoa butter results from its high content of triglycerides with oleic acid in the middle position, and saturated acids at the 1- and 3-positions: Xu (2000) quoted figures of 35% POS (palmitic–oleic–stearic), 26% SOS and 16% POP triglycerides. Similar triglycerides are found in some other oils (illipe, shea), which are used in cocoa butter replacers. Palm oil 'midfraction' contains a significant proportion of POP triglycerides; these are sufficiently similar to SOS and POS that palm midfraction is the main component of some cocoa butter equivalents (Berger, 1996a). Figure 14.1 shows the relatively narrow melting range of palm midfraction, compared with CPO or palm stearin.

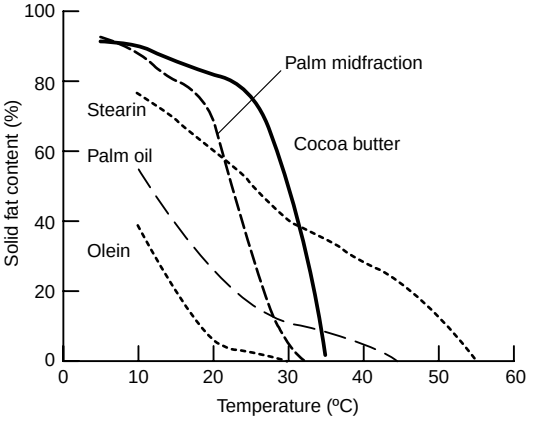

Fig. 14.1 Solid fat content of oils and fats at different temperatures. The relatively narrow melting ranges of palm midfraction and cocoa butter can be seen. Smooth curves are drawn through data points from Tang (2000) (CPO, olein and stearin) and Jinap *et al*. (2000) (cocoa butter and palm midfraction).

Margarine consists of an emulsion of water droplets in oil, stabilised by solid fat crystals. The solid fat content of a packet margarine will be about 40% at 5°C, but for a tub margarine, to be spreadable immediately it is removed from the refrigerator, this figure should be below 20% (Berger, 1996a). Vanaspati, a vegetable alternative to ghee (clarified butter, widely used in India, Pakistan and elsewhere), has a characteristic granular crystalline structure, with minimum free oil content at room temperature, but a melting point no higher than 37–38°C.

In much of West Africa, CPO is the traditional cooking oil; it has a characteristic 'nutty' flavour (Kuntom *et al.*, 1989), which is much appreciated. For many markets, though, a cooking oil should look clear at room temperature. Palm olein, with a cloud point (the temperature at which visible crystallisation starts) just below 10°C, meets this requirement in the tropics, but not in temperate climates. The liquid oils such as soya bean, corn and rapeseed have cloud points below 0°C, as do blends of these oils with up to 40 or 50% palm olein (Berger, 1996a).

The facts that a major part of the vegetable oils market is taken by liquid oils, and that palm olein generally fetches higher prices than stearin, have encouraged the view that oil palm breeders should aim for more liquid oils. The possibility of changes through breeding or biotechnology are discussed in Sections 5.5.7 and 6.6.2, but two important points may be noted here. First, if oil composition is changed by breeding, the oil must be sold as a speciality product, not as standard palm oil (with added costs for keeping it separate). Palm oil users' processes are finely tuned to oil with a standard composition, and oil with a higher iodine value than normal will not give the expected results in fractionation and product formulation. The second point is that a significant proportion of liquid vegetable oil is hydrogenated or otherwise processed to increase its solid fat content (see Section 14.4 for the health implications of this), so simply looking at the proportion of the commodity market taken by liquid oils may be misleading. Palm oil or palm stearin can substitute for these hydrogenated oils in some products.

14.3.2 Range of palm oil and kernel oil products

With the development of a refining industry in producing countries, particularly Malaysia, a wide range of palm oil products is now available on the market. Refining is discussed in Section 13.5.1, and some of the palm products exported from Malaysia are listed in Table 14.2. As noted above, Malaysia exports very little crude palm oil. The main supplier of that commodity to world markets is Indonesia. Although almost all palm oil will be refined before it reaches the consumer,

Table 14.2 Palm oil products and Malaysian standard specifications

Product	FFA (max. %)	Moisture, impurities (max. %)	IV	Colour[a]	MP (°C)
Crude palm oil	5	–	–	–	–
Neutralised palm oil	0.25	0.1	50–55	–	33–39
Neutralised and bleached palm oil	0.25	0.1	50–55	max. 20 red	33–39
RBD palm oil	0.1	0.1	50–55	max. 3 or 6 red	33–39
Crude palm olein	5	0.1	min. 56	–	max. 24
Neutralised palm olein	0.25	0.1	min. 56	–	max. 24
Neutralised and bleached palm olein	0.25	0.1	min. 56	max. 20 red	max. 24
RBD palm olein	0.1	0.1	min. 56	max. 3 or 6 red	max. 24
Double-fractionated palm olein	0.1	0.1	min. 60	max. 3 red	max. 19
Crude palm stearin	5	0.25	max. 48	–	min. 44
Neutralised palm stearin	0.25	0.15	max. 48	–	min. 44
Neutralised and bleached palm stearin	0.25	0.15	max. 48	max. 20 red	min. 44
RBD palm stearin	0.25	0.15	max. 48	max. 3 or 6 red	min. 44
Palm acid oil	min. 50	3	–	–	–
Palm fatty acid distillate	min. 70	1	–	–	–

From Berger (1996a).

[a] Colour measured with Lovibond Tintometer, 5¼″cell.

FFA: free fatty acids; IV: iodine value; MP: melting point; RBD: refined, bleached, deodorised.

a significant demand for CPO persists in international trade. One reason for this is that refining can disguise problems with quality. If free fatty acid (FFA) content is high, the oil will also contain a high level of diglycerides. The FFA is removed in neutralisation, but the diglycerides from a high FFA oil will remain, and have an influence on fractionation and crystallisation properties (Siew, 2000b). There is no quick and easy method for measuring diglyceride content, so for specialised uses, manufacturers may prefer to buy low FFA CPO to be sure of quality, and undertake the refining themselves, even though the Malaysian export duty structure is such that a refined product might be cheaper.

Special quality CPO has been produced by various countries (see Section 13.4.6.3). As Table 14.2 shows, the standard for CPO is no more than 5% FFA, but for many years there has been an excess of refining capacity in Malaysia, and the resulting competition for CPO supplies has meant that quality aspects have not been emphasised.

14.3.3 Processing of vegetable oils

Vegetable oils may be processed in various ways, to give products with different solid fat content, melting range and crystallisation behaviour from the original raw materials. The main processes are fractionation, hydrogenation and interesterification.

14.3.3.1 *Fractionation*

A vegetable oil is a mixture of several different triglycerides, and those containing a high proportion of saturated fatty acids have higher melting points than those with unsaturated fatty acids. High- and low-melting triglycerides can be separated by partial crystallisation, to give olein (liquid, more unsaturated) and stearin (solid, more saturated) fractions. After the first separation of olein and stearin, further fractionations can be done to give such products as palm midfraction and 'super olein' or second olein. It should be noted that the terms olein and stearin refer to the liquid and solid fractions obtained after fractionation. They do not describe fatty acid composition; a palm olein will have increased oleic acid, because that is the main unsaturated fatty acid, but it will still contain most of the triglycerides in the original oil, although in changed proportions. Tri-olein is the term for a triglyceride in which all three positions on the glycerol molecule are occupied by oleic acid.

The main triglycerides tend to crystallise out in the following order during fractionation: PPS, PPP, SOS, POS, PPL, PPO, OOS, POO, PLO, OOO and OOL, where O is oleic, L is linoleic, P is palmitic and S is stearic (Haryati *et al.*, 1998). The concentration of oleic and linoleic acids at low melting temperatures and palmitic and stearic at high temperatures is obvious. The unsaturated and saturated acids may be partially separated first by directed transesterification (Haryati *et al.*, 1998).

The simplest method of fractionation is 'winterisation', which involves cooling the oil slowly, allowing the stearin crystals to settle, and skimming off the liquid fraction, or separating the solid and liquid fractions by centrifugation. Other methods use a solvent or a detergent to achieve a more complete separation of high and low melting fractions. A recent review of fractionation methods was given by Kellens (1996), who stated that the principal method now in use is dry fractionation (no detergent or solvent), with semi-continuous crystallisation, and separation of the fractions by a vacuum filter or a membrane filter press. In the dry method, palm oil is heated and stirred at 70°C for 30 min, then cooled at a carefully controlled rate to around 20°C. The separation of the cooled slurry of crystals is now often done with a membrane filter instead of the conventional suction filter, as this extracts more olein because the filter cake is put under pressure.

14.3.3.2 *Hydrogenation*

Liquid oils can be hardened by reaction with hydrogen in the presence of a catalyst, the double bonds in unsaturated fatty acids being converted to saturated, single bonds (see Section 13.1.1). Thus, oleic and linoleic acids are converted to stearic acid, with a much higher melting point. After partial hydrogenation, some unsaturated fatty acids will have been converted to saturated, but others will be only partially saturated, and some *trans*-acids will also be formed. These are not found naturally in vegetable oils; they are unsaturated acids which have the same physical shape as saturated acids, unlike the *cis* conformation, which has a bend in the molecule (see Fig. 13.1). It appears that *trans*-acids in the diet have physiological effects similar to, or more harmful than, saturated fatty acids (Section 14.4.1).

The subject of hydrogenation was reviewed by Hastert (1996). The completeness of hydrogenation can be adjusted, depending on the solid fat content required, by varying the reaction conditions: temperature, pressure and type of catalyst. The proportion of *trans*-acids formed also varies with reaction conditions.

14.3.3.3 *Interesterification and transesterification*

Interesterification involves a reaction between triglycerides and fatty acids, alcohols or other esters to produce new esters. Rearrangement within the same molecule constitutes transesterification; heating the oil in the presence of a catalyst results in the random redistribution of fatty acids between triglycerides (see Section 13.1.1). Reaction with methanol produces fatty acid methyl esters (Section 14.3.6.1).

Random transesterification of palm oil causes an increase of about 20% in the solid fat content at 20°C and 30°C (de Graaf, 1976), and is thus an alternative to hydrogenation for some purposes. Interesterification with solid fats may also be used. Interesterification can be directed to the production of specific triglycerides, rather than random, by using lipase enzymes. Xu (2000) reviewed lipase-catalysed production of cocoa butter substitutes, human milkfat substitutes and other triglycerides with specific structures.

14.3.4 Use of palm oil for edible purposes

In discussing the uses of palm oil below, we use 'palm oil' as a convenient shorthand for both the oil and its fractions and processed products.

Some 90% of the world's palm oil is used for edible purposes (Sambanthamurthi *et al*., 2000b). Palm oil is a particularly good source of solid fat for many purposes. A good summary of the uses of palm oil in foods was published by the Malaysian Palm Oil Promotion Council (Berger, 1996a). Berger (1996b) gave a review covering much of the same ground, but with references to source literature.

Palm oil and its fractions are used as a cooking oil, in margarines and bakery fats (shortenings), in vanaspati, in confectionery fats (cocoa butter replacers), in ice-creams, and as a replacement for butter fat in some dairy products (coffee whiteners, reconstituted milk, whipped 'cream'). A range of products with high palm oil content has been developed by the Malaysian Palm Oil Board (MPOB). Berger (1990, 1996a) quoted formulations for bakery shortenings containing between 50 and 100% palm oil, margarines with 60–80% palm oil, and vanaspati with 70–80% palm oil. Palm oil may be the only fat in some chocolate-flavoured confectionery and cake coatings, but 100% palm fats are not suitable for ice-cream coatings, as they are too brittle at low temperature.

Palm oil is particularly suitable for deep frying, because it is relatively stable at high temperature, compared with the more unsaturated oils (Berger, 1996a). The polyunsaturated fatty acids, linoleic and linolenic acid, tend to oxidise and break down or polymerise at frying temperatures (180°C), but palm oil contains a relatively small amount of linoleic, and no linolenic acid. Refined red palm oil has been used for deep frying of potato crisps, where it gives a desirable colour to the product (K.G. Berger, pers. comm., 2001).

The use of palm oil midfraction for cocoa butter replacers has already been mentioned. This market is important, because cocoa butter prices are far above those for palm oil, and hence substitutes can command premium prices compared with palm oil. Wong (1993) explained that there are essentially three classes of cocoa butter replacers, which differ in their crystallisation properties, and hence in the extent to which they can be mixed with cocoa butter.

- *Cocoa butter substitutes*: These are incompatible with cocoa butter (Maarsen, 1985) and are used as an alternative for chocolate coatings. They are manufactured mainly from lauric oils or lauric stearins, particularly palm kernel stearin.
- *Cocoa butter extenders*: These can be mixed with cocoa butter to a limited extent. They can be manufactured from palm midfraction or hydrogenated palm olein.
- *Cocoa butter equivalents*: These can be mixed with cocoa butter in any proportions. They can be made from palm midfraction, with the addition of illipe or shea butter.

Berger *et al*. (1978) showed that the stearin fraction from *Elaeis oleifera* oil (erroneously described as hybrid oil in the paper: K.G. Berger, pers. comm., 1979) contained a higher proportion of SUS (saturated–unsaturated–saturated) triglycerides than palm oil or its olein or stearin fractions. Such oil might therefore be a good raw material for production of cocoa butter replacer, if the oil yield of *E. oleifera* or hybrids could be raised to acceptable levels (see Section 5.5.1.6).

Margarines are blends of several different fats to give the required structure. The hard component should have a solid fat content above 80% at 10°C, and at least 15% at 30°C (van Duijn, 2000). Until recently, partial hydrogenation of liquid oils was widely used to produce these components, but with increasing concern over the harmful effects of *trans*-fatty acids in the diet (see Section 14.4.1), a demand for '*trans*-free' margarine has developed. This may represent a significant market for palm oil: as Berger (1996a) noted,

trans-free products can be produced using palm and palm kernel oils as sources of solid fat, interesterified with liquid oils. Timms (1990) explained that palm oil crystallises slowly, so that margarines with a high palm oil content are at first too soft, but become too hard in storage. Hydrogenation, interesterification or blending with a faster crystallising lauric oil (coconut or palm kernel) allows the palm oil content of the margarine to be increased. Zainal and Yusoff (1999) described the production of *trans*-free margarine fats by enzyme-catalysed interesterification of palm stearin and palm kernel olein, two products for which there are few other uses. The production of *trans*-free margarines was reviewed by van Duijn (2000). An interesting point in this paper was the comment that over 600 new *trans*-free margarine blends had been developed by Unilever over the previous decade. This gives an indication of the scale of end-use research by the major food companies.

Another product of increasing interest is *trans*-free vanaspati. Aini *et al*. (1999) described the production of this from blends of palm oil and kernel oil fractions.

14.3.5 Palm kernel oil

The lauric oils, palm kernel oil (PKO) and coconut oil, are the main sources of short-chain fatty acids in world trade. PKO contains 44–50% lauric acid (C12) and 15% myristic acid (C14). Both oils have many uses in the edible field; they have a narrow melting range, just below body temperature, which, as noted above for cocoa butter, gives a 'fresh' taste to products containing them. For many purposes, they are interchangeable, but PKO has higher oleic and linoleic acid content than coconut oil, and gives a slightly softer fat, with a broader melting range (Maarsen, 1985).

PKO is used for simulated dairy products, such as coffee whiteners. Hydrogenated PKO and palm kernel stearin are used in whipped toppings, and in toffee and caramel. A variety of different PKO derivatives is used in chocolate-flavoured coatings.

14.3.6 Non-food uses of palm oil and kernel oil

14.3.6.1 *Oleochemicals*

Only about 10% of palm oil is used for non-food products (Sambanthamurthi *et al*., 2000b). Miyawaki (1998) gave a good summary of where the oleochemicals industry stood at that time. Oleochemicals in general consist of a long carbon chain, one end of which is lipophobic and water soluble, and the other hydrocarbon end lipophilic and fat soluble. Such compounds can act as an interface between water and fat, solubilising the latter by dispersing it in small 'micelles' throughout the body of the water phase. This surfactant effect is widely used in many domestic and industrial processes. Surfactants are also made from petroleum, but vegetable fats are ideal, being renewable resources, with carbon chains that are easily biodegradable when they enter the natural environment. Hirsinger *et al*. (1995) described a 'life cycle analysis' of the production of oleochemicals from palm oil and PKO. This compared the resource use and environmental effects of the entire production chain for oleochemicals, from field to consumer, with that for petrochemical materials (Franke *et al*., 1995), and showed that palm-derived oleochemicals require less energy for production, and result in lower levels of solid waste and emissions. Wood and Corley (1993) estimated that the energy output of a plantation was over nine times the input.

The production of oleochemicals is essentially the changing of the carboxyl (COOH) group at one end of a fatty acid chain into salts, alcohols, amines, amides, fatty esters or other types of compound (Fig. 14.2).

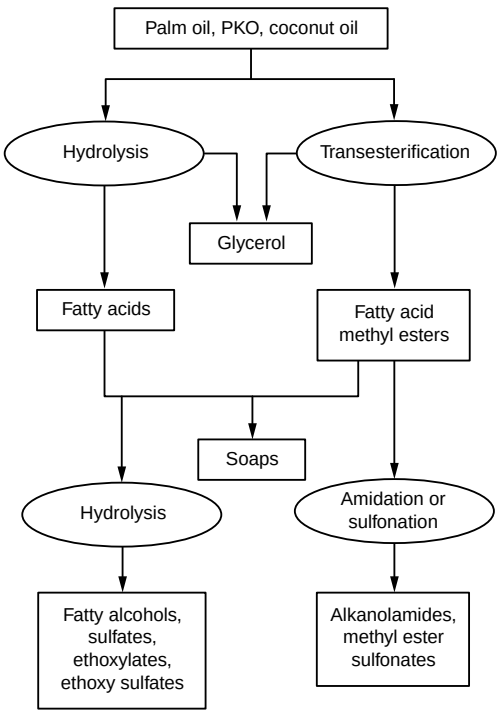

Fig. 14.2 Manufacture of oleochemicals. (Based on Miyawaki, 1998.)

The raw materials are fatty acids, produced by high-temperature splitting of the fat molecule, or the methyl esters of the fatty acids produced by transesterification. Palm oil, PKO, tallow and coconut oil are the main sources. Glycerol is always produced as the fat molecule splits, and is also regarded as an oleochemical, with numerous uses in cosmetics and medicine. Some 6 million tonnes of fat-derived oleochemicals are produced per year, with the Asian industry producing 40% of the world total (Miyawaki, 1998; Salmiah *et al*., 2000a). Important products include sodium salts (soaps) (Kuntom and Hamirin, 2000) and surfactant derivatives such as methyl ester sulfonates. Palm oil and PKO-derived oleochemicals can be used in lubricants (Margeson and Schwartz, 1993), skin-care products and cosmetics, and have been used experimentally in the drilling industry (Salmiah *et al*., 2000b). Non-edible uses of lauric oils were listed by Schwitzer (1985).

14.3.6.2 *Fuel*

Vegetable oils, including palm oil, have been used as fuel in diesel engines for many years; palm oil has particularly been used in producing countries where transport costs or foreign exchange problems have limited petroleum imports. CPO can be used, but the high viscosity causes problems. Baryeh (1990) achieved good results with a 50:50 mixture of PKO and petrol as diesel fuel. Ong *et al*. (1990) described the development of a pilot plant to produce fatty acid methyl esters from palm oil, and the evaluation of these esters for use as diesel fuel (see Choo and Cheah, 2000, for more detail). The fuel was satisfactory, with lower emissions than from standard petroleum-derived fuel.

The economics of using palm oil methyl esters for fuel depended not only on the relative prices of palm oil and diesel oil, but also on the cost of methanol, and the price obtained for glycerol as a by-product. At prices for methanol and glycerol current in 1990, the project appeared viable provided that the palm oil price was no more than 25% above the diesel price (both per tonne, ex-duty) (Ong *et al*., 1990). Fuel can also be produced in the form of alcohol, by fermentation of carbohydrates, and that could be a competitor for vegetable oil-based fuels.

14.4 PALM OIL AND HUMAN HEALTH

Oils and fats are an essential part of our diet, but the benefits gained may depend in part on the composition of the oil. The controversy over 'tropical oils' in the human diet is mentioned briefly in Section 1.6.4; the history of the controversy was reviewed by Enig (1998). In this section, we have attempted to sort out some facts from the large volume of propaganda, advertising and partisan comment. Useful reviews are by Cottrell (1991) and Sambanthamurthi *et al*. (2000b).

14.4.1 Oils and fats in human nutrition

Recommendations by the WHO and other bodies are that annual consumption of oils and fats should be at least 12 kg per head, but that oils and fats should not exceed 30% of the daily calorie intake. In much of the developing world, including China and India, the recommended minimum intake level is not reached. Conversely, in Europe and North America, up to 40% of calorie intake may be as oils and fats.

Numerous studies have shown an association between diet and the incidence of coronary heart disease. High fat intake appeared to increase the risk of heart disease and saturated fats appeared to be more harmful than unsaturated. A high blood cholesterol level was also associated with an increased risk of heart disease. In fact, cholesterol is found in the blood in two main forms, in complexes with either high-density lipoprotein (HDL-C) or low-density lipoprotein (LDL-C). It is high levels of the latter form that are associated with heart disease risk, with HDL-C being neutral or perhaps beneficial (Cottrell, 1991). Thus, measurements of LDL-C levels, or of the LDL-C:HDL-C ratio, are likely to be more useful than total cholesterol.

Cottrell (1991), in a keynote paper at a PORIM conference, made a number of important points regarding dietary fats, blood lipids and heart disease. These are summarised below, together with more recent information where available.

1. Cholesterol plays an essential role in the transport and metabolism of fats. The level in the blood depends on a balance between synthesis in the body and uptake from the diet, so that for most people dietary cholesterol has little influence on blood cholesterol level. Vegetable oils themselves contain negligible amounts of cholesterol, but the effects of fatty acids may depend on the dietary cholesterol intake from other sources (see 2, below).
2. An increase in saturated fatty acids in the diet tends to increase blood cholesterol. This relationship is described by the Keys equation, but the work of Keys *et al*. (1957) was based on diets that did not include palm oil. Subsequent work has shown that myristic acid (C14) is more harmful than palmitic or

stearic acid. Stearic appears to be neutral, while palmitic is only harmful if the level of linoleic acid in the diet is very low. Palmitic acid may also have undesirable effects if the diet is high in cholesterol, but not if it is low (Hayes and Khosla, 1992).

3. A diet high in polyunsaturated fats results in lower total cholesterol, but HDL-C is reduced, as well as LDL-C. In animal studies polyunsaturated fats have been associated with increased risk of cancer, but this does not appear to have been confirmed in human studies.
4. As noted earlier, if margarine is made from polyunsaturated oils the oil must be hardened. If this is done by partial hydrogenation, then *trans*-fatty acids will be formed. Cottrell quoted a British Nutrition Foundation study which concluded that, at the UK level of less than 6% of dietary fat intake, *trans*-acids would not affect heart disease risk. However, several recent studies have shown that *trans*-acids tend to increase total cholesterol, and to reduce HDL-C and increase LDL-C levels (reviewed by Sambanthamurthi *et al*., 2000b, and Enig, 1998).
5. In early work, monounsaturated fatty acids were regarded as neutral, but recent studies indicate that oleic acid is at least as effective as polyunsaturates in lowering total cholesterol and improving the LDL-C:HDL-C ratio (Sambanthamurthi *et al*., 2000b).

The above points present a simplified picture: the lipoproteins are not the only components of the blood affected by the fats in the diet, and there are many interactions among different dietary components. However, it is clear that no group of natural fatty acids is 'better' than another, and the American Heart Foundation recommends that the fat component of the diet should consist of equal proportions of saturated, monounsaturated and polyunsaturated fatty acids. The view that *trans*-acids should be avoided is gaining strength (see Enig, 1998).

14.4.2 Effects of palm oil in the diet

When the American Soybean Association campaign against 'tropical oils' started in the 1980s, there was actually very little information about the effects of palm oil in the diet. It was assumed that, because the oil contained 50% saturated fatty acids, it would behave like other saturated fats which had been used in trials. Since then, numerous feeding trials with palm oil have been done, many of them sponsored by MPOB, on animals and also with human subjects. These trials were reviewed by Sambanthamurthi *et al*. (2000b).

The majority of studies showed that, in broad terms, a diet with a high proportion of palm oil as the fat component is as healthy as any other. This might be anticipated from the points outlined above. Although palm oil contains 50% saturated fatty acids, these are predominantly palmitic and stearic; the harmful shorter chain saturated fatty acids represent no more than 1.5% of the total. Of the 50% unsaturated fatty acids, most is monounsaturated oleic acid.

There is some evidence that palm oil may inhibit the formation and reduce the growth rate of tumours, but these effects appear to be independent of its fatty acid composition, and may be attributable to some of the minor components in the oil.

14.4.3 Minor constituents of palm oil

Palm oil includes a variety of minor components (carotenoids, tocopherols, chlorophyll, sterols, phosphatides and alcohols), all at concentrations of less than 1000 ppm (see Section 13.1.4.2). Nutritionally, the most important of these are α- and β-carotene, which are precursors of vitamin A, and tocopherols and tocotrienols (vitamin E). Of the carotenes, β-carotene has the strongest provitamin A activity; the importance of carotenoids in human health was recently reviewed by Nicol and Maudet (2000). Vitamin A deficiency can lead to blindness, and the use of red palm oil is a good prophylactic of the condition. There is evidence that tocotrienols have protective effects against heart disease and cancer (reviewed by Sambanthamurthi *et al*., 2000b).

In conventional refining and fractionation, the carotenes, which give the oil its colour, are destroyed, and about 30% of the tocopherols are also lost (Gapor Mohd Top, 1990). Carotenes are also destroyed during hydrogenation. In view of the nutritional value of these components, methods of extracting them from palm oil have been developed. Ong *et al*. (1990) described the extraction of vitamin E from palm fatty acid distillate (the FFA removed in physical refining), which contains 0.4–0.8% of tocopherols and tocotrienols. Methods of concentrating or extracting carotenes have been described by Ooi *et al*. (1994), Lenfant and Thyrion (1996) and Baharin *et al*. (1998).

14.5 CONCLUSIONS

Supplies of palm oil are likely to continue increasing, with large areas in Indonesia that have not yet reached maturity at the time of writing. Palm oil is expected to overtake soya bean oil as the world's leading vegetable

oil before 2005. Production costs should remain below those of other vegetable oils for many years, even if oil palm workers' wages increase significantly in real terms, but in the long term, the cost of harvesting will become a serious problem for the industry. With increasing supply, the range of uses for palm oil in the oleochemicals industry seems set to continue its steady expansion of recent years. For edible uses, the strengthening opinion against *trans*-acids will favour palm oil as the solid-fat component of product formulations.

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Chapter 15
Concluding Remarks

15.1 RESEARCH NEEDS

At fairly frequent intervals the oil palm literature contains papers that set out to review the current research effort, in Malaysia or the world, and from this to suggest what should be done in the future. Two strands of thinking can be detected in these papers. The first sees the future in terms of advanced discoveries, so that the oil palm industry is taking part in agricultural research at the cutting edge (Jalani *et al.*, 1998). The second pays more attention to the immediate needs of the industry, and considers how to deal with existing and pressing problems (Chew *et al.*, 1998). Others (e.g. Tinker, 2000a) accept the need for both types of research, and urge that there should be a reasonable balance between them. Both strands agree in supporting classical or marker-assisted plant breeding, the development of clonal palms, and more research on environmental issues. However, the first strand then focuses on genetic transformation and high biology, and new and exciting uses for oil palm products, as important new developments. The second strand is interested in improving the oil extraction rate, raising the mean field yield and increasing the efficiency of the use of fertiliser and other inputs, especially labour, so as to improve the situation that we already have.

Both approaches are necessary. However, the first strand supports strategic research, and in tree crops the duration of any strategic research programme is likely to be very long. Breeding or transformation programmes can take decades. Even a breeding programme for an annual crop can take 10 years, and it may well take more than 20 years to introduce a major new feature into oil palms, and then to produce a competitive and high-yielding new palm cultivar with this feature. It is essential that this strategic research be undertaken, because the truly long-term prosperity of the industry will depend upon such work. If it is not done, the industry will gradually decline and die. However, the second approach is more immediately useful to a plantation industry trying to remain competitive in a price-sensitive world. Farmers sometimes comment that a long-term strategic research programme is all very well, but will be of little use to them if they go bankrupt before the project is completed. They may also say that if all farmers have the same improvement from the strategic research, then their own comparative advantage remains unchanged, and only the consumer benefits. This second point is only partly true if there are competing products without the advantage produced by the research, such as the other oil crops.

In this position the overall objective must be to ensure that the oil palm industry in general at least maintains its comparative advantage against other oil crops over both long and short timescales, with both strategic and applied research. For countries and companies, the second objective is that they at least maintain their own relative position within the oil palm industry. Much depends upon the potential for improvement in the shorter term through applied research. For example, the mean annual yield in Malaysia is only one-third of the potential yields of the best modern material, so there does appear to be scope to improve yields, and therefore costs, quite sharply over the short to medium term. In this type of research the application usually demands high standards of management, so that different estates may obtain very different benefits from it.

There is no alternative to a total research programme that covers all these issues, and delivers advances over a broad front. The balance and the management of such a programme require great skill, and its outputs cannot be guaranteed. Many unexpected issues can arise during the course of the long-term programmes, as is discussed below.

15.2 GENETIC MODIFICATION

Genetically modified crops are now widely distributed and successful. However, the developed world is polarised in its view of genetic modification of food crops. Broadly, the US and Japan see few problems, and consider the technology to be entirely safe. In Europe there is a very strong Green movement, based partly on organic farming, that considers genetically modified organisms (GMOs) to be potentially harmful and quite

unacceptable as food crops. The concerns of this movement are that food from GM crops may not be safe because we do not understand the biological consequences of the technique, and that far more testing is required before GMOs are declared to be safe. Activists now look very carefully at every single ingredient in complex food products to make sure that no GMO material is included. This attitude is almost certainly a consequence of the agricultural and food scandals that have affected Europe in recent decades. The second concern is that one cannot predict the consequences of releasing GM crop plants into the environment, and allowing the spread of GM genes through pollen flow. At its simplest, this fear is based upon the idea that 'superweeds' may be developed that cannot be eradicated. Some of the activists involved may never accept GMOs, despite the most authoritative statements about their safety and environmental harmlessness, but the views of the general population are less clear, and may gradually change.

Europe is a major market for palm oil, and at present GM oil would meet a great deal of resistance. Many organisations and supermarket chains now guarantee to their customers that the products they sell do not contain GM materials of any kind. At some point this may change, but the time of this is quite unknown. Possibly the change will occur before GM palm oil can be produced, but this situation must always be kept under observation. The palm oil industry has already had experience of the damage that can be caused by quasi-scientific criticism, in relation to the effects of palm oil on human health.

15.3 THE ENVIRONMENT AND SUSTAINABILITY

15.3.1 General

Rather than bringing everything to do with the environment into a single chapter, we have dealt with environmental matters in the appropriate chapters in this book (Sections 1.4, 3.3, 3.4, 8.1, 8.2, 8.3, 11.1, 11.6, 11.7, 13.4.8). It is however desirable to consider the total impact of the oil palm industry on the environment, and draw a conclusion about its sustainability . The potential complaints against the industry are:

1. Oil palm plantations require the clearing of valuable forest, and therefore damage biodiversity and increase the carbon dioxide content of the atmosphere.
2. Oil palm mills produce large quantities of pollutants that may be disposed of in rivers.
3. Oil palm plantations themselves are monocultures, and use fertilisers and pesticides, and thus attract all the 'green' criticisms directed at modern intensive agriculture (Tinker, 1997).
4. Palm oil as a food is unhealthy (see Section 14.4).

Our conclusions on these points are set out below.

15.3.2 Loss of forest

All agriculture has required the clearing of natural forest or grassland, and most developed countries converted large fractions of their forested area to agriculture long ago. Some land has to be cleared for plantations, but the loss of forest is minimised with oil palm, compared to other crops, because of the high yield of oil per hectare, and because palms can be replanted indefinitely on the same soil, as far as is known. Brazil alone has a larger area of soya beans than the total world area of oil palms (Fearnside, 2001), and this relatively low-yielding crop is starting to encroach into rainforest areas. Almost all temperate arable oil crops have relatively low yields per hectare, even when they are grown under intensive conditions, and have to be subsidised by Governments to overcome this inherent disadvantage in the market. Much present oil palm land was originally cleared for other crops (rubber, cocoa, coconuts in South-east Asia, grassland in Latin America) and has simply been converted to oil palms as a more profitable or less troublesome crop.

The indiscriminate and wasteful approach of some organisations to opening up land in Indonesia for oil palm cultivation (Section 1.4.3.1) is very unfortunate (Casson, 2000), and has given the critics of the industry plenty of ammunition. However, the size of the oil palm industry needs to be put into perspective against the claimed rate of forest loss. FAO (2001) states that the loss of tropical forest is now approximately 13.5 M ha/yr, with 1 M ha/yr regrowth of secondary forest. If the loss continues over 20 years, it will amount to 250 M ha. Mielke (2001) postulated that the oil palm demand would be double the present amount, or an extra 10 M t oil per year, by 2020. The present global area under oil palm is about 6.5 M ha. If we assume that average yields remain the same, the oil palm industry needs an additional 6.5 M ha, or 0.33 M ha per year. Whether this expansion actually happens or not, it only amounts to a little over 2.6% of the expected forest loss. If the yield level is increased by 1% per year, the area needed in 2020 will be roughly 20% less, or about 2.1% of the forest loss.

An associated issue is that of carbon sequestration. Global climate change is largely caused by an increase

in atmospheric carbon dioxide (IPCC, 2001). Any long-term process that removes carbon dioxide, such as an increase in plant biomass or soil carbon, delays this process, and net sequestration can be used for 'carbon trading'. The value of storing a tonne of carbon appears to be roughly US$10 at present. Tinker (2000a) considered that there was only limited scope for carbon sequestration in oil palm plantations, as forest will normally contain far more carbon than a plantation, and most of the carbon fixed by oil palms returns to carbon dioxide over a few years. However Chan (2002) took a rather more optimistic view of the possibilities.

15.3.3 Pollution

Pollution of soil and rivers results in loss of aquatic biodiversity, and causes other problems by the creation of eutrophic conditions after the release of plant nutrients. However, the pollution from palm oil mills has been virtually completely stopped in Malaysia, and there is very little damage now (see Section 13.4.8). The techniques that have been developed have also included the recycling on to the plantation of a large part of the plant nutrients in the effluents and wastes. This has greatly increased the sustainability of the industry (Section 11.7) and we expect to see the usage of fertiliser decline steadily. These technical solutions to the problem in rivers have been so successful that there is no reason why pollution should be accepted anywhere. Other countries have followed the Malaysian lead in establishing strict regulations to control such pollution, and it seems certain that this issue will diminish rapidly throughout the industry.

15.3.4 Sustainability

A strong argument can be advanced that oil palms are naturally a sustainable crop. In fact, the main environmental question after a forest has been cleared is whether the soil will be irreversibly damaged by its subsequent use. This can happen most easily with arable crops, that encourage erosion. With oil palms the soil is protected to a considerable extent, erosion can be controlled by field techniques, and the soil chemical composition will then normally move gradually to an acceptable equilibrium steady state. The use of pesticides is far smaller than on most tropical crops, such as cotton or cocoa, and Integrated Pest Management is extensively used (Section 12.2.1). The rate of fertiliser application is indeed large, but in theory the nutrient off-take should be very small because of the low content of nutrient elements in palm oil and kernels (Section 11.7; Vis *et al.*, 2001). The recycling of nutrients is steadily improving.

Cropping produces large yields of a high-energy product per hectare, is repeatable on the same fields, and is not prone to produce erosion. It therefore produces very little damage to natural resources or non-replaceable resources. Palm oil can easily be converted to a substitute for diesel fuel, and this may become a major advantage at some time in the future.

The question of the nutritional value of palm oil is discussed in Section 14.4. It is clear from a great deal of research that palm oil is an entirely satisfactory source of dietary fat, and it is to be hoped that this issue will soon be laid to rest.

15.3.5 Biodiversity

The remaining problem is to manage plantations so as to ensure that biodiversity is better protected. The biodiversity within an oil palm plantation will certainly be less than under natural forest (Andersen, 1996). The diversity of plants is obviously less, and this must lead to a lower diversity of the fauna that lives on and under trees. More research on this issue is needed. Sustainability demands that marginal land with steep slopes or unsuitable soil, on which soil damage is likely, should not be used for plantations. The ideal situation is to leave forest 'islands' within plantations as habitat for a more diverse biota, and these islands can be the parts of the estate less suitable for oil palms. The industry needs to accept that a mixed landscape with such islands must be managed to contribute to biodiversity conservation. The situation to aim for is a matrix of oil palm areas and natural forest, as a system of landscape conservation. Much more needs to be known about landscape ecology, so that landscapes can be designed to include both efficient plantations and conservation areas for wildlife (Szaro and Johnson 1996).

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Sections in which papers are cited are indicated in square brackets. References to tables and figures are numbered according to the section in which they appear.

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