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Annex 3.1 T

TABLES ON RICE PRE-HARVEST OPERATIONS

Table 3.1.1. Grain losses at different harvesting times based on crop maturity date.

Loss, %	0.77	3.35	5.63	8.64	40.70	60.46
Harvesting time, week(s)	-1	0	+1	+2	+3	+4
		Maturity date				

Source: Almera, 1997

Table 3.1.2. Average losses related to condition of ripeness of three rice varieties when harvested by traditional hand cutting method, Philippines.

Variety	3 days before normal stage, %	Normal stage for traditional, %	3 days after normal stage, %	5 days after normal stage, %

IR8	13	17	23	29
Peta	3	7	11	15
Raminad	3.5	6	8	9

Source: NAPHIRE, 1997.

Table 3.1.3. Percentage grain losses resulting from dates of cutting of two varieties of rice.

Cutting date	Grain loss, %			
	Before reaping		During reaping	
	IR-36	IR-38	IR-36	IR-38
	0.05	0.23	0.39	0.35
5 days before maturity				
5 days after maturity	0.16	0.23	0.49	0.58
At maturity	0.16	0.54	0.42	0.42

Source: Calpatura, 1978.

Table 3.1.4. Average cutting losses related to condition of ripeness of rice.

Harvesting system	3 days before normal stage %	Normal stage for traditional %	3 days after normal stage %	5 days after normal stage %
Traditional hand cut	6.00	8.70	10.50	12.00
Reaper-binder	1.00	3.10	1.20	5.80
Combine	2.00	3.10	1.20	5.80

harvester

Source: Hilangalantileke

Table 3.1.5. The effects of grain maturity or time of harvest on paddy quality (Zhejiang, China, 1988).

Type of rice crop/ time of harvest	Milling recovery %	Head rice recovery %	Immature kernels %	Germination rate %
Early rice crop				
Early	71.58a	30.45a	16.91a	92.65b
Optimum	72.90a	43.68a	9.2a	97.68a
Delayed	71.35a	35.48a	7.8a	97.48a
Late rice crop				
Early	76.54a	64.98a	14.24a	86.64a
Optimum	76.97a	73.77a	10.83a	92.38ab
Delayed	77.25a	90.91a	6.79a	97.04a

Means followed by the same letter in a column are not significantly different at 5% level (Duncan's multiple range test).
Source: Ren-Yong, et al. 1990.

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FIGURES ON RICE PRE-HARVEST OPERATIONS

Figure 3.1.1. Optimum time of harvesting rice.

{Insert AutoCad generated figures}

Source: PCARRD, 1988.

Figure 3.1.2. Effect of moisture content on field and milling yields of IR-8 rice variety.

{Insert AutoCad generated figures}

Source: PCARRD, 1988.

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Annex 3.5F

FIGURES ON RICE DRYING

Figure 3.5.1. The 1-2 ton capacity very low cost dryer for small farmers developed by the University of Agriculture and Forestry, Ho Chi Minh City, Vietnam.

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Annex 3.5 T

TABLES ON DRYING

Table 3.5.1. Methods of drying paddy or rough rice.

Method	Description	Process	Additional information	Comments	References
Field drying	Cut panicles are spread in the field to dry for few hours or days. Sometimes cut panicles are bundled and let standing in the field to dry. Allowing paddy to dry before cutting.	Sun or solar drying of unthreshed or uncut panicles in the field.	Usually practiced during the rain season harvesting after rain.	Subject the grain to more losses due to rats, birds and grain shattering. Quality deterioration due to heating when left longer in the field.	35, 45, 63
Shade drying	Bundled cut panicles are placed under the shade to dry. Threshed paddy are spread on mat, floor or any other materials or surfaces inside the house or shaded place to dry.	Shade or air drying.	Used for seeds during rains; long drying time; Sometimes bundled panicles for seeds are hang above cooking place in the kitchen.	Subject to grain loss due to pests and spillage.	45
Sun drying	Spreading threshed paddy in drying floors (Mats, pavement, roadside and others) to dry under the sun. An improved unit where air heated by solar heat absorber is passed through a thin layer of wet paddy on perforated flooring by	Sun or solar drying. Frequent stirring by hand, feet, rake or others.	Cheapest and most common method used by all sectors involved in paddy production or processing.	Losses occur due to spillage, animals feeding, checking of grain if soaked by rain and others. Laborious, usually done by women or children in the farm.	31, 35, 45

	convective current.				

Table 3.5.1. Methods of drying paddy or rough rice (continued).

Method	Description	Process	Additional information	Comments	References
Shallow bed batch type	Grain placed on perforated flooring of up to 40 cm thickness is dried by forcing heated air through the grain.	Continuous heated air batch drying until grain is safe for storage or milling.	Air heated to 43 C, no stirring, higher air temperature cause uneven layer drying.	Easy to operate, commonly used by small paddy processors.	
Deep bed batch drying	Deep bin with perforated floor where dry or slightly heated air is forced through the grain layer.	Drying and cooling of grain in storage.	Sometimes perforated pipes are inserted on the bin to force and exhaust the air through the grain.	Method used to prevent grain deterioration while waiting for dryer availability. Used in big paddy processing plants.	34, 42, 45
Continuous flow non-mixing dryer	A column of grain about 30 cm thick supported by perforated sheet walls with feeding hopper on top and discharge mechanism at the bottom.	Heated air of up to 70 C is forced through the column of grain to effect drying as it flows downward. Exposure time is about 10-15 minutes.	Grain is transferred to an aerated tempering bin to remove evaporating moisture and moisture in the grain to equilibrate.	Used in big commercial installations; total exposure time to heated air is decreased compared with continuous drying; Uneven drying due to one side exposure of grain.	42, 45

Table 3.5.1. Methods of drying paddy or rough rice (continued).

Method	Description	Process	Additional information	Comments	References
Continuous					42, 45

flow mixing dryer	A column of grain with perforated sheet walls with baffles, loading hopper on top and discharge mechanism at the bottom. The LSU (US) design has inverted Vs alternately arranged inside the bin. Heated air is forced in one layer of inverted Vs and discharged to the adjoining inverted Vs as the wet grain flows downward.	Baffle with grain flow zigzagging downward as heated air forced across to dry the grain mass.	Grain is transferred to an aerated tempering bin to remove evaporating moisture and in the grain to equilibrate.	Used in big commercial installations, total exposure time to heated air is decreased compared with continuous drying. More even grain drying due to mixing process.	

Notes:
For each mechanical heated air drying method power is provided to drive the blower to move the air, a heater to heat the drying air, ducting and associated elevators, conveyors and others as needed. Power can be petrol or diesel engine or electric motors and the heat source could be electricity, kerosene, LPG, rice husk and others depending on the cost and availability in the area.

2. Other methods of drying as the fluidized bed, flame, heated sand and other materials as steel balls, use of infra red lamps in flowing grain layer, rotary dryers, tray dryers and other dryers are also used in drying paddy. These methods however are seldom used because of availability of equipment, technical requirements, critical operations and high risk of losing the grain if not operated properly.

Table 3.5.2. Methods of drying, their suitability and losses.

Method of drying	Features	Comments
Sundrying		Labour-intensive, high losses uncontrolled quality of dried paddy, unreliable during the rainy season,

		environment friendly, suitable for household level drying, most popular method among developing countries.
Aeration in storage	Can be a very low cost drying and storing system for home stocks of paddy ranging from 1 to 2 tons per family; however, needs heating element such as electric heating coils mostly during times when drying need is critical, i.e., wet paddy during the rainy season.	Long duration; ineffective/damage risk under high humidity; ties up storage structure; prototype design of low-cost in-store dryer is available from the University of Agriculture and Forestry, Vietnam.
Heated air or mechanical		High capital and operational cost; Polluting and GHG emitting due to fuel burning; seasonal and low utilization except by commercial mills.
Batch		Small capacity; uneven drying; high cost
Continuous flow		High energy; controlled and uniform drying; suitable for commercial mills
Recirculating		High energy; suitable for commercial-scale mills

Table 3.5.3 Types, capacities, sources of supply, and prices of commercial grain dryers available in the Philippines as of October 1995..

Price, Philippine

Type of dryer	Capacity	Manufacturer supplier/dealer[a]	pesos[b] as of October 1995
Batch Type			
Flat bed	2 t/6-8 hours	14 local accredited manufacturers	65,000
Twin bed	3 t/6-8 hours	Marinas Industries, Pila, Laguna	130,000
Reversible flat bed	2 t/4-6 hours	Kuizon, Tacloban, Leyte	130,000
Columnar (Kongskilde)	10 t/8-12 hours	Scancon (imported), Manila	2.6 million
Columnar	5 t/8 hours	Marinas, Oila, Laguna	300,000[c]
In-store	60 t/6 days	NAPHIRE, Munoz, Nueva Ecija	250,000
Continuous recirculating			
LSU	1-4 t/hour	Padiscor (local), Pasig City	1-2 million
Cimbria	10-15 t/hour	Padiscor (imported, Denmark), Pasig City	~ 5-10 million
Shanzer	10-15 t/hour	Leverson (imported, USA), Pasig City	~ 10-15 million
Satake	5-10 t/hour	Mechaphil (imported, Japan), Pasig City	~ 3-5 million
Suncue	1.2-6 t/10-12 hours	H.E. Enterprises Inc. (imported, Taiwan), Tondo, Manila	400,000
Columnar	500-600 kg/hour	14 local accredited manufacturers (all over the country)	1000,000

Rotary	600-80 kg/hour	Jamandre, Iloilo City	100,000
Fluidised bed	500 kg/hour	ASIS, Cagayan de Oro City	85,000
Flash	1 t/hour to 18% m.c.	BUPHRE [d], Munoz, Nueva Ecija	80,000 [c]

[a] Not an endorsement of any manufacturer, dealer or product.

[b] During October 1995, about 25 Philippine pesos (PHP) = US$1, subject to changes.

[c] As of January 1998, about 41 PHP=US$1, subject to change.

[c] Bureau of Postharvest Research and Extension, formerly NAPHIRE

Source: Andales, 1996.

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Annex 3.7

TABLES ON STORAGE OF PADDY AND MILLED RICE

Table 3.7.1. Storage of paddy and milled rice.

Method of storage	Purpose	Advantage	Disadvantage	Comments
Household level Bulk dried paddy in bamboo, wooden or metal bin with or without aeration and pest control measures	Safekeeping, food security, protection from pests and weather	Cheap; suitable for small-sized requirements	Protection against pests is usually inadequate	In Indian sub-continent neem leaves are usually used to ward off insect pests; moisture content must be 14% or below for the humid tropics
Dried paddy in jute or propylene sacks stacked inside house or in separate granary	Food security and protection from pests	Low cost; flexible system	Theft; jute sacks vulnerable to pests	Traditional; granary posts are wrapped with GI sheets or cones for rodent control
Field-dried paddy on straw stacked in house yard	Safekeeping; in some places, as a status symbol	No structures needed	Vulnerable to pest attacks; fire hazard	Traditional practice; moisture content must be 14% or below for humid tropics
Commercial level Small-scale rice mills: dried paddy in jute or propylene sacks of 50- to 100-kg capacities stockpiled in rice mill building or separate warehouse	Protection against pests; flexibility in handling of various varieties procured from farmers	Economy of scale; can standardize product	May be under or over-capacity; must have drying facilities during rainy season; capital -intensive	Moisture content must be 14% or below for the humid tropics
Large-scale rice mills Dried paddy in bulk pile on	Protection against pests; economy of scale; maintaining	Good quality control and protection against pests; economy opf	Capital-intensive; suitable for large-scale rice production	Common in rice-exporting countries; moisture content must be 14% or below for the humid

vented floor for aeration; dried paddy in sacks stockpiled in warehouse; metal or concrete silo with aeration and automated loading and unloading devices	country's rice buffer stock and price stability	scale		such as in rice-exporting or densely populated countries	tropics

Table 3.7.1. Storage of paddy and milled rice (continued).

Type of storage	Period of storage	Purpose of storage	Condition of product	Maintenance of stored product	Comments
Small bulk in wooden, bamboo, metal or plastic boxes, cabinets or bins; in jute or propylene sacks	3 to 4 months or until next harvest of paddy	Own consumption; food security; cash conversion in case of need or emergency	Usually sun dried; moisture content usually determined by feel of farmer	Containers are vented but screened ; protected from rain; in India and Pakistan, neem leaves are sometimes used to ward off insect pests	Short-term storage
Same storage for rice as in above	Up to one month	For household consumption	14% moisture content or lower	Vents for aeration and covered for protection against insects and rodents	Short-term storage as quality deteriorates fast if milling has not been good or moisture content is high
Bulk or sack storage of paddy in large rice mills or commercial warehouses	For wholesale distribution; buffer stock for food security and rice price stabilization in case o0f government grain supply agency	3 to 4 months buffer stock by government ; indefinite period or until supply lasts and fresh stocks are procured in the case of private rice mills	Well-milled and dried	Sacks or bags stacked in sandwiched, window or block arrangement in warehouse to achieve optimum aeration of paddy or rice	The Indian Grain Storage Institute experimented on low-cost dehumidifiers using silica gel as medium of absorption and achieved a 10% reduction of relative humidity after 12 hours
Bulk storage in	Food security; buffer	3 to 4 months or		Aeration; chemical and	Common in government

Bulk storage in metal or concrete silos by large-scale commercial and government food grain agency	Food security; buffer stock in the case of government grain agency ; wholesale distribution in the case of privately owned rice mills	3 to 4 months or until next harvest of rice crop	14% moisture content or lower	Aeration, chemical and physical protection against pests; fast turn-over of stocks; professional or skilled warehouse management	Common in government grain agency mills or warehouses or in rice-exporting countries

Table 3.7.2. Storage structures used for paddy.

Description	Stored product maintenance	Expected losses and causes	User	Other information	Comments	References
Straw woven basket - built to different sizes; with or without mud/dung plaster, on ground or elevated. Elevated when outside with thatch or GI roof	None to simple maintenance	4-5% rodents, insects, moulds (moisture)	Farmer	Sometimes with rat protection on support	For short storage, susceptible to rodents, birds, insect infestation	33, 35, 72, 82, 83
Bamboo poles, woven basket or ma t - often plastered with mud-dung-straw. Elevated on platform with weather protection outside the house	None to simple maintenance	2-5%	Farmer	Sometimes with rat protection on support	For short storage, susceptible to rodents, birds, insect infestation	35, 41, 82
Wooden boxes - different sizes, kept indoor, elevated with thatch roof or GI roof when outside.	None to simple maintenance	2-5%	Farmer	Sometimes with rat protection on support	For short storage, susceptible to rodents, birds, insect infestation	33, 35, 82
Jute or propylene bags -	Inspection and	2-3%, rodents,	Farmer, coop,	Bags reusable,	Preferred for easy	29, 33, 82, 83

piled with dunnage	fumigation as needed	insects, spillage, moisture	private and public	hiding places of insects	handling	

Table 3.7.2. Storage structures used for paddy (continued).

Description	Stored product maintenance	Expected losses and causes	User	Other information	Comments	References
Jars, pots, gourds and other small containers	None	Minimal loss; insects	Farmer	Used for seeds and immediate consumption	Short-term storage	35, 82
Bins made of brick or mud-dung-straw or husk mix, different shapes and sizes, usually top loading and unloading with weather protection when outside house	Inspection, temperature monitoring, drying and fumigation when needed	Insect, moisture, rats, birds, 2-6%	Farmer, cooperative, and public sectors	Different names in different countries	Protect grain from entry of rats, birds, insects and moisture by proper instruction	33, 35, 72, 82
Underground pits or silos with mud, bricks, stone or cement wall lined with water proofing asphalt	Inspection and insect control as needed	3.4% due to rodents, moulds and insects	Farmer, and public sectors	Used for long storage duration	-	41, 72, 82

Table 3.7.2. Storage structures used for paddy (continued).

Description	Stored product maintenance	Expected losses and causes	User	Other information	Comments	References
Empty oil drums, tin cans,	Inspection	Minimal	Farmer			35, 82

GI bin containers and other small none traditional or metallic containers						
Barns, flat houses, granaries, separate structures made from traditional materials as mud, dung, straw and non-traditional materials as steel, cement and GI sheets	Inspection, drying, fumigation as needed		Farmer; cooperative, private, public sectors	Structure used for on- or -off-farm storage bulk or bag		29, 33, 72, 83
Silos (large capacity) made from local materials (mud-dung/ straw) concrete, bricks or metallic materials coupled with loading and unloading equipment usually associated with drying and milling operations	Inspection, aeration, temperature monitoring, intermittent drying and insect control	1%	Cooperative, private and public sectors	Used for bulk storage only	Rarely used in tropics due to high humidity; proper aeration imperative to avoid high temperature/ humidity spots.	35, 41, 72, 82, 83

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Annex 3.8

TABLES ON MILLING - DEHUSKING PADDY AND POLISHING RICE

Table 3.8.1. Rice mill components for husk and bran removal.

Name	Description	Process	Additional information	Comments	Sources[a]
Beam hammer/pounder	Consists of a wooden mortar sunk on the ground and a pestle fitted at one end of a wooden beam (about 3.7 meters long) which is supported at the fulcrum about 0.8 m from the other end; the operator steps on the short side of the beam thereby raising the pestle end, and then releases it on the mortar	Dehusking and polishing by repeated pounding of the paddy inside the mortar until milled rice is produced.	Usually operated by female family members. One operates the pounder while the helper turns over the grain in the mortar and then cleans the milled rice by the winnowing; in some places, one woman operates the husker.	High friction at the oblonged hole fulcrum, laborious, high percentage brokens and grain loss, by-product (bran and brokens) are lost with husk and during winnowing.	35, 91
Mortar and pestle	Consists of stone or	Dehusking and	Mortar is not sunk on	Laborious, high	35

Mortar and pestle	Consists of stone or wooden mortar and long heavy wooden pestle which is repeatedly pounded on the paddy inside the mortar	Dehusking and polishing to produce milled rice	Mortar is not sunk on the ground. pounding rice can be done by 4 persons operating synchronously	Laborious, high percentage brokens and grain loss, by-product (bran and brokens) lost with husk and and winnowing.	35

a Numbers in references.**Table 3.8.1. Rice mill components for husk and bran removal (continued).**

Name	Description	Process	Additional information	Comments	Sources
Wooden manual husking machines	Consists of two hollowed-out hardwood cones, an upper half and an inverted cone lower half.	Husking. Paddy is fed on top and flows between the cones as the upper half is rotated back and forth.	Husk is winnowed; unhusked grain is separated and returned to the machine	High brown rice recovery, no polishing is done, brown rice is nutritious	35
Bamboo-clay husker	Upper and lower cylinders with the outer shell made of woven bamboo splits into which an adhesive mixture of clay, lime and salt is pressed. The surfaces of the upper rotary and lower stationary cylinders are lined with bamboo strips. A long handle is placed on the upper cylinder to serve as crank.	Paddy is fed into the hole at the middle of the upper rotary cylinder and is hulled as it passes along the surface of the cylinders.	Husker be operated by one or two persons	High brown rice recovered, which is nutritious . .	91
Manually operated	Consists of a rotating	Separates the husk	Performance is	Laborious, needs	35

centrifugal husker	disc, a rubber-coated ring, a gear system, two handles and a base.	from the paddy. Two operators alternately push and pull a handle forward and backward rotating the disc through a gearing system. Paddy grain fed into the center of the disc is thrown out radially; the impact on the inside of the rubber-lined ring splits the husk.	dependent on grain variety, moisture content, and cleanliness as well as the operator. Machine is commercially available.	separation of the husk and polishing of the grain.	

Table 3.8.1. Rice mill components for husk and bran removal (continued).

Name	Description	Process	Additional information	Comments	Sources
Centrifugal husker	Consists of a rotating disc, a rubber-coated ring, and a pulley and belt drive from an engine power source.	Operates as the centrifugal husker above except for the engine drive.	Same as the centrifugal husker above; part of the disc in contact with the abrasive paddy wears out very fast.	Has more broken brown rice than the rubber roll husker at low grain moisture content (14% and below).	4
Rubber roll husker	Machine consists of two rubber rolls rotating in opposite directions with adjustable clearance, housing, hopper, feed and discharge openings, and	Husk is removed through shearing action as the grain is passed between the rubber rolls rotating in opposite directions.	Rubber rolls are sold in different sizes up to about 25 cm diameter; normally, are commercially available.		4, 30, 35,37,45, 70, 78

	aspirator blower for husk separation.	Resilient rubber rolls do not normally break dried grain but without cracks.			
Disc sheller	Consists of two horizontal emery-faced discs, the upper disc, stationary and the lower rotating on a vertical axis. Huller has husk aspirator.	Paddy fed at the center opening of top disc, flows down and horizontally out by centrifugal force created by the rotating bottom disc. Husk is aspirated as it comes out from the husker.	Friction between the two rotating discs remove the husk. Disc clearance is critical to husking and breaking of the grains.	Results in more broken brown rice than the rubber roller husker.	4, 30, 45, 70, 78

Table 3.8.1. Rice mill components for husk and bran removal (continued).

Name	Description	Process	Additional information	Comments	Sources
Huller mill (Engleberg, steel roller husker)	Consists of a fluted cylinder on a shaft enclosed in a hollow cylinder with cast iron top and perforated metal bottom, an adjustable blade, hopper, a pulley and metal frame.	Separates the husk and the bran in one operation. The helical ribs at the inlet push paddy to the discharge side. The straight ribs of the cylinder rotate the grain inside while the blade stops the rotation of the grain causing intense pressure and friction separating husk, bran,	Some hullers are provided with aspirator to remove husk and powdery materials mixed with milled rice. Grounds husk, bran, brokens, germs and powdery materials are discharged mixed. Milling recovery is usually lower by a minimum of 4%	Small capacity milling done in one pass. Generally very poor milling performance due to process limitation. Can be used as polisher or whitener to remove bran.	23, 30, 35, 37, 70

		germ and brokens which drop at the screen perforation. Milled rice is discharged at the outlet.	compared with other type of rice mills.		
Pearling or whitening cone	Consists of an inverted frustum of a steel cone which is lined with reinforced emery-carborundum and rotates on a vertical shaft. A stationary screen which fits outside the cone and strips of rubber brakes provide the frictional resistance for polishing the brown rice.	Part of the bran is removed as the grain flows from the top through friction between emery stone, screen and rubber brakes. Bran discharges separately.	Rotating cone can be lowered to adjust clearance; usually used in series of up to 3 units for gradual polishing of the grain.	Grain must be paddy-free; polisher does not remove husk in the process, bran removal can be regulated.	30, 70, 78

Table 3.8.1. Rice mill components for husk and bran removal (continued).

Name	Description	Process	Additional information	Comments	Sources
Horizontal abrasive roller whitener	Consists of a cylindrical carborundum formed on a hollow shaft with screw iron roll at inlet and cap cover at the outlet enclosed in a perforated	Primarily for bran removal. As brown rice is fed, the iron screw roll pushes the grain to the outlet side. The emery roll scours	Grain coming out from this machine has a rough surface. It must be pass through a polisher to remove the remaining bran and	This machine has high capacity and is usually used for commercial installations.	4, 30, 45, 70, 78

	steel cylinder. At the inlet is a hopper shutter, regulating valve and resistance piece. A weight at the outlet of an adjustable resistance piece is installed at the perforated cylinder to control degree of whitening.	the bran as it passes with the resistance piece regulating the extent of bran removal. Discharge is regulated by the resistance plate through the adjustable weight.	smoothen the grain surface. Paddy will not be husked by this machine.		
Iron roll friction whitening machine	Consists of a milling roll, a screw iron roller and a lock nut fixed on a hollow shaft. This is enclosed in a hexagonal perforated screen provided with inlet and outlet controls.	The pressure and friction between the rubbing surfaces of the grain, the screen, and the rotating cylinder smoothen the surface of the grain.	Air is injected into the shaft and enters the milling chamber through perforation of the shaft; milling roll cools the grain and separates bran from the grain.	This is the last section for whitening the grain in big rice mill installations.	4, 30, 45, 70, 78

Note: Machines not directly involved in the removal of the husk and bran during the milling process were not included in the above table. These ancillary equipment are the paddy cleaners, husk and bran aspirators, destoner, paddy separator, automatic weigher, brown rice thickness grader, automatic weighing and bagging grain, elevators, conveyors and others which may be added by the mill operator.

Table 3.8.2. Comparative rice milling tests.

Milling System	Actual Capacity	Commercial milling[1]				Laboratory milling			
		Milling	Head	Broken	Brewer's	Milling	Head	Broken	Brewer's

	(kg/hr)	recovery	rice	rice	rice	recovery	rice	rice	rice
		Percent							
Rubber roll single pass (Kyowa)	225	69.75	60.77	38.50	0.95	72.65	82.94	14.97	2.09
Rubber roll multipass (Satake)	4200	69.43	77.71	21.94	0.35	71.33	80.00	17.25	2.75
Rubber roll steel huller combination	300	68.47	59.05	40.50	0.45	71.31	86.07	11.50	2.43
Cone[2]	630	68.36	74.55	24.61	0.84	70.90	80.22	17.37	2.41
Stone disc steel huller combination	444	65.56	53.68	43.63	2.69	68.80	80.00	17.67	2.33
Steel huller[2]	380	64.50	29.18	68.86	2.06	72.29	81.19	16.45	2.36

[1] Tests for each milling system were replicated four times (4x).

[2] Average values from four different mills.

Source:

Table 3.8.3. Rice milling methods practiced in selected West African countries.

Country	Milling method practised, %		
	Hand pounding	Village mill[1]	Commercial mill[2]
Benin	30	30	40

Gambia	92	6	2
Ghana	62	24	14
Ivory Coast	46	31	23
Nigeria	92	6	2
Senegal	Data not available	Data not available	Data not available

[1] Predominantly U.K.- Engleberg types

[2] Japanese rubber roll dehusker - friction whitener or Engleberg whitener

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Annex 3.9

TABLE ON PACKAGING OF PADDY AND MILLED RICE

Table 3.9.1. Methods of packaging paddy and milled rice.

Method of packaging	Purpose	Relevance to final product
Sack, jute or propylene, 50-kg and 100-kg for paddy	Field to house, drying area/ rice mill transport	Prompt drying and safe storage
Bulk in small lorries for paddy	Field to rice mill/drying site transport	Prompt drying and safe storage
Sack, jute or propylene, 50-kg and 100-kg bags for milled rice	Wholesale and retail marketing	Consumer size packages in countries where rice is staple
Bag, polyethylene or brown paper, 2-kg, 5 kg, 10-kg, and 25-kg, for milled rice	Retail market	Marketing strategy; attractive and environment friendly packaging

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Appendix 4.0 F losses

Annex 4.0 F

FIGURES ON RICE POSTHARVEST LOSSES

.

Figure 4.0.1. Field grain post-production loss components, Zhejiang, China, 187-1989.

Source: Ren-yong, et al., 1990.

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 % loss

Grain Shattering sickle
during and after combine
cutting

Shattering after
harvesting just sickle
before threshing

Unharvested sickle

combine

Straw Loss combine

combine

Unthresthed

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 % loss

Figure 4.0.2. Loss components of manual (sickle) and combine harvesting (Zhejiang, China, 1987-1989).

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 %loss

Unthreshed pedal thresher
loss motor thresher

Straw Loss pedal thresher
motor thresher

Shattering
during pedal thresher
threshing motor thresher

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 %loss

Figure 4.0.3. Loss components of pedal and motor threshing (Zhejiang, China, 1987-1989).

0.2 0.4 0.6 0.8 1.0 1.1 1.2 1.4 1.6 1.8 2.0 2.2%s

Separation Jinhua
Jiaxin
Nimbo

Jinhua
Blower
Jiaxin
Nimbo
Jinhua

Jiaxin
Drying
Jiaxin

0.2 0.4 0.6 0.8 1.0 1.1 1.2 1.4 1.6 1.8 2.0 2.2%loss

Jinhua: Jiaxin Nimbo

sun dried on bamboo sun dried on cement sun dried on cement
mat-rethreshed by hand yard-bamboo sieve plus yard-mechanical vibrating
and cleaned by wooden electric blower screen with electric blower
winnower

Figure 4.0.4. Loss components of manual (sickle) and combine harvesting (Zhejiang, China, 1987-1989).

%loss %loss

4.0 4.0

3.0 3.0

2.0 2.0

1.0 1.0

Loss due to Loss due to Loss due to
moulds insect pest rat damage

Figure 4.0.5. Loss component of storage (Zhejiang, China. 1987-1989).

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Appendix 4.0 F losses

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TABLES ON PROCESSING LOSSES OF RICE

Table 4.0.1. Possible losses of rice, theoretical estimated percentages.

Paddy (%)				Milled rice (%)		
Harvesting		Transport to	Storage at	Processing at	Transport to	Retail
Reaping	Threshing	mills	mills	mills	storage	Storage
2-3.5	1.5-2.0	0.5-1	0.5-1.5	0.2-0.5	ca. 0.5	0.5-1.5

Overall average losses: about 6-10%.
Note: Bird losses before reaping can be up to 20% by weight.

Table 4.0.2. Quantitative loss ranges of grain postharvest system for three seasons, Zeijiang, China, 1987-1989.

Postharvest operation and method	Loss range, %		Average share of	
	Min	Max	%	Total loss, %
Harvesting	0.29	2.34	0.85	5.81
By sickle	0.29	0.58	0.43	

Combine harvester-thresher	2.73	4.29	3.38	
Threshing	0.62	2.68	1.31	8.85
By pedal thresher	0.62	1.08	0.80	
By motor thresher	0.92	2.68	1.52	
Drying and cleaning	1.72	7.36	3.47	23.43
Sun dried on bamboo mat, re-threshed by hand and use of wooden winnower	2.59	4.32	3.35	
Sun dried on cement yard, bamboo sieve plus electric blower	2.61	5.61	4.10	
Sun dried on cement yard,, mechanical vibrating screen with electric blower	2.58	3.05	2.90	
Storage	2.89	8.124	5.46	36.87
Moulds	1.27	2.02	1.59	
Insects	0.43	2.18	1.15	
Rats	1.00	3.98	2.72	
Transportation	0.59	1.11	0.97	6.55
Milling	1.95	4.39	2.74	18.5
Total	8.02	26.02	14.81	100.01

Source: Ren-Yong et al., 1990.

Table 4.0.3. Typical values of quantitative postharvest grain losses in Indonesia.

Operation	Loss, %
Harvesting	0.89
Threshing	0.99

Threshing	0.99
Drying	3.16
Storage	3.74
Milling	4.78
Total	13.56

Source: FAO, 1981.

Table 4.0.4. Average physical losses among alternative postharvest systems in two regions, Philippines, 1975-1977.

Operation	Manual, %	Mechanical, %	Difference, %
Threshing			
Central Luzon (threshing frame vs axial-flow)	2.4	1.1	1.3
Bicol (flailstick vs axial-flow)	1.2	0.5	0.7
(threshing frame vs axial-flow)	1.6	0.5	1.1
Cleaning			
Central Luzon (winnowing basket)	1.1	a	1.1
Bicol (wooden winnower)	1.1	a	1.1
Drying			
Central Luzon	1.2	0.1	1.1
Bicol	1.2	0.4	0.8

[a] With mechanical threshing using the axial-flow thresher, the threshing and cleaning operation s accomplished simultaneously during threshing.

Source: Toquero and Duff, 1985.

Table 4.0.5. Losses of rice within the postharvest system.

Region and country	Total weight loss %	Remarks
WEST AFRICA	6 - 24	Drying 1-2; on-farm storage 2-10; parboiling 1-2; milling 2-10
Sierra Leone	10	
Uganda	11	
Rwanda	9	
Sudan	17	Central storage
Egypt	2.5	
ASIA		
Bangladesh	7	
India	6	Unspecified storage
	3 - 5.5	Improved traditional storage
Indonesia	6 - 17	Drying 2; storage 2-5
Malaysia	17 - 25	Central storage 6; threshing 5-13;
	c.13	Drying 2; on-farm storage 5; handling 6
Nepal	4 - 22	On-farm 3-4; on-farm storage 15; central storage 1-3
Pakistan	7	Unspecified storage 5
	2 - 6	Unspecified storage 2
	5 - 10	Unspecified storage 5-10
Philippines	9 - 34	Drying 1-5; unspecified storage 2-6; threshing 2-6 Malaysia workshop

	up to 30	Handling
	3 - 10	
Sri Lanka	13 - 40	Drying 1-5; central storage 6.5; threshing 2-6
	6-18	Drying 1-3; on-farm storage 2-6; milling 2-6; parboiling 1-3
Thailand	8-14	On-farm storage 1.5-3.5; central storage 1.5-3.5
	12-25	On-farm storage 2-15; handling 10
LATIN AMERICA		
Belize	20-30	On-farm storage
Bolivia	16	On-farm 2; drying 5; unspecified storage 7
Brazil	1-30	Unspecified storage 1-30
Dominican Republic	6.5	On-farm storage 3; central storage 0.3

Source: FAO

Table 4.0.6. Losses in drying and storage.

Method	Range of losses, %	Average losses, %
Harvesting	0.29-2.34	0.86
Sickle	0.29-0.53	0.43
Combine	1.54-2.34	1.82
Threshing	0.2-2.68	1.31
Pedal thresher	0.62-1.03	0.80
Motor thresher	0.90-2.68	1.52
Cleaning and drying		3.47
	2.59-4.32	3.35
Dried on bamboo mat and cleaned by wooden winnower		
	2.61-5.16	4.10

	2.61-3.16	4.10
Dried on concrete yard and cleaned by electric blower		
	2.58-3.05	2.90
Dried on concrete yard and dried by vibrating screen and electric blower		
Storing		5.23
	1.9-3.88	2.89
In wooden cabinet		
	3.17-5.17	4.67
In bamboo mat cylinder		
	6.04-10.24	8.14
Stacking on the ground		

Source: Yong et al., 1997.

Table 4.0.7. Estimated losses in caloric value, protein and thiamin in rice samples infested by *Sitophilus oryzae*.

Losses per kg of Grain*

Infestation period Months	Infested Grains %	Weight Loss %	Caloric Value	Protein, g	Thiamine mg
Raw milled rice					
2	1.1	0.2	7	0.15	0.05
4	7.9	1.65	58	1.2	0.03
6	11.0	2.9	103	2.2	0.03
8	13.5	4.7	163	3.5	0.03
Raw handed-pounded rice					
2	8.7	0.3	11	0.2	0.04

4	26.1	2.5	86	1.9	0.12
6	42.5	6.1	213	4.6	0.18
8	49.6	14.2	497	10.6	0.26
Raw husked rice					
2	6.6	1.1	38	0.8	0.14
4	19.0	6.9	243	5.2	0.22
6	31.5	16.0	561	12.0	0.29
8	39.0	22.8	800	17.1	0.36
Parboiled milled rice					
2	0.6	0.1	4	0.1	0.03
4	2.5	1.0	36	0.8	0.06
6	6.9	3.0	106	2.3	0.12
8	12.7	4.6	160	3.4	0.11

Source: Pingali et al. 1957.

Table 4.0.8. Estimated losses of paddy and rice at each stage of production and processing (a suggested format)

Region/Country	Stage of production and post production/ Source of losses	Grain loss, % of yield	Sources
	Pre-harvest - field shattering at maturity due to wind, rain and natural dehiscence		

as influenced by varietal characteristics

Low-shattering variety

Medium-shattering variety

High-shattering variety

as attacked by birds and rodents

Harvesting

Traditional manual gathering of panicles of low-shattering variety

---

Stage of production and post production/ Grain loss, Source

Source of losses % of yield

Pre-harvest - field shattering at maturity
due to wind, rain and natural dehiscence
as influenced by varietal characteristics

Low-shattering variety
Medium-shattering variety
Medium-shattering variety

as attacked by birds and rodents

Harvesting

Traditional manual gathering of panicles
of low-shattering variety

Traditional cutting of stalks, piling in
small bundles and stacking

Traditional cutting of stalks and windrowing

or laying to field dry

Two-wheeled tractor-mounted reaper

Sri Lanka

Four-wheeled tractor-mounted reaper

Pakistan

Self-propelled reaper binder

Self-propelled stripper gatherer

Rice combine

Thailand
Malaysia
Japan, Rep. of Korea, Taiwan prov. of China
USA
Italy
Spain
Africa
Latin America

Threshing

Human treading, manual winnowing and bagging
Animal treading, manual winnowing and bagging
Four-wheeled tractor treading, manual winnowing

and bagging

Throw-in type, engine-powered portable thresher and bagging

Philippines, Indonesia (1-2 t/h capacity)

Thailand (2-3 t/h capacity)
Vietnam (2 t/h capacity)

Hold-on type thresher and bagging

Pedal-powered (Philippines, some areas)
Engine-powered (Japan and Rep. of Korea)

Handling and transporting

Traditional cut stalk, windrow or lay on field

to dry, bundle and carry on back

Preparation of bundle and loading
Carrying on back, loss on trails
Carrying on back, loss on resting points

Traditional cut panicle, bundle and carry on head

by women; low shattering variety

Traditional cut panicle, bundle, balance bundles at ends

of pole and carry on shoulder by men

Bagging paddy output from threshing and cleaning

From pedal thresher
From mat after beating paddy against wood block,

rock or bamboo slats or beating paddy with
stick or flail

From hold-on type thresher (engine-powered)
From throw-in type thresher (engine-powered)
From small combine (Japan, Rep. of Korea)
From stripper harvester-gatherer and re-thresher

Bulk transfer from combine to lorry or wagon and

transport to drying compound or rice mill

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FIGURES ON RICE GRAIN LOSSES

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 % loss

Grain Shattering sickle
during and after Combine
cutting

Shattering after
harvesting just sickle
before threshing

Unharvested sickle
combine

Loose straw combine

combine
Unthreshed

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 % loss

Figure 4.0.1. Loss components of manual (sickle) and combine harvesting (Zhejiang, China, 1987-1989).

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 %loss

Unthreshed pedal thresher
loss motor thresher

Loose straws pedal thresher
motor thresher

Shattering
during pedal thresher
threshing motor thresher

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 %loss

Figure 4.0.2. Loss components of pedal and motor threshing (Zhejiang, China, 1987-1989).

0.2 0.4 0.6 0.8 1.0 1.1 1.2 1.4 1.6 1.8 2.0 2.2%s

Separation Jinhua
Jiaxin
Nimbo

Jinhua
Blower
Jiaxin
Nimbo
Jinhua

Jiaxin
Drying
Jiaxin

0.2 0.4 0.6 0.8 1.0 1.1 1.2 1.4 1.6 1.8 2.0 2.2%loss

Jinhua: Jiaxin Nimbo

sun dried on bamboo sun dried on cement sun dried on cement
mat-rethreshed by hand yard-bamboo sieve plus yard-mechanical vibrating
and cleaned by wooden electric blower screen with electric blower
winnower

Figure 4.0.3. Loss components of manual (sickle) and combine harvesting (Zhejiang, China, 1987-1989).

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%loss %loss

4.0 4.0

3.0 3.0

2.0 2.0

1.0 1.0

Loss due to Loss due to Loss due to
moulds insect pest rat damage

Figure 4.0.4. Loss component of storage (Zhejiang, China. 1987-1989).

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Annex 5.1

TABLES ON PEST CONTROL

Table 5.1.1. Categories of major rice insect pests and their regional distribution.

Insect pest	Common name	Distribution
Root and Stem Feeders	Rice water weevil	America, Japan
Lissorhoptrus oryzophilus	Stripped stemborer	Africa, Asia, Australia
Chilo suppressalis	Stalk-eyed borer	Africa
Diopsis thoracica	Pink stemborer	Asia
Sesamia inferens	Yellow stemborer	Asia

Scirpophaga incertulas	White stemborer	Asia, Australia
Scirpophaga innotata	Black paddy bug	Asia
Scotinophora coarctata		
Foliage feeders - sucking type	Rice thrips	Asia
Baliothrips biformis	Green leafhopper	Asia
Nephotettix virescens[1]	Brown planthopper	Asia, Australia
Nilaparvata lugens[2]	Whitebacked planthopper	Asia, Australia
Sogatella furcifera	Rice delphacid	America
Sogatodes oryzicola[3]		
Foliage feeders - chewing type	Leaf folder	Asia, Australia
Cnaphalocrocis medinalis	Rice hispa	Asia
Dicladispa armigera	Whorl maggot	Asia
Hydrellia philipina	Earhead cutworm	Asia, Australia
Mythimna separata	Caseworm	Africa, Asia, Australia,
Nymphula depunctalis	Gall midge	America
Orseolia oryzae	Armyworm	Africa, Asia
Spodoptera mauritia		Africa, Asia, Australia
Grain feeders	Rice bugs	Asia, Australia
Leptocorisa spp.	Green stink bug	Africa, Asia, Austr.,
Nezara viridula	Rice stink bug	America
Oebalus pugnax		America

1 Vector of the rice *tungro* virus

2 Vector of the grassy stunt virus and of the ragged stunt virus

3 Vector of the *hoja blanca* virus

Source:

Table 5.1.2. Relative status of major pest species.

Insects	*Distribution* Coleoptera or beetles and Lepidoptera or moths constitute about 60% and 6%, respectively, of the nearly a thousand species of insects associated with stored products worldwide. *Postharvest conditions* Dried milled rice stored in warehouses or village and household granaries and containers/bags; stable environment inside warehouse favors breeding; these stored product pests can breed under low humidity and dry food (2-14% mc); limits.are 14-34oC; 28oC generally optimum with shorter life cycles at higher temperatures. *Stage/time of infestation* Stored grain in warehouses and small village structures, granaries, containers and bags; bulk stored grain; primary pests attack undamaged grains, complete development therein, and initiate a succession of events in which the grain is gradually consumed by a variety of other insects, fungi and bacteria. Secondary pests feed on already damaged grain. Infestations sources: cross and residual infestations, infested containers, bags and especially jute sacks, mobility by flying or crawling, habitats in uncleaned mills, threshers and combines. *Main control* Integrated pest management (IPM): integrates methods for effectiveness without undesirable environmental

	and health effects. IPM concepts: efficient warehouse design, best hygiene, minimum insecticides, complete kill and thorough inspection programme. Biological control - only limited potential due to constraints parasitoids, predators or pathogens, pheromones, host resistance, sterility. Physical control - hygiene, exclusion, drying, refrigeration, aeration, heat, hermitic and controlled atmosphere storage, ionizing radiation, inert dusts, physical shock or disturbance, and light. Chemical control - (see Table 5.2.1) - residual (structural) and space treatment, grain protectants, surface sprays, fumigation.

Table 5.1.2. Relative status of major pest species (continued).

Rodents	*Distribution* About four percent of stored rice and other grains is damaged by rodents. Adult rats weighing more than 50 g consume an amount equivalent to 10% of their body weight per day and those weighing less than 50 g consume 15%. While feeding, they spill 7.5 times as much as the amount they consume. Secondary losses are caused by fungi because of contamination with rodent hairs, urine and feces. *Biology and ecology* Have keen sense of smell, touch through whiskers and body guard hairs, hearing (males and newborns emit ultrasonic sound) and taste; movements guided by odor trails; can detect extremely minute quantities of bitter, toxic or unpleasant substances which are significant to rodent control measures. They are good swimmers and can remain underwater for up to 30 seconds, thus, they can swim through water seal in toilet; prolific breeders year round and can restore decimated population easily; a female rat can produce 32 offsprings in the field and 37 in the warehouse because of the favorable conditions in the latter; density controlled by birth,

	mortality, immigration and emigration factored by quality of environment and food and water availability as well as competition in case of high population density. Feeding behavior of taking food to cover (large particles or pellets or in packets and sachets) is important to consider in baiting. *Postharvest conditions* Damage is due to consumption, spillage, contamination and hoarding. *Main control* IPM - combination of any or all of the methods described below. Environmental sanitation -removal of waste grain and other debris; limit access to open water. Biological method - cats, dogs and Salmonella; indirectly by habitat manipulation such as rapid stock turn-over, first-in, first-out stock movements to disturb habitat; Physical method - Proofing by galvanized sheet metal; conical sheet on top of each post in a granary house in villages; Blocking all entry points such as wall gaps, broken windows, air bricks, along cable and through ventilator, weak foundation, up gutter pipes and under eaves, behind sliding doors and overhanging branches; rodents can gnaw almost any material softer than their incisor enamel; Trapping and baiting - traps to be placed in areas with clear signs of rodent activity; leave traps baited but unset for a few days; be wary of the rat's cautious behavior like avoiding new objects; Electric barriers are hazardous and had only limited field applications; Ultrasound devices are not entirely effective and are expensive.

Table 5.1.2. Relative status of major pest species (continued).

Rodents	*Distribution* About four percent of stored rice and other grains is damaged by rodents. Adult rats weighing more than 50 g consume an amount equivalent to 10% of their body weight per day and those weighing less than 50 g consume 15%. While feeding, they spill 7.5 times as much as the amount they consume. Secondary losses are caused by fungi because of contamination with rodent hairs, urine and feces.

	Biology and ecology Have keen sense of smell, touch through whiskers and body guard hairs, hearing (males and newborns emit ultrasonic sound) and taste; movements guided by odor trails; can detect extremely minute quantities of bitter, toxic or unpleasant substances which are significant to rodent control measures. They are good swimmers and can remain underwater for up to 30 seconds, thus, they can swim through water seal in toilet; prolific breeders year round and can restore decimated population easily; a female rat can produce 32 offsprings in the field and 37 in the warehouse because of the favorable conditions in the latter; density controlled by birth, mortality, immigration and emigration factored by quality of environment and food and water availability as well as competition in case of high population density. Feeding behavior of taking food to cover (large particles or pellets or in packets and sachets) is important to consider in baiting.

Table 5.1.2. Relative status of major pest species (continued).

Rodents	*Postharvest conditions* Damage is due to consumption, spillage, contamination and hoarding. *Main control* IPM - combination of any or all of the methods described below. Environmental sanitation -removal of waste grain and other debris; limit access to open water. Biological method - cats, dogs and Salmonella; indirectly by habitat manipulation such as rapid stock turn-over, first-in, first-out stock movements to disturb habitat; Physical method - Proofing by galvanized sheet metal; conical sheet on top of each post in a granary house in villages; Blocking all entry points such as wall gaps, broken windows, air bricks, along cable and through ventilator, weak foundation, up gutter pipes and under eaves, behind sliding doors and overhanging branches; rodents can gnaw almost any material softer than their incisor enamel; Trapping and baiting - traps to be placed in areas with clear signs of rodent

activity; leave traps baited but unset for a few days; be wary of the rat's cautious behavior like avoiding new objects; Electric barriers are hazardous and had only limited field applications; Ultrasound devices are not entirely effective and are expensive.

Chemical method - Rodenticides provide cheap and convenient control method, classified as acute (single-dose fast-acting poisons), chronic (multiple-dose or single-dose slow-acting anti-coagulants), fumigants, chemosterilants and chemical repellents. Acute rodenticides are extremely hazardous to man and animals and include acute poisons such as arsenic trioxide, bromothalin, fluoroacetamide, phosacetim, silatrane, sodium fluoroacetate, strychnine and thallium sulfate. The moderately hazardous chemicals include alpha-chloralose, alpha-chlorohydrine, calciferol, zinc phosphide and pyrinuron. The minimally hazardous chemicals include equill and norbormide.

Table 5.1.2. Relative status of major pest species (continued).

Birds Biology and behavior

Major bird pests belong to genera Lonchura (Family Estrildidae) and Passer (Family Plocerdae)
Weavers weigh 10 to 30 g and build covered nests. They feed on rice and *Echinoloa spp* weed seeds, as well as corn tassels, sorghum and certain algae. Feeding times are from dawn to about 10:00 a. m. and from about 3:00 p. m. to dusk. They are abundant during harvest period and population flows the cropping pattern. They were observed to consume 30% of their body weight in rice.

Prevention and control

Physical method - good warehouse design, maintenance by hygiene, egg collection and pest destruction, mist nets, traps and to a limited degree, foot stickers, noise and ultrasonic disturbances.

Biological method - In the field bigger predatory birds and other animals feed on weavers. Rodents and cats may also be considered as predators inside stores. some enterprising persons catch birds at night at their roosting places for food or for trade.

Chemical method - Baiting with food attractive to bird species (cake or bread is universal) may be tainted with poison of avicide, but these are potentially hazardous. They should be used only when all physical and biological methods are ineffective and used with utmost care and caution. Pre-baiting for 3 to 4 days brings success. Repellents like methiocarb discourage birds from feeding on seeds. Alpha-chloralose stupefy birds without killing them but can kill at high doses.

Table 5.1.2. Relative status of major pest species (continued).

Fungi	Fungi are multicellular microorganisms having threadlike structure called hypha and sexual and asexual spores. They do not posses chlorophyll and depend on organic matter for nutrition. They are useful in fermentation such as in brewing, production of antibodies and in food processing such as baking, cheese-making and wine fermentation. However, they can cause grain deterioration. They are cosmopolitan in distribution and grow under a wide range of environment. Certain postproduction practices are favorable to fungal invasion. Storage fungi - These include *Aspergillus* and *Penicillium* which produce toxic metabolites and cause grain discoloration, produce off odors and off tastes. They are adapted to life without free water and several species invade grains with moisture contents of 13-18% in equilibrium with 70-80% RH. They usually invade seed embryos. Damage caused Decrease in germinability, altered nutritional value, heating, discoloration, caking of grains, and low milling yields. Fortunately, rice is a poor substrate for aflatoxin (level set by WHO is below 20 parts per billion for human consumption of grains and 50 parts per billion for animal consumption) production by *Aspergillus flavus* and *A. parasiticus.*

Table 5.1.3. Grain protectants currently in use.

Insecticide	In use since	Application rate (mg per kg)
Bromophos	1968	10
Chlorpyrifos-methly	1978	5-10
Dichlorvos	1966	4-10
Fenitrothion	1977	6-12
Malathion	1960	8-20

Primiphos-methyl	1969	4-8
Bioresmethrin	1975	1.0
Carbaryl	1979	5.0
Deltamethrin	-	1.0
Fenvalerate	-	2.0
Permethrin	-	2.0
d-phenothrin	-	2.0
Pyrethrins	1935	2-3

Source: Snelson, 1985 as cited by Ong, 1992.

Table 5.1.4. Insecticide mixtures in admixture treatment of paddy.

Pesticide mixtures	Application rate (mg per kg)
Pirimiphos-methyl	12
+ Permithrin	1
+ piperonyl butoxide	5
Fenitrothion	20
+ Fenvalerate	0.5
+ Piperonyl butoxide	5
Chlorpyrifos-methyl	10
+ carbaryl	8
Methacrifos	12
+ Permithrin	1
+ Piperonyl butoxide	8
Pirimiphos-methyl	12
+ Bioresmethrin	1

+ Bioresmethrin	1
+ Piperonyl butoxide	8
Fenitrothion	20
+ d-Phenothrin	1
+ Piperonyl butoxide	8
Deltamethrin	1
+ Piperonyl butoxide	8

Source: Rahim Muda and Ong , 1992.

Table 5.1.4. Insecticide mixtures in admixture treatment of paddy.

Pesticide mixtures	Application rate (mg per kg)
Pirimiphos-methyl	12
+ Permithrin	1
+ piperonyl butoxide	5
Fenitrothion	20
+ Fenvalerate	0.5
+ Piperonyl butoxide	5
Chlorpyrifos-methyl	10
+ carbaryl	8
Methacrifos	12
+ Permithrin	1
+ Piperonyl butoxide	8
Pirimiphos-methyl	12
+ Bioresmethrin	1
+ Piperonyl butoxide	8
Fenitrothion	20

Fenitrothion	20
+ d-Phenothrin	1
+ Piperonyl butoxide	8
Deltamethrin	1
+ Piperonyl butoxide	8

Source: Rahim Muda and Ong , 1992

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Annex 5.2

TABLES ON DETAILS OF RICE POSTHARVEST PESTS

Table 5.2.1. Life history, distribution, infestation and main control of major insect pest species in rice postharvest.

Pest species	Distribution	Postharvest conditions	Stage/time of infestation	Main control	Loss status
Rice weevil, *Sitophilus*	Worldwide	Optimum for insect		Parasitoid	One of the most

Rice weevil, *Sitophilus oryzae* (Coleoptera) Life size, 2.5-4.5 mm Longevity, 4-5 months, some more than 1 year Eggs, 300 - 500 Development completed, 4 weeks Temperature, adults die in 3.5 hours at 47oC;	Worldwide	Optimum for insect development is brown rice m.c., 18%; temperature, 30oC; minimum limit for growth, 14oC		Parasitoid - *Anisopteroma-lus calandrae* Drying	One of the most destructive pests causing substantial weight loss
Lesser grain borer, *Rhizopertha dominica* (Coleoptera) Life size - 2-3 mm Eggs - 200-500, single or in 30-egg clusters Life cycle - 33 days at 30oC; Life span - 6 months Generations - 2 in temperate; 5 in tropical countries	Cosmopolitan insect; one of most destructive insects in tropical and subtropical regions	Eats mainly grain kernels but can also develop in milled rice Temperature, can breed at 37.8oC; Development completed inside kernel or in grain dust	Adult; larva will feed on ground grain produced by adult ; sometimes will bore directly into the kernel	Parasitoid - *Anisopteroma-lus calandrae*	

Table 5.2.1. Life history, distribution, infestation and main control of major insect pest species in rice postharvest (continued).

Pest species	Distribution	Postharvest conditions	Stage/time of infestation	n control
Rust red flour beetle, *Tribolium castaneum* and *Tribolium confusum*	Worldwide	Flour and bran; *T. castaneum in* warm and *T confusum* in cool climate,	A secondary pest acting on damaged product by	Most destructive insect pests of milled products

(Coleoptera); Secondary pest Life size - 2.5-4.5 mm Longevity - 6 months; some >1year Development - 7 weeks to 3 months		temperature limits, 18-33oC	grinding, milling, handling and action of primary pests	such as flour and bran
Saw-toothed grain beetle, *Oryzaephilus* spp.; *O. surinamensis* (Coleoptera); Secondary pest; Life size, 2.5-3.5 mm Life cycle, 25-28 days Eggs - 45-285 Life span - 6-10 months; some up to 3 years Generations - 7/yr	Worldwide	Damaged grain; optimum development at 30oC and 70% RH	A secondary pest acting on damaged product by grinding, milling, handling and action of primary pests	

Table 5.2.1. Life history, distribution, infestation and main control of major insect pest species in rice postharvest (continued).

Pest species	Distribution	Postharvest conditions	Stage/time of infestation	Main control	Loss status
Tropical warehouse moth, *Ephestia cautella* (Lepidoptera) Secondary pest Wing span, 11-28 mm Longevity - 5 days	Widespread in tropical and subtropical regions	Damaged or processed grains	Secondary pest acting on damaged product by grinding, milling, handling and		

Eggs - 90-190			action of primary pests
Khapra beetle, *Trogoderma granarium* (Coleoptera) Life size - 2-3 mm oblong-oval Life cycle - 4-6 weeks to several years Eggs - 30-100 Generations - 4-5 per year in tropics, 2 per year in temperate countries	Tropical regions, 4-5 generations/year; temperate, 1-2 generations/year	Max. 40oC, larvae can develop at 10oC; adults resistant to low moisture conditions, can breed in grain <2% moisture content Larvae tolerant tp food deficiencies and can survive at 10oC for 3 days	
Rice moth, *Corcyra cephalonica* (Lepidoptera) Secondary pest			Larval stage

Table 5.2.1. Life history, distribution, infestation and main control of major rodent pest species in rice postharvest (continued).

Pest species	Distribution	Postharvest conditions	Stage/time of infestation	Main control
Rodents				
Norway rat, *Rattus norvegicus* Tend to burrow under secure coverings,	Worldwide;origin - temperate countries but has moved worldwide; adapted to different habitats and environments	Attacks both standing and stacked harvested grains in the field; infest accessible stored	Whenever grain is stored.	L-shaped wall discourages rat to circumvent an obstruction at foundation level after meeting a wall after digging. Can jump 77 cm vertical and 1.2 m horizontally from a standstill. Cats and dogs

concrete or rock piles; habitat: spaces between floors and walls, near water and long ditches and streams.		rice.		Owls Trapping Sealing entry points
Roof rat, *Rattus rattus* Excellent climber; lives in small colonies; inhabits warehouses, restaurants, large food stalls, poultry houses, and residential buildings.	Worldwide;	Accessible grains are vulnerable.	Whenever grain is stored	Cats and dogs Owls Trapping Sealing entry points
House mouse, *Mus musculus*	Worldwide in cereal growing areas; Has hoarding habit	Accessible grains are vulnerable.	Whenever grain is stored	Ditto

Table 5.2.1. Life history, distribution, infestation and main control of major bird pest species in rice postharvest .

Pest species	Distribution	Postharvest conditions	Stage/time of infestation	Main control
Birds House sparrow - *Passer montanus;* Lays an average of 6 eggs in 6 days; incubation is 10 days and birdlings are	Origin- Taiwan	Grains in store whether in sacks or in bulk are vulnerable to bird infestation if left unprotected.	Ripening rice crop, threshing and sun drying of the grains; careless handling of grains in and around stores attract birds which feed on residues around mills and processing plants and spillage.	Bird-proofing using nets or wire screens on eaves, air vents and windows. Catching adults with mist nets, traps and foot glue , collecting eggs and deserting nests are most effective methods. Doorways could be provided with hanging plastic strips which

ready to fly in 17-19 days after hatching.	Once residence is established in a warehouse or building, they multiply rapidly especially if food is abundant. They peck sacks, eat grains and cause spillage and collapsing of stacks under severe cases of infestation in a warehouse or rice mill. Indirectly, they cause wetting damage to stored grains because nests built on gutters block the water flow. Their droppings, feathers and dead bodies contaminate foodstuffs, packaging and handling facilities. Droppings get infected by poisonous bacteria, (Salmonella) and disease-causing fungi.	deter birds but do not restrict entry and exit of personnel, vehicles and commodities. Sanitation of premises.

Table 5.2.1. Life history, distribution, infestation and main control of major fungus pest species in rice postharvest (continued).

Pest species	Distribu-ion	Postharvest conditions	Stage/time of infestation	Main control	Status of losses
Fungus *Fusarium*	Worldwide	Wet grain; fungi can thrive at low moisture contents; temperature	After harvest of rice; highly vulnerable to fungi	Drying, aeration, proper harvesting, and processing	Losses are most heavily incurred during harvest

chlamydos-porum	range favorable to fungal growth is 5-35oC but optimum is 25-35oC; fungal growth is inhibited by 20% carbon dioxide atmospheric gas composition but the composition will not prevent deterioration at high moisture content.	at high moisture content which must be reduced to at most 18% within 24 hours to prevent discoloration and deterioration and from then may be stored safely for no longer than 3 weeks.	of grains, modifying storage atmosphere and chemical treatment. The safe moisture content for paddy is 14%. Aeration prevents heat and respiration water accumulation. Kernel damage during harvesting and threshing becomes an entry point of storage fungi. More than 20% carbon dioxide is needed to prevent fungal deterioration of high moisture grain. Chemical treatment is not recommended.	coinciding with the rainy period as the grain may not be dried immediately. Flash drying or application of high heat for a few seconds will skin-dry the paddy and buy time for normal drying when good weather comes or when a suitable dryer becomes available.

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Annex 5.3

TABLE ON PESTICIDE RESIDUES

Table 5.3.1. Percentage reduction of residues brought about by various steps in processing raw grain for human consumption.

Insecticide	Rice in husk to husked rice	Rice in husk to polished rice	Rice in husk to cooked rice
Bioresmethrin	85	93	97
Bromophos	..	..	..
Carbaryl	93	98	99
Chlorpyrifos-methyl	..	..	..
Deltamethrin	..	..	..
Dichlorvos	90	96	100
Etrimphos	..	..	..
Fenitrothion	92	97	99
Fenvalerate	..	..	..
Malathion	90	97	98
Methlicriphos	90	97	99
Permethrin	..	..	..
Phenothrin	90	97	98
Pirimiphos-methyl	85	93	97
Pyrethrins	..	..	..

.. = not available

Source: FAO, 1982.

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CHAPTER II INSECT DAMAGE: Damage on Post-harvest

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1. Introduction

Insects are the most diverse species of animals living on earth. Apart from the open ocean, insects can be found in all habitats; swamps, jungles, deserts, even in highly harsh environments such as pools of crude petroleum (Imms, 1964). Insects are undoubtedly the most adaptable form of life as their total numbers far exceed that of any other animal category. The majority of insects are directly important to humans and the environment. For example, several insect species are predators or parasitoids on other harmful pests, others are pollinators, decomposers of organic matter or producers of valuable products such as honey or silk. Some can be used to produce pharmacologically active compounds such as venoms or antibodies. Less than 0.5 percentage of the total number of the known insect species are considered pests, and only a few of these can be a serious menace to people.

Insect pests inflict damage to humans, farm animals and crops. Insect pests have been defined by Williams (1947) as any insect in the wrong place. Depending on the structure of the ecosystem in a given area and man's view point, a certain insect might or might not be considered a pest. Some insects can constitute a major threat to entire countries or a group of nations. One prominent example is the tsetse fly that puts about 100 million people and 60 million head of cattle at risk in sub-Saharan Africa due to the transmission of trypanosomiasis (ICIPE, 1997).

Herbivorous insects are said to be responsible for destroying one fifth of the world's total crop production annually. One major reason why there are pests is the creation of man-manipulated habitats, that is, agroecosystems that fulfil man's needs, where crops are selected for their large size, high yield, nutritious value, and clustered in a confined area. This does not only satisfy man's demand, but provides a highly conducive environment for herbivorous insects at the same time. In the process of artificially selecting suitable crops for human consumption, highly susceptible plants for infestation by insects are also selected. Many of the crop varieties that were developed during the past 30 years produced high yields, but, they also had poor storage characteristics (Kerin, 1994). Insect pests are capable of evolving to biotypes that can adapt to new situations, for example, overcome the effect of toxic materials or bypass natural or artificial plant resistant, which further confounds the problem (Roush and McKenzie, 1987).

Provision of food has always been a challenge facing mankind. A major cornerstone in this challenge is the competition from insect pests. Particularly in the tropics and sub-tropics, where the climate provides a highly favourable environment for a wide range of insects, massive efforts are required to suppress population densities of the different pests in order to achieve an adequate supply of food. In the developing countries, the problem of competition from insect pests is further complicated with a rapid annual increase in the human population (2.5-3.0 percentage) in comparison to a 1.0 percentage increase in food production. Taking into consideration sudden problems caused by drought in places such as Africa, considerable losses of agricultural products add a serious burden to people's daily life.

The introduction of alien pests into new habitats due to the global increase of trade and transport causes another dilemma. When a pest is carried to a new geographical area, its natural enemies that keep it in check in its aboriginal home are normally left behind. This situation, in most cases, may lead to critical complications. One major example is the introduction of the spotted stemborer, *Chilo partellus* Swinhoe, into Africa coming from Asia early this century, that is now responsible for significant losses in maize and sorghum in many parts of Eastern and Southern Africa. The exotic pest may have also led to partial displacement of the native African stemborers such as *Sesamia calamistis* Hampson, *Chilo orichalcociliellus* Strand and *Busseola fusca* (Fuller) (Overholt *et al*., 1994; Kfir, 1997). Recent estimates of yield losses due to stemborers alone in sub-Saharan Africa are in the neighbourhood of 20-40 percentage of the potential yield (Youdeowei, 1989; Seshu Reddy and Walker, 1990). These losses indicate the importance of stemborers as a limiting factor affecting crop productivity in Africa.

Prostephanus truncatus (Horn) is another exotic storage pest native to Mexico. It has recently been introduced to Africa (McFarlane, 1988; Pike *et al*., 1992), where it is currently a more destructive pest of stored maize and cassava than in its native Central America (Dick, 1988). *P. truncatus* attacks maize before and after harvest. Adults bore into the maize cob causing severe damage and weight loss. In Tanzania, maize losses of up to 35 percentage may occur due to *P. truncatus* in 5-6 months if improperly stored (Mallya, 1992), and up to 60 percentage after nine months of storage (Keil, 1988); a situation that may result in a serious famine.

Subsistence grain production is essential for the growing population of Africa. Maize is the main staple food in sub-Saharan Africa. An area of 20.7 million hectares is planted to maize in the whole of the African continent, with an average annual production of 29 million tons (Christopher *et al*., 1996). In sub-Saharan Africa, three quarters of the total production of maize is consumed as human food, which is also the case with other cereals such as sorghum and millet. The area planted by sorghum in Africa accounts for 21.8 million hectares with an average yield of 0.78 ton/ha, while 18.5 million hectares are planted with different types of millet (finger millet, pearl millet, presom and foxtail millet), yielding an annual average of 0.61 ton/ha (FAO & ICRISAT, 1996). Several factors are responsible for this considerably low level of production, of which insect pests are chiefly involved. In the Kenyan highlands, total losses due to pests in maize were estimated at 57 percentage, with insect pests being more important than diseases (Grisley, 1997). In Zimbabwe, grain damage of 92 percentage in stored maize was reported due to insect pests. Treatment with malathion reduced the damage by only 10 percentage (Mutiro *et al*., 1992). In Namibia, up to 30 percentage losses in pearl millet production can take place due to the bush cricket, *Acanthopolus* *discoidalis* (Wohlleber *et al*., 1996).

Root crops, such as cassava and potatoes, and pulses, which are legumes grown for their edible seeds, provide the basic source of carbohydrates and protein for people in many parts of the African continent. The area planted to cassava in sub-Saharan Africa is estimated to be 8.9 million hectare producing 72 million tons annually (Sengooba, 1994). Insect pests, in addition to fungal diseases, are responsible for 50 percentage damage in cassava (Yaninek,1994). Pulses, described as the poor man's food (Aykroyd & Doughty, 1982), are widely planted in west Africa. Cowpea, for example, is grown extensively for seeds, pods and leaves in about 15 African countries, among which Nigeria and Niger produce half of the world's total crop (Pandey & Westphal, 1989). Cowpeas are attacked by a complex of insect pests, particularly towards the end of the planting season. In storage, the bruchid, *Callosobruchus maculatus*, causes the major losses. Infestations of stored cowpeas can be as high as 90 percentage in markets and in village stores (Alebeek, 1996).

Almost 80 percentage of these food crops are produced by small scale farmers and stored on the farm (Wongo, 1996). Due to poor storage structures and conditions, severe losses in quality and quantity of stored food are inflicted annually. Quantitative assessment of losses is difficult because of the high variability in infestation from year to year, however, estimates from several countries in Africa indicate an intense impact of insect pests (see table 1). In Kenya, the National Food Policy Document reported up to 30 percentage destruction of harvested maize due to pests during storage and handling (Wongo, 1996). In West Africa, up to 100 percentage damage to cowpeas may happen in a few months after storage due to the infestation of *C. maculatus* (Lienard & Seck, 1994). Such high levels of losses continue to take place because of poor threshing, cleaning, drying and storing techniques.

1.1 Magnitude of the problem

After the crop is harvested, it undergoes several operations that, if improperly done, may result in serious losses (see Laubscher & Cairns, 1983; Giga, 1987; Jonsson & Kashweka, 1987; Gwinner *et al*., 1996). As a start, it should always be recognised that an intact grain is an essential item for successful storing. Cracked or broken grains provide an entry point for infestation by insects and moulds during storage. Damage to grains may happen due to improper application of post-harvest practices such as threshing, drying or transporting (see Rowley, 1984; Dadzie, 1994; Simone *et al*., 1994). Threshing, which is the removal of grain from its protective case, may inflict a degree of physical damage to the grains (Laubscher & Cairns, 1983; Swamy & Gowda, 1987; Wilson, 1987). Millet for example is sensitive to threshing (see Appert, 1987; UNIFEM, 1988), therefore it is stored unthreshed and pounded on a daily basis according to the farmer's needs. Wongo & Pedersen (1990) found that threshed sorghum grains were more susceptible to *Sitophilus oryzae* than unthreshed grains. Maize, specially in wet regions, is normally stored in its shucks, but with modern varieties shucks are removed. In this case, proper care should be taken and insect repellents or antifeedants should be applied.

Crop transportation is another process where losses are common. Physical damage, grain spilling or deterioration might occur, specially if transport is prolonged. However, such losses can be avoided through proper packing, loading and handling of the crop (see Youdeowei & Service, 1983; Gwinner *et al*.,1996)

Crop products are eventually stored for varied periods of time depending on market demand, size of production and the farmer's needs. Storage is the most important and critical post-harvest operation. Deterioration of the grain quality during storage can be due to improper storing conditions, which leads to contamination with fungi or insect infestation. A primary source of infestation of the stored crop is the field where the crop has grown. In many cases, infestation starts in the field. In the case of the potato tuber moth (*Phthorimaea operculella*), adult females lay eggs on the plant leaves early in the season before the crop is harvested. With cowpeas, only a 1-2 percentage initial field infestation by *C. maculatus* may result in 80 percentage of the pods attacked after 6-8 months in storage (Youdeowei, 1989). The problem can be more complex if the crop is planted or stored near by old granaries, which is the case with most of Africa's small scale farmers. The infestation can easily move to and from storage sites. Moreover, using the same bins year after year without proper hygiene, provides a continuous chain of infestation. Insects can hibernate or even continue to feed on wooden structures of the store or hide between holes and cracks in the walls. They can then reinfest the new crop in the same store and resume feeding.

Storing generally leads to a degree of quality change in the product due to seed's respiration, which depletes seed's nutrients over time (see Hodges, 1989; Piergiovanni *et al*., 1993; Kadlag *et al*.,1995). Combined with attack by insects and mould, rapid deterioration of the crop quality might occur. In case of whole cereal grains, a rise in temperature is expected due to respiration, which might also occur due to insect or fungal activity. Heating leads to moisture condensation in cool areas within the grain mass. This in turn encourages further fungal growth and insect infestation (see Appert, 1987; Imura & Sinha, 1989). The exact safe moisture contents varies slightly between the different grains, however, moisture should not exceed the range of 12-13 percentage for most cereals. For pulses, intact dry grains are relatively resistant to damage, but moist, broken, split or shelled pulses are highly sensitive to infestation. On the other hand, very dry pulses with a moisture content less than 11 percentage have a breakable seed coat that cracks easily (see Youdeowei & Service, 1983; Gwinner *et al*., 1996).

In most parts of sub-Saharan Africa, harvesting of maize and other cereals is done by hand. Farmers have to wait until the crop is sufficiently dry. Some farmers leave the plant standing in the field until it dries up. This, however, might not be adequate as the longer the plant stays in the field the riskier it gets. Infestation by post-harvest pests are mainly encouraged during this stage. In Zimbabwe, for example, four months may elapse after physiological maturity of maize and before harvesting and treating the crop, during which 9.1 percentage of potential yield is lost due to attack by pests (Mvumi *et al*., 1995). Alternatively, maize might be picked up when it is still in need for drying, specially in the rainy regions of the tropics. In this case, quick drying should take place as soon as the crop is harvested. In drier areas, getting rid of excess moisture may be much easier than in wet tropical regions.

Traditional methods usually provide cheap and feasible ways of post-harvest handling of the crops. Farmers adopt different methods for grain drying depending on the farmer's environment and socio-economic status. Sun drying, for example, is a widely practised method wherever there is enough sunshine and little rains. In this case, grains are spread on wide plastic sheets to isolate the crop from soil dampness, and to make it feasible to move the crop later after drying or in case of sudden rains. Continuous checking should be done on the stored crop to investigate the moisture content, presence of pests, moulds or deteriorating grains. However, farmers may use fire to dry the grains, specially in the rainy areas of the tropics where sun drying is not applicable. A more appropriate method is the use of "bush dryers", where air is heated up by burning wood and then circulated through metal tunnels. Grains are spread on grids on top of the tunnels. One disadvantage with this method is that temperature might not be well controlled. Caution should be maintained as abrupt or overdrying will cause loss of nutrients or germination capacity. Temperature should not exceed 43^0C for cereal seeds and 35^0C for legumes. Higher temperatures (up to 60^0C) can be used to dry cereals meant for consumption (see Gwinner *et al*., 1996).

A more controlled sun drying method is the use of solar dryers, where the product is spread on grids and placed inside a cylindrical metal tunnel (see Mbengue *et al*., 1987; Odogola, 1994). The tunnel is painted black to absorb heat and contains an opening from one side to let in air. A chimney is provided on the other end to serve as air and moisture outlet (see Ekechukwu & Norton, 1997). Inflow of air can be regulated through the entrance, thus adjusting air temperature inside the tunnel. Solar dryers are adequate devices, specially for smaller quantities of products, in which grains are fairly well protected against adverse weather conditions and the invasion of insect pests. Continuous improvements in the structure and utilisation of solar dryers are taking place in Africa (Bechis *et al*., 1997; Ekechukwu & Norton, 1997), however, the use of solar dryers does not seem to be as wide spread as other drying methods in Africa, probably due to the relatively high cost and their limited capacity. Solar dryers may not be applicable in highly humid or cloudy areas of the tropics (but see Asota, 1996;

Ekechukwu & Norton, 1997).

1.2 Storage and Losses

1.2.1 Small scale storage structures

At a small farming scale, grains are stored traditionally in different styles of containers, depending on the farmer's socio-economic status and his environment (see Audette & Grolleaud, 1983). Structures used traditionally are often inexpensive and environmentally motivated. Subsistence stores may be made out of clay, thatch, mud, wood or stones (see Rukuni *et al*., 1988; Bani, 1991). Larger granaries, meant for storing large quantities for longer periods of time, may be built with more permanent structures, as in case of metal silos or wooden granaries with iron sheet roofs. Open storage is probably the most common system used traditionally in sub-Saharan Africa, specially in the humid areas, where the crop is harvested with high moisture contents and continues to dry in the store. Open structures can simply be wooden platforms on stakes or posts, on top of which the crop rests either in heaps or regular layers. A straw roof is usually provided to protect the crop from rains. Farmers may use fire underneath this structure for insect control and to provide further drying. An even simpler method is hanging the crops in frames or sheaves to tree branches, which is applicable for smaller quantities that would be rapidly consumed. Open storage provides natural ventilation and allows for further drying of the crop. It also discourages development of fungi due to continuous aeration. However, open storage does not provide adequate protection against insect pests or other animals such as birds and rodents (see Appert, 1987; Gwinner *et al*., 1996).

A more protected storage system, adequate for the semi-arid regions of Africa, is the use of "cribs" (see FAO, 1985; Appert, 1987). Cribs are wooden four-cornered structures with ventilated sides. The sides are covered with woven straws, grass stalks or wire netting materials and a thatch roof is provided on top. An elevated floor is made out of wooden branches and attached to the posts about 50 cm above ground. This structure proved to be excellent for drying maize in Nigeria, where it is made out of bamboo and used mainly for drying and storing maize cobs. It is also used in other humid regions of sub-Saharan Africa with considerable success.

In the dryer regions of Africa, where crops can be harvested with satisfactory low moisture contents, more closed types of granaries are used. Different sizes and types of such closed structures are widely spread in Africa, where they can be made out of mud, woven straws or a mixture of mud and chopped straws (see Figure 1). Farmers in the semi-arid zones of sub-Saharan

Africa, such as Mauritania, Senegal, Mali, Niger and Chad, use a mixture of clay or mud and straw called "Banco" to build concealed granaries. Banco granaries can be four-cornered, spherical, with a straw roof containing a protecting lid, or in the shape of a cone with the tip pointing downwards and resting on a foundation of stones. Grains inside these banco granaries are well protected against rains and the invasion of insect pests. If the structure is well built and maintained, insect pests would find it very difficult to survive inside due to the lack of oxygen. Granaries made out of mud or clay provide a cool environment that keeps grains viable for germination. This structure is appropriate for dryer areas of Africa where sudden heavy rains are unlikely. However, Banco granaries require good maintenance such as filling cracks, which are common with mud structures, sealing holes or fissures and thorough cleaning.

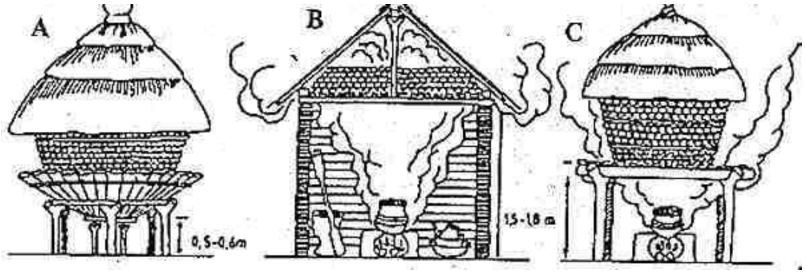

Figure 1: Traditional maize storage systems in the southern region of Togo (Pantenius, 1988)
(A: noy-heated granary; B: Regularly heated in house storage; C: Irregularly heated granary)

In some parts of Africa, such as Morocco, Mauritania, Nigeria, Chad, Cameroon and Somalia, grains are stored underground (see Bartali *et al*., 1990; Bakhella *et al*., 1993; Lemessa & Handreck, 1995), however, it is not as widespread in the African continent as it is in India. In India, an underground pit, 2-2.5 meters in depth, is dug in soil and a fire may be lit to dry up the walls. Afterwards, bricks can be used to build a wall or otherwise walls are plastered with clay and the bottom is covered with chopped straws or husks. The pit is sealed from the top with a roof at or slightly above ground level. Underground storage provides excellent protection to the stored products specially in arid areas, however, it may also be applicable in rainy areas provided that the entry of both ground and rain water is prohibited through careful cementing and lining of the walls (see Mantovani *et al*., 1986; Smith & Sanders, 1987).

Smaller amounts of grains can be stored in different types of containers, calabashes, clay pots, sacks or woven baskets (see Kennedy & Devereau, 1994). Such containers allow for frequent consumption of the product on a daily or weekly basis. Baskets can be made out of local plant materials and may themselves be placed inside the granary or in the farmer's house. Jars made out of clay are also used to store beans or cowpeas, as in west Africa, where they are usually placed inside the farmer's house. Jars have a narrow opening and are hermetically sealed with a stone on top. Hermetic storage leads to depletion of oxygen and accumulation of carbon dioxide inside the container, which eventually lead to elimination of insect pests (see Mantovani *et al*.,1986).

Traditional storing systems can be satisfactory if built and maintained properly. Recently, farmers in sub-Saharan Africa started adopting newer storing systems. Concrete or metal silos, with capacities up to 5 tons of cereals, are now used in many parts of the continent among medium scale as well as large scale farmers. The use of plastic sacks, bag storage, prefabricated iron halls and flexible plastic silos are increasingly gaining ground among farmers for short-term storage (see Peterson & Simila, 1990; Compton *et al*., 1993; Bartali, 1994). Large warehouses and metal silos, run under state control, are common among co-operatives and traders. Centralised storing has emerged due to the change in the social and economic structures of the farm community. Centralised stores can be large metal constructions that may contain up to 3000 tons of produce. Though the adoption of bulk storage has led to a significant decrease in the amount of food stored by small scale farmers for emergencies, it does form an important function in sustaining sufficient food supply. Bag storage in large warehouses is a suitable system for bulk storage in the tropics and sub-tropics (see Carvalho *et al*., 1994; Cabrera & Lansakara, 1995)

1.2.2 Warehouses

Warehouses are practical and appropriate structures for storing and protecting food crops (see Cabrera & Lansakara, 1995; Gwinner *et al*., 1996). Stored crops can be easily maintained and treated, transported to and from the warehouse and regularly checked for insect or fungal infestation. Good and effective warehouses are simple four-cornered buildings with ample ventilation. It is always preferable to build a concrete floor one meter above the ground level to guarantee adequate isolation of ground moisture or water flooding. Concrete walls are the most suitable if properly built with no cracks or holes to discourage insects. Aluminium sheets provide adequate roofing and are better used than corrugated iron to avoid raising of temperature. Appropriate and controlled ventilation is essential for successful storage in warehouses. Lower and upper ventilation openings for inlet and outlet of air should be fitted with wire mesh or grids , but with the possibility for sealing to allow for secure pesticide fumigation. A well designed and maintained drainage system is important for preventing rain water from affecting the stored produce (For more details on warehouse structures see Bisbrown, 1992).

Sanitation in stores is a key factor for preserving products in good condition (see Suss & Locatelli, 1993; Rotundo *et al*., 1995). Sanitation is a simple practice that can save the product from losses due to infestation. Sanitation starts with the removal of any unnecessary objects from the store. Thorough cleanliness of the store through sweeping, removal of left overs and prompt burning the trash is essential before receiving in a new lot. Clearing the surroundings is a recommended practice, in which grasses, shrubs and any kind of vegetation around the building should be cut down thoroughly. The produce should be checked on a regular basis and the presence of any insect pests, rodent debris, damaged cobs or rotten grains should be recorded and dealt with accordingly (see FAO, 1985; Cruz & Diop, 1989; Vinuela *et al*., 1993).

1.3 Insect damage

Insect pests inflict their damage on stored products mainly by direct feeding. Some species feed on the endosperm causing loss of weight and quality, while other species feed on the germ, resulting in poor seed germination and less viability (Malek & Parveen, 1989; Santos *et al*., 1990). Thus, due to damage done by insects, grains lose value for marketing, consumption or planting. Most storage pests are able to increase in numbers drastically within a relatively short time. At an early stage of development, population growth takes the "exponential" form, where the number of insects at a given time can be expressed by this equation: $N_t = N_0 e^{rt}$, where N_t is the number of insects at time t, N_0 is the original number of insects and *r* is the rate of intrinsic increase of the population (Figure 2). However, this pattern of growth would eventually reach an upper plateau due to depletion of food and intraspecific competition (Figure 3). In that case, the number of insects at any given time can be expressed by the equation:

$$N_t = K /(1+((K- N_0)/N_0)\ e^{-rt})$$

where *K* is the maximum number of insects that the environment can support, which is also known as the "carrying capacity" of the environment. In grain stores, *K* is not constant and will decrease as the food is consumed. Eventually, the insect population will start to decline due to the decrease in food availability and competition among individuals, which is when a proportion of insects will have to migrate and search for other food sources (Figure 4).

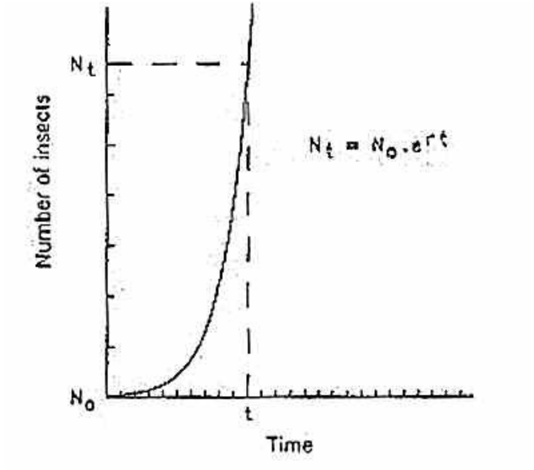

Figure 2: The theoretical exponential increase of an insect population (Haines, 1991)

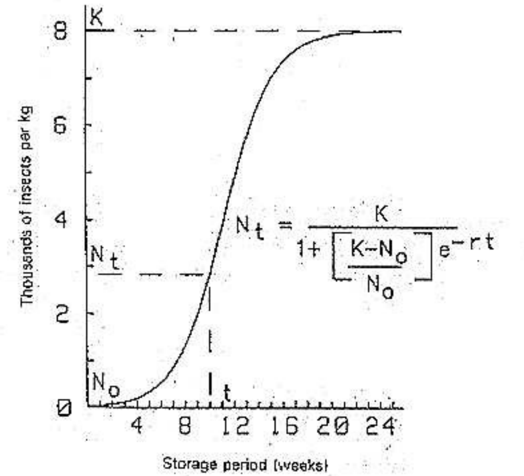

Figure 3: The logistic growth of an insect population in a restricted environmen (Haines, 1991)

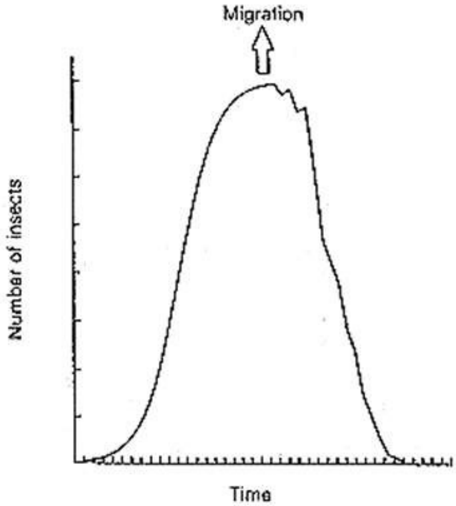

Figure 4: Insect population growth in a restricted environment without food replenishment (Haines, 1991)

In addition to direct consumption of the product, insect pests contaminate their feeding media through excretion, moulting, dead bodies and their own existence in the product, which is not commercially desirable. Damage done by insect pests encourages infection with bacterial and fungal diseases through transmission of their spores (Cravedi & Quaroni, 1982; Ekundayo, 1988; See also Dunkel, 1988). The presence of insects also raises the product temperature, due to their feeding activity, resulting in "hot spots" (see Appert, 1987; Mills, 1989). These spots in turn lead to concentrating of humidity within the product, thus stimulating seed deterioration and further fungal activity. There are a wealth of studies examining the effect of insect pests on grain contents. In Brazil, for example, Santos *et al*. (1990) showed that the presence of *Sitophilus zeamais* and *Sitotroga cerealella* in maize grains led to a reduction in germination with increasing developmental stage of the insects, from 13 percentage at the egg stage for *Sitophilus zeamais* and 10.9 percentage for *Sitotroga cerealella*, to 93 percentage and 85 percentage at the adult stage for *S. zeamais* and *S. cerealella* respectively. In India, Sudesh *et al*. (1996 b) found that infestation of wheat, maize and sorghum grains with single or mixed populations of *Trogoderma granarium* and *Rhyzopertha* *dominica* resulted in substantial reductions in the contents of total lipids, phospholipids, galactolipids, and polar and nonpolar lipids, while Jood *et al*., (1995) recorded a significant decrease in essential amino acids in the same crops due to mixed infestation with the same two pests, with maximum reduction found in methionine, isoleucine and lysine. Similarly, Kumar *et al*., (1996) recorded a substantial reduction in starch in parboiled cassava chips due to infestation with *Sitophilus oryzae* and *Rhyzopertha dominica* as compared to the uninfested chips. In Nigeria, Okiwelu *et al*. (1987) recorded high level of moisture, combined with a decrease in germination ability of maize due to infestation by *Sitophilus zeamais*, while Mbata (1994) showed that infestation of bambarra groundnuts (*Vigna subterranea*) with *Callosobruchus subinnotatus* reduced seed viability and increased free fatty acids and peroxides, which are indices used in measuring biochemical deterioration.

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CHAPTER II INSECT DAMAGE: Damage on Post-harvest

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2. Major insect pests of stored foods

Two major groups of insects harbour the mostly economically important post-harvest insect pests: Coleoptera (beetles) and Lepidoptera (moths and butterflies). Several Coleopteran and Lepidopteran species attack crops both in the field and in store. Crop damage by Lepidoptera is only done by the larvae. Several lepidopteran larvae entangle the feeding media through silky secretion which turns products into entwined lumps. In the case of Coleoptera, both larvae and adults often feed on the crop and the two stages are responsible for the damage.

Post-harvest insect pests may be primary, i.e. able to attack intact grains such as the genus *Sitophilus*, while others are secondary pests, attacking already damaged grains or grain products such as the genus *Tribolium*. The following is a list of the most common post-harvest and storage pests, their biology, distribution and common host plants.

2.1 Coleoptera

The order Coleoptera is the largest order of insects and contains the most common and important stored product pests. Adults have their forewings modified as hard elytra. Beetles inhabit a wide variety of habitats and can be found almost everywhere. Those associated with stored products exhibit different behavioural types; some are primary and secondary pests feeding directly on the product, others are general scavengers, fungus feeders, wood borers or predators of other insects. arvae lack the presence of prolegs (abdominal legs) and only possess true legs on the three thoracic segments. Larvae of a few species may also lack true legs, e.g. *Sitophilus* spp.

2.1.1 Curculionidae (Snout Beetles)

This is a large group of beetles that contains some of the most serious crop and stored grain pests. Members of this family are characterised by the form of the snout (rostrum) which is elongated in most species. This family contains the most destructive stored grains pests in the world.

The Rice Weevil: *Sitophilus oryzae* (L.) (=*Calandra oryzae* L.)

Figure 6: 
Rice weevil

The Maize Weevil: *Sitophilus zeamais* Motsch. (=*Calandra zeamais* Motsch.)

Figure 12: 
Maize Weevil

The Granary Weevil: *Sitophilus granarius* (L.)

The first two species are major primary pests that have a virtually cosmopolitan distribution throughout the warmer parts of the world. The rice weevil (*S. oryzae)* mainly attacks rice and wheat in stores, while *S. zeamais* is a serious primary pest of stored maize. However, both species are able to develop on all cereals, dried cassava and other processed food products. The two species are morphologically identical. In Europe, the two species are replaced by the granary weevil, *S. granarius*, which is wingless and can be distinguished by the sculpturing on the prothorax and elytera.

Natural history:

The life cycle and damage caused by both *S. oryzae* and *S. zeamais* are similar. However, *S. zeamais* is a little larger (5 mm in length) and a very active flier. Infestation usually starts in the field and later continues in the store. Both species are capable of inhibiting reserved breeding grounds near the threshing floors that are normally full of plant residues, where the population builds up in before moving to granaries. Adult females chew grains creating a small hole in which they lay eggs and then seal the hole with a secretion. The optimum temperature for oviposition is around 25^{O}C and at grain moisture contents of over 10 percentage (Brich, 1944). Larvae tunnel in grains and are responsible for most of the damage. pupation takes place inside the grain and adults chew their way out through the outer layer of the grain. Adults live for 5-6 months depending on the temperature and humidity of grains (see Kuschel, 1961; Giles, 1969; Mound, 1989).

S. oryzae adult females can lay more than 500 eggs during their lifetime. The optimal temperature for development is 30^{O}C with maximum oviposition taking place at 18 percentage humidity. The rice weevil can live without food for 6-32 days depending on temperature. This species is highly affected by changes in temperature; all stages die in about a week at 0^0C. On the other hand, *S. zeamais* tolerates lower temperatures than *S. oryzae* and can live for 37 days at 0^0C (see Floyd, & Newsom, 1959; Stoyanova, 1984; Zewar,1993).

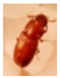
Natural history:

The granary weevil, *S. granarius*, lives for one full year at $20\text{-}25^0$C and a relative humidity of about 15 percentage. Biology of this species is similar to the other two species, but it is unable to fly, thus restricted to the store (see Dobie & Kilminster,1978; Stein, 1994). This species prefers softer grains such as wheat, rye and barley, as food and habitat. In addition, *S. granarius* has a high resistance to low temperatures; adults can stay alive for up to two months at -5^0C. Insects can be controlled if exposed to 50^0C for 35 minutes which will kill all stages (see Pradzynska, 1995). Buchi (1989) showed that *S. oryzae* is displacing *S. granarius* in Switzerland.

2.1.2 Tenebrionidae (Darkling Beetles)

This is a large and varied group of insects that contains more than 10,000 species of which about 100 are associated with stored products. Most of the tenebrionids are black or dark brown in colour and mainly phytophagous. Adults are characterised by the tarsi of the hind leg with only four segments. Infestation by these beetles results in an unappealing smell due to the secretion of benzoquinones from abdominal glands. The following tenebrionids are serious secondary pests of stored grains and flour.

The Red-Rust Flour Beetle: *Tribolium castaneum* Herbst.

Figure 9: 
Red-Rust Flour Beetle

The Confused Flour Beetle: *Tribolium confusum* J. du Val

These two species are probably the most common secondary pests of all plant commodities in store throughout the world. Several other species of *Tribolium* are occasional minor pests and can be found in almost every store containing infested cereals or cereal products, specially in tropical and sub-tropical climates. Both species attack maize, wheat, flour and other foodstuffs, but *T. confusum* does not seem to be as common as *T. castaneum* in tropical climates (see Hill, 1987; Mills & White, 1994). Members of genus *Tribolium* are known to produce toxic quinones which contaminate flour and flour products (Gorham, 1989). Damage is done by both larvae and adults specially to broken or damaged grains.

Natural history:

T. castaneum adult females lay small, cylindrical, white eggs scattered in the product. At an optimum temperature of 32.5^{0}C, females lay up to 11 eggs daily. Larvae are yellowish with a pale brown head, and they live inside grains until pupation. Adults are about 3-4 mm long and can live for a year or more. Females are highly fecund and able to lay a maximum of 1000 eggs during a lifetime, with 40^{0}C and 22^{0}C as upper and lower limits for development. This species is also highly tolerable to humidity as low as 11 percentage. Adults are highly adapted to feed on a very wide range of commodities and perfect colonizers of new habitats. In tropical conditions, this species is dominant to *T. confusum* (see Howe, 1962; Dawson, 1977).

The confused flour beetle, *T. confusum*, is often confused with *T. castaneum* but they can be separated using the last three segments of the antenna which are much larger than the rest in *T. castaneum* and forming a club, while the last five segments in *T. confusum* gradually enlarge towards the tip. Just like *T. castaneum*, the confused flour beetle develops in crushed grain products and a constant inhabitant of flour mills specially in the temperate regions of the world. In contrast to *T. castaneum*, this species is not able to fly, but has a long life span that can reach three years under moderate climatic conditions (25-30^{0}C) (see Sokoloff, 1972; 1974; 1977).

2.1.3 The Yellow Mealworm Beetle: *Tenebrio molitor* L.
Natural History:

Tenebrio beetles are black or dark brown and they feed as larvae and adults on grain products. *T. molitor* is an important post-harvest pest and occurs spread all over the world. Adults are elongate, 16 mm long, and active fliers. Females can lay up to 600 eggs during its lifetime. Larvae firstly eat the germs of stored grains and can feed on a wide variety of plant products such as ground grains, flour, tobacco and foodstuffs. Larvae are very voracious and highly resistant to low temperature; they can remain alive for 80 days at -5^0C.

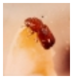
Other tenebrionids are less common polyphagous pests around the globe such as *T. destructor*, *T. madens* and *Palorus depressus*.

2.1.4 Bostrichidae (Branch and Twig Borers)

Members of this family are elongate with the head bent down ventrally to the thorax. Adults are characterised by rasp-like hooks on the pronotum. Most of the species are borers in wood or roots. Wood boring activities of these beetles may weaken timbers or wooden walls of the stores. This family contains two serious stored grain pests:

The Lesser Grain Borer: *Rhizopertha dominica* (Fabricius)

The lesser grain borer (*R. dominica*) attacks a wide range of stored cereals. It can be found attacking cassava, flour and other cereal products and is also able to attack rough rice grains. The pest originated from South America, but is now found in all the warmer parts of the world. This species is a serious pest in Australia, from where it was carried to the USA and other parts of the world during World War I. Adults of this species are tiny dark beetles, 2-3 mm in length, and are very voracious with a long life span. Females may continue to lay eggs for four months and are able to lay up to 500 eggs at 34^0C. They feed externally on grains and lay eggs on their surface. Larvae feed either externally or inside the grain and pupation takes place within the eaten grain. Larval development is relatively faster when fed on whole grains than on flour. Both adults and larvae eat the endosperm leaving powdered grains. This dust can accumulate on the walls of the warehouses and it is a sign of high infestation. Though are not common on pulses, adults are able to breed in grains that are too dry for fast development of *Sitophilus*. At 34^0C, development is possible on grains with moisture contents as low as 9 percentage, and they can daily destroy grains equal to their body weight (see Birch, 1945; Fisher, 1950; Aitken, 1975).

Figure 5: 
Lesser Grain Borer

2.1.5 The Larger Grain Borer: *Prostephanus truncatus* (Horn)

The larger grain borer is a primary pest, often attacking maize in the field towards the end of the season, then continuing in the store. *P. truncatus* is a serious pest of maize in Central America and many parts of Africa. It was first reported in East Africa in 1981 and in 1984 in West Africa. Since then, it has spread rapidly in the African continent where it has become a major pest of stored maize and dried cassava. In Togo, soon after the discovery of *P. truncatus*, mean losses of 30.2 percentage were reported on stored maize six months after storage (Pantenius, 1988). Stored dried cassava is also known to become heavily infested by *P. truncatus*, which may lead to cross infestation of maize. Hodges *et al*. (1985) reported 70 percentage loss in dried cassava roots after four months of storage due to this species.

Figure 10: 
Larger Grain Borer

Figure 11: 
Larger Grain Borer

Adults of *P. truncatus* bore in maize grains and produce large quantities of dust, in which their larvae seem to feed and pupate. This species proved to be highly tolerable to low moisture contents in grains. Field studies in Tanzania recorded heavy infestation in maize at a moisture content as low as 9 percentage. The introduction of this pest in Africa has influenced the economy of several countries, specially those depending on exporting of maize. Many countries now refuse to import maize from areas infested with the larger grain borer (see Boeye *et al*., 1992).

2.1.6 Bruchidae (Seed Beetles)

Most bruchids are short, stout-bodied beetles with a short forewing not reaching the tip of the abdomen. Adults are characterised by their compact hairy bodies and relatively long antennae. Larvae of most species feed inside seeds and some develop in stored dry grains or legumes. All bruchids are phytophagous with most species able to avoid feeding on seed covers that contain toxins. This family contains several important field and stored crop pests.

2.1.7 The Cowpea Weevil: *Callosobruchus maculatus* (Fabricius)

This is an important pest that mainly attacks beans of various species, and can alternatively attack other pulse crops (see

Lienard & Seck, 1994). This species originated in Africa but is now found all over the tropics and sub-tropics. Adults are 2-4 mm, brownish with black markings. They have a short life span of about 12 days and do not feed. Two forms of this species have been identified; the active (flying) form and the flightless form. The flying form disperses and colonises cowpea fields. Adult females lay about 100 eggs glued to the seed surface or to pods. Larvae tunnel inside the seed where the entire development takes place. In the store, the normal form continues to reproduce until the end of the storage season. The flying form appears again in response to disperses to new locations. This species causes major problems in Nigeria and Niger, where most of Africa's cowpeas are produced (see Alebeek, 1996). Other species such as *C. rhodesianus* and *C. subinnotatus* may also be important in some parts of Eastern and Central Africa (see Gillon *et al*., 1992; Giga *et al*.,1993).

2.1.8 The American Bean Weevil: *Acanthoscelides obtectus* Say (*Bruchus obtectus* Say).

Figure 7: 
American Bean Weevil

This species is widely distributed in Africa, Central and South America, New Zealand, USA and Southern Europe. *A. obtectus* exhibits high tolerance to varied degrees of temperature, thus, it is found in cool highland areas as well as the warmer parts of the tropics. It mainly attacks beans of various types and other pulse crops. Adults are grey and oblong in shape, with the body covered by yellowish green hairs. Females are almost twice as large as males. Infestation starts in the field when females lay eggs on the mature beans in plant pods. Larvae are tiny with strong mandibles and feed inside the seeds where life cycle is completed. Adults exit the seed through round holes about 2 mm in diameter (see Wendt, 1992).

2.1.9 The Groundnut Borer (Seed Beetle): *Caryedon serratus* (Olivier) = (*C. gonagra* (F)).
Natural history:

This species is common in West Africa and parts of South Eastern Asia where it probably originated. Adults are 4-7 mm in length with distinct serrate antennae. *C. serratus* attacks mainly groundnuts and other legumes, pods and seeds of Acacia tress and tamarind. Adult females glue their eggs on groundnut seeds soon after harvest. Larvae bore inside seeds making a large hole in the cotyledon. Pupation may take place inside or outside the kernel in paper-like cocoon attached to the pod. *C. serratus* is a serious pest of stored groundnuts in West Africa (see Delobel 1995; Satya *et al*, 1996).

Several other bruchids are known as post-harvest pests in different geographical areas of the world:

Species	Remarks
Callosobruchus chinensis (Linnaeus)	Originated in tropical Asia, but is currently distributed all over the tropics and sub-tropics. It attacks chickpeas, cowpeas and green grams. Life cycle and damage is very similar to *C. maculatus* (see Parajulee *et al*., 1989).
Callosobruchus subinnotatus (Pic)	Formerly described as a strain of *C. maculatus*. It is found in West Africa where it attacks "Bambarra groundnuts" (see Mbata, 1994).
Callosobruchus theobromae (Linnaeus)	A pest of pigeon pea in India and was recorded in a groundnut field in Nigeria.
Bruchidius atrolineatus (Pic)	Mainly a field pest of cowpeas but eggs and larvae are taken to storage after harvest (see Monge *et al*., 1988). (Huignard *et al*., 1985) recorded 90% pods infestation from Niger in West Africa.
Bruchus atomarius L.	Distributed in Europe and parts of Asia. Attacks beans, peas and lentils.
Bruchus lentis Frol	A monophagous species that occurs in some warmer parts of the world. This species infests lentil seeds in stores (see Mozos, 1992).
Bruchus pisorum L.	Reported from Europe, Canada, South East Asia and former USSR. A monophagous species that attacks ripe plant pod and can only develop on peas (see Almasi, 1990).
Bruchus rufipes Herbst	Distributed in central and southern Europe, Asia and south Africa. Attacks vetch seeds in which they develop (see Bakoyannis, 1988).
Bruchus dentipes Baudi	This species occurs in bean cultivating area. Infests seeds of broad beans and other species of the genus *Vicia* (see Bakoyannis, 1988; Wendt, 1992).

2.1.10 Cucujidae (Flat Bark Beetles)

Members of this family are small flattened beetles, mostly found under the bark of trees or in tunnels made by other beetles. This family contains one common pest of stored grains.

2.1.11 The Red Rust Grain Beetle: *Cryptolestes ferrugineus* (Stephens)

Adults of this species are oblong flattened small beetles (1.5-2 mm long), with the head and prothorax relatively big and conspicuous. *C. ferrugineus* is a widespread secondary pest of stored grains, specially in the humid tropics. The genus *Cryptolestes* was reported to be of economic importance towards the end of the maize storage season in Togo (Pantenius, 1988). However, it might not be as serious as other pests in stores, often following an infestation by other insects. It usually attacks the germs of broken or cracked grains thus reducing germination. Other species such as *C. pusillus* (Schonherr) and *C. pusilloides* (Steel and Howe) are common in humid areas of the tropics (see Banks, 1979).

Silvanidae

This family was formerly included in Cucujidae. It includes two important species:

The Saw-toothed Grain Beetle: *Oryzaephilus surinamensis* (L), recognized by the toothed lateral margins of the pronotum.

The Merchant Grain Beetle: *Oryzaephilus mercator* (Fauvel), which is found in association with *O. surinamensis*.

Both species are virtually cosmopolitan and they infest a wide variety of stored grains, processed foodstuff and other food products. They are mainly secondary on stored products following more destructive primary pests. However, *O. surinamensis* prefers cereal products while *O. mercator* is more frequent on oil-seed products and more temperature sensitive. They enter damaged grains and feed specially on the germ. Optimum conditions for development are between 30- 35^{0}C and 70-90 percentage relative humidity.

Natural history:

Adults are 3 mm flattened narrow winged beetles but they rarely fly. Females lay their eggs loosely within the stored products. Larvae are free living and start by feeding on the embryo and the endosperm. They require 60-90 percentage humidity for optimal development, and neither species cannot develop or breed at temperatures less than 19^{0}C. All stages die in ten minutes if exposed to 55^{0}C (see Howe, 1956; Halstead, 1980).

2.1.12 Dermestidae (Skin Beetles)

Members of this family are ovoid in shape with hairy or sometimes scaly bodies. Larvae are very hairy. When stores are infested, these setae may be seriously hazardous if inhaled by workers. This family contains a number of very destructive and economically important species. One of the most serious stored product pests that belongs to this family is the Khapra Beetle: *Trogoderma granarium* Everts. Apparently the only phytophagous species in the genus *Trogoderma*. A native of India, the Khapra beetle is now found in most parts of the world specially hot and dry areas. Adults are oval, red brown insects with a dark thorax. Adult females may lay up to 120 eggs within the stored products. Larvae are considered primary pests as they attack undamaged grains and seeds and bore into stored pulses. They are highly mobile, and in the absence of food they enter a diapause that might last for more than two years, in which they can be highly resistant to the application of pesticides or fumigation. Adults are 3-4 mm long, dark wingless beetles that do not feed. Populations of this pest build up rapidly, specially in the hot humid tropics. This species was apparently eradicated in the United States and the former Soviet Union. It also seems to be absent from East and southern Africa (see Banks, 1977; Rebolledo & Arroyo, 1995; Sudesh *et al*., 1996 b).

2.1.13 Anobiidae

Anobiids are cylindrical pubescent beetles, 1-9 mm in length. The head is usually concealed from above by the hoodlike pronotum. Most anobiids live in dry vegetable materials or bore in wood, while others are fungus feeders. About 1000 species of Anobiidae are known, most of which are found in the tropics. The following are two widespread storage pests belonging to this family.

The Cigarette Beetle: *Lasioderma serricorne* (Fabricius) is a common pest of stored cereals, cocoa beans, tobacco, ground nut, peas, beans, flours and other foodstuffs. Originally from South America, it is now found in most of the warmer parts of the world. This species is notorious for attacking a wide range of intact cereal grains, pulse seeds and food stuffs.

Natural History:

Adults can breed anywhere at optimum temperatures of around 28-32^{0}C and a relative humidity of 75 percentage. Newly hatched larvae are very active and responsible for most of the damage. Adults are small brown beetles and the only damage they cause is due to their emergence holes. This pest can be controlled if exposed to temperatures below 18^{0}C. At 55^{0}C, all stages die in two hours (see Howe, 1957; Lefkovitch & Currie, 1967).

The Drug Store Beetle: *Stegobium paniceum* (Linnaeus) Another widespread pest that infests several cereals, but less common than *L. serricorne* in the tropics.

Natural history:

Adults are 3.5-4 mm in length, brown hairy beetles, and they do not feed. Females lay about 75 eggs and optimum conditions are 30^{0}C with 60-90 percentage relative humidity. Larvae are active feeders and they can be indiscriminate in their food choice, biscuits, macaroni, dry fruits and other products. This species is commonly found in the temperate areas of the world (see Lefovitch, 1967; Haines, 1991).

2.1.14 Trogossitidae (Bark Gnawing Beetles)

Trogosittids are brownish beetles. The Caddle (*Tenebroides mauritanicus* (L.)) is a common pest in granaries. Observed for the first time in Mauritius, it is now considered a cosmopolitan pest associated with a wide variety of commodities. *T. mauritanicus* attacks mainly cereals, oilseeds and their products. Both adults and larvae are highly tolerant to very cold conditions. Though larvae are known to predate upon other insects, both adults and larvae feed directly on stored food and larvae are able to tunnel in wooden walls of the store to create a pupation chamber (see Girish & Pingale, 1968; Aitken, 1975).

2.2 Lepidoptera

Lepidoptera is the second most important order of insects pests of stored products. Adults are active flyers with two pairs of scaly wings. Mouthparts of the adults are modified to suck plant nectar or other fluids and are not able to chew, while those of the larvae possess well-developed mandibles. Larvae are distinguished from beetle larvae by their pseudopods (false legs) on some of the abdominal segments. Lepidoptera larvae occur frequently in a wide range of habitats and are known for their silk-spinning activities that result in the additional loss of quality of stored products. Some species attack the product in both the field and store. Several moths are pests of the ripening crop and their larvae can be found in recently harvested stored grains. They either continue their attack for a short time in the store or form an entry point for further attack by true storage pests. The following families contain the most economically important lepidoptera post-harvest pests.

2.2.1 Pyralidae

Pyralidae is a large family, of which only a few species are stored product pests. Most pyralids are small and delicate moths. Members of this family exhibit a great deal of variation in appearance and habits. Larvae of all species possess glands which secrete silk with which they interlink food products as they move. This family is divided into a number of subfamilies, with the subfamily Phycitinae containing some of the most important stored grain pests. The best-known species in this subfamily are the following:

The Tropical Warehouse Moth: *Ephestia cautella* (Walker) = *Cadra cautella* Hb.

A very serious cosmopolitan stored product pest infesting a wide variety of hosts such as maize, wheat, and other grains in stores. It can also feed on dried fruits, beans, nuts, bananas and groundnuts.

Natural history:

Adult females lay up to 300 small round sticky eggs within the substrate and through holes in bags. Optimum conditions for larval development are 32-33^{0}C and 70 percentage relative humidity. Larvae feed on the seed germ and are fairly mobile within the produce. A considerable amount of damage results from webbing in the grain and on the surface of bags forming large lumps, therefore food is no longer fit for consumption once infested. Pupation takes place in crevices or between bags. Adult moths spread the infestation in the warehouse through egg laying. This pest is cosmopolitan in tropical and sub-tropical parts of the world (see Burges & Haskins, 1965; Hill, 1987; Mound, 1989; Bowditch & Madden, 1996).

The Warehouse Moth: *Ephestia elutella* (Hub.)

This species is a polyphagous pest that feeds on a vast variety of stored products such as dried cocoa beans, dried grains, pulses, nuts, tobacco, coconut and dried fruits. Infestation is mainly post-harvest.

Natural history:

The whole life cycle takes about 30 days at 30^0C and 70 percentage relative humidity. Most of the damage is due to contamination of food with exuviae, dead bodies and frass. Silk produced by larvae may be extensive. The warehouse moth is a world wide pest, but more abundant in the sub-tropics and temperate areas of the world. This pest shows high levels of resistance to several groups of pesticides (see Kamali & Taheri, 1985; Meng *et al*., 1990; Ryan, 1995).

The Mediterranean Flour Moth: *Ephestia kuehniella* = *Anagasta kuehniella* (Zeller).

Adults are similar to *E. cautella* but the body is relatively longer. A major pest of flour mills, its main habitats are flour and grout mills, corn milling plants, bakeries and any other place used for processing grains or preparing flour products. *E. kuehniella* occurs in most of the temperate and sub-tropical parts of the world, where average temperatures are around 20^0C-25^0C. Complete development requires about 74 days at 25^0C and 75 percentage relative humidity. Larvae entwine all the material on which they feed resulting in solid lumps of food particles, faeces and larval exuviae (see Jacob & Cox, 1977; Locatelli & Biglia, 1995).

Indian Meal Moth: *Plodia interpunctella* (Hübner)

This insect feeds mainly on meals and flours but can attack raisins, nuts and some pulses and whole cereals. The Indian meal moth is distributed all over the tropics and sub-tropics and in some parts of the temperate regions, specially in heated buildings. In the hot tropics, it is more abundant in cooler highland areas. Most of the damage occurs due to larval feeding on the germinal part of the grains. Damage also occurs through the contamination of foodstuff with dead larvae, frass and silk webbing.

Natural history:

Larvae feed in tubes they weave from silk secretions. Adult females stick about 200-400 eggs to the substrate or to the storage walls. Larvae develop and feed within the substrate and are sensitive to changes in temperature. The number of generations may be only two per year in Europe, but increases in the tropics to eight generations. Complete development takes about 27 days at 30^0C and 70 percentage relative humidity. Development ceases below 15^0C. All stages die at 55^0C in five hours (see Bell, 1975; Aitken, 1984; Locatelli & Biglia, 1995).

2.2.2 Gelechiidae

Gelechiidae is a large family of lepidoptera. All moths are small in size and several species are important plant pests. This family contains two serious post-harvest pests:

The Angoumois Grain Moth: *Sitotroga cerealella* (Olivier)

Figure 13: 
Angoumois Grain Moth

This species is a serious primary pest that mainly attacks maize, wheat and sorghum, both in the field and in stores. A recent survey in southern Ethiopia revealed that this pest alone was responsible for 11.2 to 13.5 percentage weight loss in stored maize (Emana & Assefa, 1998). Infestation with *S. cerealella* starts in the field as females lay their eggs, singly or in groups, on grains. Larvae start feeding inside the grains, while still in the milk stage, and spend their entire life inside one grain. Thus, infestation is difficult to detect at this stage. Adults leave a conspicuous emergence hole at one end of the kernel. Infested grains are characterised by this circular window created by the larvae. Stored grains may be completely destroyed. Adults are active fliers, thus, they are able to infest neighbouring granaries, which is known as "cross-infestation". This pest is distributed throughout the warmer parts of the world (Africa, South and Latin America and southern Asia and Australia) (see Grewal & Atwal, 1969; Boldt, 1974)

The Potato Tuberworm: *Phthorimaea operculella* (Zeller) = (*Gnorimoschema operculella* (Zeller))

This species is a cosmopolitan pest of potatoes, tomatoes and eggplants. It attacks plants mainly in the field, but continues to feed on tubers in storage. Larvae mine in the leaves and stems and later bore into the tubers. Damage can be seen on leaves as silver spots due to the tunnelling larvae, or as tunnels in the plant stem.

Natural history:

Each female lays about 150-200 eggs and larvae tunnel through leaves and stem down to the tuber where pupation may take place. In the store, eggs are laid individually on the tubers near the eyes or on sprouts. *P. operculella* is an important pest in traditional potato stores in North Africa (Arx *et al*., 1987; Lagnaoui *et al*., 1996. See also Haines, 1977). High infestations of up to 50 percentage of tubers can take place in Yemen due to this pest (Kroschel, 1994).

2.2.3 Acaridae

The Flour Mite: *Acarus siro*

Mites are widely distributed tiny arthropods. They can live and develop on various plant in the field or indoors. Mites can be found in granaries, feed mixing plants, threshing floors, stacks of hay and straw, dead organic matter, soil or plant residues. Several species are predacious on other mites or insects. Mites are easily transmitted by virtue of their tiny size which allows them to be carried with dust, winds, insects, birds or rodents. About 30 mite species are known to be associated with stored products. Family Acaridae contains some damaging species, in which *Acarus siro* is probably the most important and commonly encountered mite in granaries. This mite is about 0.7 mm in length with an oval body. *A. siro* is a widely distributed polyphagous species that can be found on almost all products of plant or animal origin. It requires relatively high humidity (70 percentage), with humidities below 11 percentage being lethal to the mite. Temperatures below -15^{0}C for 24 hours kill all stages. At 60^{0}C, all stages die in 5 minutes.

Attacked grains lose nutrients and the ability to germinate due to feeding on the germ. Crushed bodies of *Acarus* cause coloration in flour that reduces the products value. Under normal conditions, this mite develops according to the following pattern: egg, larva, nymph I, nymph II, and adult. Some strains of *A. siro* may produce hypopus under favourable conditions. Hypopus is a diapause form that can be carried by rodents or insects to other storing places. However, this species does not seem to occur in most of the tropical lowlands, though it might sometimes infest grains in cooler upland areas (see Haines, 1991).

2.3 Fungal contamination and production of mycotoxins

Another important cause of grain deterioration is infection by fungal diseases. Just like infestation by insect pests, fungal infection mainly starts in the field and is later carried to the store. High relative humidity is a crucial factor for encouraging fungal infestation. Factors influencing the degree of humidity in the store can be a high moisture content in the product if it has not sufficiently dried after harvest, infestation with insect pests that results in hot spots and increased humidity, or improper storing technique that allows for contact with rain water or humidity condensation (see Ayertey & Ibitoye, 1987; Gwinner *et al*., 1996). Fungal infestation results in reduction of grain quality, change in colour, taste, smell, reduction in nutritional value, increase in free fatty acids (FFA) and reduction of germination ability (Dutta & Roy, 1987; Prasad *et al*., 1987; White & Jayas, 1993; Dharmaputra, 1997).

2.3.1 Fungal diseases

Fungal diseases may be highly hazardous as certain species of fungus produce mycotoxins (Christensen, 1975; Reddy & Nusrath, 1988; Latus *et al*., 1995; Miller, 1995), which are poisonous substances produced by moulds during their growth and development. Mycotoxins are highly stable compounds that cannot be destroyed through food processing, and the only way to avoid them is to prevent the fungal growth. The first recorded case of poisoning due to food contamination with fungal infestation was in the early 1930s, when 5000 farm horses died in Illinois, USA, due to a disease that was called the "mouldy corn disease". It occurred among farm animals that fed on maize left in the field after harvest (see Christensen & Kaufmann, 1969). Later in the mid 1930s, a plant pathologist in Minnesota, USA, isolated *Fusarium* sp. from maize infected by ear rot, and the extract gave similar disease symptoms on swine. A few years later in the former USSR, hundreds of people were affected by what was later described as "alimentary toxic aleukia" (see Taylor *et al*., 1996; Wild *et al*., 1996). People had eaten millet from plants overwintered in the field and gathered later in the spring. The grains were infected by different species of fungi, some of which produced potent toxins. In 1960, about 100,000 turkeys died in England of an unknown disease. Later a fungus identified as *Aspergillus flavus* was isolated from a suspected groundnut meal that was imported from Brazil. Extracts from this fungus confirmed the presence of a toxic substance that was given the name "aflatoxin" (see Christensen & Meronuck, 1986). This material has been extensively studied and proved to be highly toxic to man and farm animals. It is a liver toxin which can induce cancer in susceptible animals. Fungal growth can be very rapid as well as the production of aflatoxin, specially in tropical and sub-tropical countries, where environmental conditions are highly conducive (see Highley *et al*., 1994; Hennigen & Dick, 1995, Scudamore & Hetmanski,1995).

The fungus is widely distributed all over the world and has been found on all foodstuff and their products (Christensen & Kaufmann, 1969; Wareing, 1997). Several strains of *A. flavus* produce aflatoxin and can contaminate grains, pulses, cassava, oilseeds and other foodstuff. Factors during cereal storage can favour the development of the fungus and the production of aflatoxin (Cloud & Morey, 1980; Christensen & Sauer, 1982; Bhatti *et al*., 1990). A moisture content that is slightly above 9 percentage in groundnuts or around 16 percentage in cereals is enough to support the development of the fungus

(Christensen & Meronuck, 1986; Paderes *et al*., 1997).

Aflatoxin has been found in sausages in Germany and other meat products. In the Philippines, aflatoxin was found in the majority of the samples of peanut butter in stores. Moreover, aflatoxin consumed by dairy cattle, though altered in their body, still remains toxic and shows up in the milk (see Christensen & Meronuck, 1986; Gwinner *et al*.,1996).

A. flavus can grow and produce aflatoxin in many kinds of plants and plant products. However, major agricultural crops in which aflatoxins can create a serious problem are groundnut, maize and cottonseeds, specially where crops are grown in warm and humid conditions (see Awuah & Kpodo, 1996; Bankole *et al*., 1996; Fufa & Urga, 1996). On the other hand, not all strains of *A. flavus* produce aflatoxins, some can even be used in the preparation of foods for human consumption. Several other *Aspergillus* species and other fungi in different genera are associated with stored products, some of which may produce other important mycotoxins (Jacobsen *et al*., 1995; Bottalico, 1997; Cvetnic & Pepeljnjak, 1997). The following is a list of the most common stored product fungus species.

Aspergillus candidus

This fungus is common in stored grains and their products where moisture content is at least 15-16 percentage. It is known to cause preliminary heating of stored grains. Its presence is an indication that a stored lot is contaminated with spoiled grains (see Jevtic *et al*., 1990; Bujari & Ershad, 1993; Awuah & Kpodo, 1996).

Aspergillus clavatus

This fungus is commonly found in soil and decaying plant materials. It requires a moisture contents of 23-25 percentage in cereal seeds and can grow at lower relative humidities on groundnut meal or copra (see Adisa, 1994; Famurewa *et al*., 1994; Lopez-Diaz & Flannigan, 1997).

Aspergillus fumigatus

This fungus occurs in decaying plant materials and requires relatively high temperature to develop (40^{0}C). It was reported to result in a high level of abortion in cattle feeding on contaminated food. *A. fumigatus* may also infect human lungs. However, this species requires a high relative humidity of 95-100 percentage to grow (see Darwish *et al*., 1991; Pandey & Prasad, 1993;

Abdu *et al*., 1995).

Aspergillus parasiticus

An aflatoxin producing fungus which attacks maize, groundnuts and oilseeds (see Christensen & Meronuck, 1986; Le *et al*.,1995).

Aspergillus restrictus

This species is known to have a "restricted" growth. It is able to kill and discolour wheat germ at a narrow range of relative humidity of 13.8-14.3 percentage. *A. restrictus* is usually associated with rice weevils, but even when the insect pest is eliminated, the fungus will continue to grow. It is also associated with some grain infesting mites (see Jevtic *et al*.,1990; Silva *et al*.,1991; Udagawa, 1994).

Alternaria alternata

An important mycotoxin producing fungus that attacks rice, sorghum and soybeans (see Jevtic *et al*.,1990; Jacobsen *et al*., 1995; Hasan, 1996).

Fusarium graminearum

This species produces deoxynivalenol, which is a serious and acute human toxin. It also produces zearalenone. Both toxins are produced on maize, wheat and barley (see Wang *et al*., 1990; Sidorov *et al*., 1996; El-Sayed, 1997).

Fusarium moniliforme

This species commonly invades stems of maize plants and it is known to produce the mycotoxin, fumonisin. In high moisture conditions, *F. moniliforme* may be involved in rotting of the kernel. However, it requires a 22 percentage moisture contents to grow, thus, it does not cause serious problems in stores (see Lee *et al*., 1994; Tavares *et al*., 1995; Bacon & Hinton, 1996; Jin & Qiu, 1996).

Fusarium roseum

This species causes scab of wheat, barley and oats. Symptoms are the discoloration of seeds. It also causes "ear rot" in maize and may continue developing on maize left on the plants after harvest (see Biswal & Narain, 1991; Assemat *et al*., 1995; Adam, 1996).

Fusarium tricinctum

A mycotoxin producing fungus. Heavy infestations are common when maize is stored on the cobs in cribs (see Bao & Wang, 1991; Roinestad *et al*., 1994; Lin *et al*., 1994).

Helminthosporium spp.

Fungi belonging to this genus may cause seed infections in different cereals such as maize and rice (see Kedera *et al*., 1994).

Scopulariopsis spp.

A predominant fungus associated with black and white pepper, soybean flour and powdered milk (see Jevtic *et al*., 1990; El-kady & Youssef; 1993).

Penicillium verrucosum

This fungus infects barley and wheat. It produces ochratoxin, a mycotoxin that may lead to kidney damage in farm animals. Other certain species of *Penicillium* produce citrinin, an important mycotoxin that may lead to kidney damage in humans and farm animals. (see Skrinjar & Dimic, 1992; Mantle & McHugh, 1993).

2.3.2 Fungal infestation

Improper handling of crops during post-harvest processes can cause fungal infestation. Any damage to stored products increases their susceptibility to fungal contamination (see Tagliaferri *et al*., 1993). More importantly, insects activity can have a profound effect on the spread of fungal diseases through transmitting the spores and increasing the surface area susceptible to fungal infection, which eventually increases the production of mycotoxins. Dunkel (1988) indicated that some storage insect species are disseminators of storage fungi while others are exterminators; some storage fungi attract storage insects and promote their population increases while others repel and secrete toxins harmful to insects. Therefore, knowledge of basic biological relationships between insects and fungi in the stored grain ecosystem is crucial for their management. Several studies demonstrate the importance of insect pests as promoters or facilitators of fungal infection. In Nigeria, for example, Acholo *et al*. (1997) showed that the yam beetle, *Heteroligus meles*, which was the largest cause of damage to tubers, facilitated the spread of different *Fusarium* species and other less abundant fungi. None of the fungi was able to infect undamaged yams in the laboratory. In India, Pande & Mehrotra (1988) sampled wheat grains for *Sitophilus oryzae* and found that *A. flavus* was the most frequent species in their alimentary canals, followed by *A. candidus*, *A. sojae*, *A. fumigatus*, *Penicillium rugulosum* and *Cladosporium cladosporioides*. This indicates the possibility that *S. oryzae* transmits fungus spores from infested to healthy grains. In the USA, Beti *et al*. (1995) showed that maize kernels infested with *A. flavus*-contaminated *Sitophilus zeamais* weevils had higher levels of aflatoxin than *A. flavus*-inoculated maize without weevils. The presence of *S. zeamais* resulted in increased kernel moisture content which was positively correlated with aflatoxin contents. In addition, aflatoxin levels in infested maize increased with increasing numbers of *A. flavus*-contaminated *S. zeamais*, as *S. zeamais* carried spores both internally and externally on their exoskeleton.

In some crops, efforts to remove broken and discoloured seeds can effectively reduce the production of mycotoxins. However, this may not be practical for many products, especially when the fungal growth is internal and difficult to detect. In Thailand, an in-store drying system to control aflatoxin contamination in maize was developed. High moisture maize is dried to 18 or 19 percentage moisture content within 2 days and continuously dried to 14 percentage within 14 days. An airflow rate of 3.6-4.6 m3/min per m3 of maize is required to decrease moisture content from 19 to 12 percentage (Prachayawarakorn *et al*., 1996). In an experiment in India, cinnamon oil treatment of maize, in combination with sodium chloride, synergistically inhibited fungal infection, growth and aflatoxin production (Chatterjee, 1989).

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CHAPTER II INSECT DAMAGE: Damage on Post-harvest

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3. Control Methods

Farmers, through a long history of battle against stored product pest, have learnt to exploit natural resources, or to implement accessible methods, that would lead to a degree of population suppression of pests. Traditional methods usually provide cheap and feasible ways of post-harvest handling of the crops. Basically, farmers should be fairly aware that hygienic practices are essential for successful storing, i.e. thorough cleaning of bins or granaries, avoidance of mixing infested grains with healthy ones, burning crop residues after-harvest, sealing cracks and holes in muddy structures and any other practices that insure that the crop is stored in a clean and uncontaminated environment. During storage, some traditionally used materials are often added to the product, which contribute to the reduction of pests activity (Dakshinamurthy, 1988). Inert dust, for example, is added in variable amounts to the stored product. Friction of dust particles with insect's cuticle leads to desiccation and hampers the development of the pest (Golob *et al*., 1997). Grahn & Schmutterer (1995) showed that hydrophobic amorphous silica dusts resulted in efficient control of *Callosobruchus chinensis*, as no beetles survived after 48 hours at a concentration of 0.1 percentage. A similar effect can also be achieved through treatment with wood ash, collected from burnt tree wood or a farmer's stove. Some farmers may also add fine sand to hinder the pests activity, in which the high proportion of quartz causes damage to the sensitive cuticle of the newly hatched larvae (Kroschel & Koch, 1996). In an experiment in India, pre-treatment of *Vigna radiata* seeds with inert clay resulted in 100 percentage adult mortality of *Callosobruchus chinensis* within 24 hours. Seeds maintained over 80 percentage germination for up to 12 months of storage under ambient conditions (Babu *et al*., 1989). In Bangladesh, covering potato tubers with rice husk, sand or wood ash resulted in good control of *Phthorimaea operculella* in store (Das *et al*., 1995). Botanical insect deterrents or seed protectants may also be applied to products by some farmers with varied degrees of success. Plant products such as *neem* powder, leaves of hoary basil (*Ocimum* spp.), mint (*Mentha* spp.) or black pepper (*Piper* spp.), showed some positive results in limiting insect infestation. *Neem* tree has been exploited widely and *neem* extracts showed good results in reducing damage by certain pests (see Ishrat *et al*., 1994). In the Sudan, spraying potato tubers with *neem* and then placing them in jute sacks reduced post-harvest loss caused by *Phthorimaea operculella* (Siddig *et al*., 1987). Other extracted oils, such as coconut, maize or ground nut oil, have been recognised as toxicants or growth inhibitors of bruchids (Ramzan, 1994; see also Reddy *et al*., 1994).

3.1.1 Control using sunlight

Exposure to sunlight, or exposure followed by sieving of the grains, is a well known technique among farmers in sub-Saharan Africa, specially against the different pests of beans (Chinwada & Giga, 1996). In this method, grains are spread on a dark paper or a black polyethylene sheet and left exposed to sunlight for at least seven hours. After sunning, grains are sieved using a 5 mm sieve. The process may be repeated every three to four weeks depending on the size of production and availability of labour. This method proved to be quite effective in reducing bruchid infestation with no, or minimal, effect on grain quality or germination (Songa & Rono, 1998; see also Chinwada & Giga, 1996; Lale & Sastawa, 1996). In an experiment in Costa Rica, Leal & Zeledon (1994) showed that periodic sieving of stored maize decreased populations of adult pests by up to 99 percentage in 24 weeks.

3.1.2 Control by drying

Farmers, as mentioned earlier, may use bush dryers, solar dryers or light fire underneath the crop, to reduce the water contents and to deter or kill the different insect stages. In Cameroon, for example, the use of a 50 kg capacity solar heater eradicated infestations of *Callosobruchus maculatus* from cowpea seeds. It was also demonstrated that temperatures of up to 85^{0}C did not adversely affect seed germination (Ntoukam *et al*., 1997). Other traditional methods include mechanical removal of insects, infested grains or cobs. Winnowing, shaking and restacking the grains led to the disturbance of insects and a reduction of their activity.

3.2 Pesticides

Due to the significant increase in the human population, and the consequent increase in the amounts of food and grains produced, many small scale farmers adopted the use of pesticides as a means of pest control. Dusting and fumigation of grains are the most commonly used chemical methods among small-scale farmers (see Rai *et al*., 1987; Gwinner *et al*., 1996). Dusting, in particular, is an easily applied method, and can be implemented with very cheap tools such as small perforated metal cans or jute bags. For small amounts of grains, dust can be mixed with grains using a shovel. Dust should be mixed thoroughly and distributed evenly all over the produce. Dusters can also be used as a surface treatment to treat the bags, sacks or the whole granary. For larger amounts of grains or when storing maize cobs, a "sandwich method" is applied, whereby dust is spread lightly inside the granary, covering the bottom and walls with a thin layer, then the produce is entered in to make a layer of 20 cm, followed by another layer of dust, and so on until the granary is full.

The most commonly used insecticide dusts among farmers belong to two main groups of chemicals: (1) organophosphorus compounds, such as chlorpyrifos-methyl, fenitrothion, malathion, methacrifos and pirimiphos-methyl, and (2) pyrethroids, such as cyfluthrin, deltamethrin, fenvalerate and permethrin (see Table 2 a, b).

3.3 Fumigation

Fumigants are low molecular weight chemicals, highly toxic and volatile, that are used during storage to kill all insect stages residing in the produce. Fumigation is a widely used method all over the world on small as well as large storage scale. The method can be applied at the farm level in gas-tight granaries or silos, under gas-tight sheets carefully covering the product or at a large scale storage as in large warehouses. Fumigants are commercially available in a solid, liquid or gaseous state. Phosphine (PH_3), for example, is a formulated fumigant commercially available as either tablets, pellets, bags or plates. Methyl bromide (CH_3Br), on the other hand, is gaseous in form and packed in a liquid form in pressurised steel bottles. At temperature above 4^0C it takes a gaseous state, thus, once the container is opened, the gas is released and starts to act as a fumigant. The two compounds are the most widely spread fumigants in use. However, a problem of human toxicity due to inadequate application of the method is considered a drawback regarding this industry, specially in the developing countries, where inappropriate handling of such toxicants is widespread. Another problem with the use of fumigants has recently aroused, which is the developing of resistance from insects against fumigants. The problem started as a result of improper application of the chemicals in use, i.e. application of incorrect doses, fumigation in non gas-tight containers or insufficient exposure time. Recently, fumigation has been highly discouraged at a small-scale level. moreover, the use of methyl bromide has been strongly restricted in industrialised countries because of its ozone-depleting potential. However, fumigation is still the most widely operated method as an essential large scale post-harvest practice.

3.4 The search for other alternatives

Trials have been conducted on the use of carbon dioxide as a fumigant to replace methyl bromide in the control of insects and mites damaging stored products (Newton *et al*., 1993). The use of Co2 rich atmospheres showed promising results in disinfesting food commodities in small storage facilities (Krishnamurthy *et al*., 1993). A relatively new technique used by the Indonesian National Logistic Agency (Bulog) for milled rice is to seal bag sticks into large plastic enclosures flushed with carbon dioxide (Hodges & Surendro, 1996).

Treatment with high-pressure carbon dioxide under different temperatures may result in different rates of mortality, for example, at 15^0C, 95 percentage mortality of *Lasioderma serricorne* was observed after 38.5 min of treatment, while the same level of control was achieved within 1 minute at 45^0C (Ulrichs, 1995). Corinth & Rau (1990) showed that each tonne of grain requires about 19-27 kg carbon dioxide to achieve complete mortality of *Oryzaephilus surinamensis*, *Tribolium castaneum* and *Sitophilus granarius* in 4-6 weeks.

The use of "Biogas" as a fumigant, with methane and carbon dioxide as its main components, may achieve good results in the control of stored pests. Subramanya *et al*.(1994) showed that biogas significantly reduced infestations and loss in stored pigeon pea infested with *Callosobruchus chinensis*. Gursharan *et al*. (1994) recorded up to 100 percentage mortality of *Sitophilus oryzae*, *Rhyzopertha dominica*, *Trogoderma granarium* and *Tribolium castaneum* after six days' exposure to biogas in PVC bins. Another method for the control of insects in industrial premises was developed, where a Gas Operated Liquid Dispensing system was used to mix separate sources of carbon dioxide and insecticide concentrate. The system, given the name Turbocide GOLD, produces a fine insecticidal aerosol that was reported to give excellent control of *Tribolium castaneum*, *T. confusum* and *Lasioderma serricorne* (Groome *et al*., 1994).

Several studies have focused on developing post-harvest technologies as a key role in ensuring food security. Consumers are now aware of the danger in the use of chemical pesticides to protect stored products. This, and the world-wide trend to minimise the use of toxic substances applied on food products, have led scientists to seek less dangerous alternatives. Fumigation, for example, has become an endangered technology due to pressures regarding environmental contamination and health concerns (Banks, 1994). The following is a list of some of the most recent trials to use natural products in place of synthetic pesticides. Materials listed here are only the ones that showed a significant degree of success, and can be widely used in stores with confidence against certain storage pests.

Material Used as Plant / Product pest Country Reference

Seed extract
of *Ricinus communis* Protectant Wheat grains *S. oryzae* Egypt Mahgoub & Ahmad, 1996

Leaves & stems of Repellent & Maize & sorghum *S. zeamais* Kenya Bekele *et al.,* 1996
Ocimum suave protectant grains *R. dominica*
S. cerealella

Seed powder &
essential oils of
Dennettia tripetala
Piper guineense Seed protectants Maize & *S. zeamais*

Monodora myristica cowpea *C. maculatus* Nigeria Okonkwo & Okoye, 1996
Xylopia aethiopica

Dried & powdered tissues of
Dicoma sessiliflora Seed protectants Wheat grains *S. oryzae*
Neorautanenia mitis P. truncatus Malawi Chimbe & Galley, 1996

Citrus peel oils Fumigant Cowpea & cereal *S. zeamais*
grains *C. maculatus* Nigeria Don Pedro, 1996

Eugenol (essential oil of Repellent & grain Grains *S. zeamais Ocimum suave)* protectant *S. granarius*
T. castaneum Germany Obeng-Ofori &
P. truncatus Reichmuth, 1997
Plant powders of
Ricinus communis
Gaura coccinea
Larrea tridentata
Ribes ciliatum
Castilleja tenuiflora Grain protectants Stored maize *S. zeamais*
Alchemilla procumbens & beans *A. obtectus* Costa Rica Araya *et al*., 1996
Guazuma tomentosa

Acorus calamus oil Space treatment _ *S. zeamais* Egypt Risha, 1993
Dried plant material of
Cydista aequinoctialis
Ageratum conyzoides Graine protectants Maize seeds *S. zeamais*
Catharanthus roseus T. castaneum Philippines Vallador *et al*., 1994
Gliricidia sepium

Leaves of Post-harvest grain Maize & sorghum *S. zeamais* Kenya Jembere *et al.,* 1995

Ocimum kilimandscharicum protectant grains *R. dominica*
S. cerealella
Essential oils:
Cassia oil Grain protectants Stored wheat *T. castaneum*
Illicium verum O. surinamensis China Xu, H. *et al.,* 1993
Clausena dunniana R. dominica

Japanese mint Fumigant Stored sorghum *S. oryzae* China Singh *et al*., 1995
(*Mentha arvensis*)

Extracted oils of
Nigerian Indigenous plants:
Mondora tenuifolia
Lippia adoensis
Cymbopogon citratus Natural insecticides Maize grains *S. zeamais* Nigeria Odeyemi, 1993
Petiveria alliacea

Leaf powder of
Lagundi (*Vitex negundo*) Seed protectant Maize grains *S. zeamais* Bangladesh Buiyah
& Quiniones, 1990

Extracts of Feeding deterrent Food stuffs *S. granarius*
Helenium aromaticum R. dominica Poland Bloszyk *et al*., 1990

Neem (*Azadirachta indica)* oil
Copra oil Seed protectant Stored maize *S. zeamais* Ghana Cobbinah & Appiah, 1989
Palm kernel oil

Neem oil Natural insecticide Stored maize *S. zeamais* Benin Kossou, 1989
Acetone extract of
Dill (*Anethum graveolens*) seeds Seed protectant Wheat grains *S. oryzae* USA Su, 1989

Oils of
castor (*Ricinus communis*)
radish (*Brassica campestris*) Grain protectants Stored wheat *S. oryzae* India Ran *et al.*, 1988

Garlic (*Allium sativum*) Insect repellent Stored maize *Sitophilus* sp Brazil Sasaki & Calafiiori, 1988

Groundnut oil Carriers for Wheat grains *R. dominica*
Sesame oil pyrethrin *T. castaneum* India Trivedi, 1987

Alcohol extracts of:
Neem (*Azadirachta indica*)
Sweet flag (*Acours calamus*) Natural insecticides _ *T. granarium* India Pal *et al.*, 1996
Chandani (*Taberna montana coronaria*)
Imli seeds (*Tamarindus indica*)
Asriple (*Lantana camara*)

Oils from:
Citrus (*Citrus limon*)
Garlic (*Allium sativum*)
Pondia (*Mentha spicata*) Natural insecticides Sorghum grains *T. granarium* India Sudesh *et al.*, 1996 a

Powdered leaves of:
Mentha longifolia
Thymus vulgaris Natural insecticides Wheat grains *T. granarium* Egypt Mostafa, 1993
& powdered seeds of:
Piper nigrum

(-)-Homogynolide: Isolated Insect Antifeedant Different grains *T. granarium*
from *Homogyne alpina S. granarius* Japan Mori &
T. confusum Matsushima, 1995

Extracts of
African plants:
Entandrophragma sp. Insect Antifeedants _ *S. granarius*
Kaaya sp. *T. confusum* Zaire Szafranski *et al*., 1993
Quassia sp. *T. granarium*
Vernonia sp.

Extract of
Water Hyacinth Insect Antifeedant Rice *C. maculatus* India Rani & Jamil, 1989 (*Eichhornia crassipes*)

Extracts from dried fruits of Grain protectants Rice *T. castaneum*
Star anise (*Illicium verum*) *S. zeamais* Singapore Ho *et al*., 1995

Oil of:
Cinnamomum micranthum Grain protectant Different grains *T. castaneum* China Xu *et al*., 1996

Isolates from leaves of:
Nicotiana tabacum Antifeedant _ *T. castaneum* India Archna *et al*., 1995

Dried plant materials of
Gliricidia sepium Grain protectant Stored maize seeds *T. castaneum*
Cosmos caudatus *S. zeamais* Philippines Vallador *et al*., 1994

Seed extracts of:
Aphanamixis polystachya Insect repellents Wheat flour *T. castaneum* UK Talukder & Howse, 1995

Extracts of:
Chenopodium ambrosioides Natural insecticides Grains *T. castaneum*
Convolvulus arvensis *S. granarius* Egypt Abdallah *et al*., 1988
Conyza dioscoridis

Eucalyptus powder Insect toxicant Rice *S. cerealella* India Dakshinamurthy, 1988

Leaf extracts of:
Lantana inica Insect toxicants Grains *S. cerealella* India Ranganath, 1993
Mentha sp.

Extracts of *Piper nigrum* Insect toxicant Grains *S. cerealella* Brazil Boff *et al*., 1995

Dried meant leaves
(*Mentha spicata*)
Powdered seeds of custard
apple (*Annona squamosa*) Protectants Stored wheat *R. dominica* India Patel & Valand, 1994

Leaf powders of:
Chromolaena odorata
Calotropis procera Natural insecticides Rice grains *R. dominica* India Jacob & Sheila, 1993
Datura metel
Azadirachta indica

Essential oils of Goldenrod Insect toxicant *R. dominica*
(*Solidago canadensis*) & repellent Grains *S. granarius* Poland Kalemba *et al*., 1990
T. confusum

Plant extracts of:
Origanum vulgare Natural insecticide Kidney beans *A. obtectus* France Regnault & Hamraoui, 1995

Essentials oils of:
Rosmarinus officinalis
Thymus vulgaris Fumigants, ovi-&
Thymus serpyllum larvicides Kidney beans *A. obtectus* France Regnault &
Ocimum basilicum Hamraoui, 1994

Cinnamomum verum

Soybean oil
Black pepper (*Piper nigrum)* Natural insecticides Stored beans *A. obtectus* Brazil Faroni, 1995

Sunflower oil Natural insecticides Stored grains *A. obtectus* Cuba Roche & Simanca, 1987

Ground powder of Grain protectant Wheat grains *R. dominica*
Fenugreek (*Trigonella foenum*) *O. surinamensis* Egypt Afifi *et al*., 1988
S. oryzae

Extracts of:
Pongamia glabra
Jatropha cureas Seed protectants Potato seeds *P. operculella* India Shelke *et al*., 1987
Ipomoea carnea

Powdered leaves of
Lantana aculeata Tuber protectants Potato tubers *P. operculella* India Lal, 1987
Eucalyptus globulus

Dried foliage of:
Eucalyptus globulus
Lantana camara Tuber protectants Stored potato tubers *P. operculella* Peru Raman *et al*., 1987
Minthostachys sp.

Calamus oil of Contact toxicant & Wheat & cowpea *S. oryzae*
(*Acorus calamus*) seed protectant seeds *C. maculatus*
T. confusum
L. serricorne USA Su, 1991 a

Chenopodium oil from

Chenopodium ambrosioides Toxicant & repellent Wheat & cowpea *S. oryzae*
C. maculatus
L. serricorne USA Su, 1991 b

Coconut oil
Groundnut oil Seed surface protectants Chickpea seeds *C. chinensis* India Singal, 1995
Mustard oil

Dust and ether extracts of
Brown pepper (*Piper guineense*) Natural insecticide _ *C. maculatus* Nigeria Mbata *et al*., 1995

Seed powder of neem
Sweetflag (*Acorus calamus*)
Custard apple (*Annona squamosa*)
Black pepper (*Piper nigrum*)
Rhizome powder of turmeric
(*Curcuma longa*) Seed protectants Red grams *C. chinensis* India Shivanna *et al*., 1994

Neem kernel powder
Melia azedarach
Solanum incanum Seed protectants Faba bean seeds *C. maculatus* Yemen Al-Hemyari, 1994
Acacia wood stove ash

Margosan (neem based pesticide)
Saponin (extract of
Castanospermum australe)
Juliflorine (extract of Natural insecticides _ *C. analis* Pakistan Rahila *et al*., 1994
Prosopis juliflora)

Coconut oil Grain protectant Green gram,

bengal gram, *C. chinensis* India Jacob, 1994
green peas and cowpeas

Leaf poders & volatile oils of
Lippia adoensis
Cymbopogon citratus
Lantana camara Grain protectants Cowpea seeds *C. maculatus* Nigeria Adebayo & Gbolade,
Eugenia uniflora 1994

Oils of
mustard
Groundnut
Soyabean Grain protectants Chickpea *C. chinensis* India Singal & Singh, 1990
Rapeseed

Seed oil of
Neem
Brown pepper (*Piper guineense*) Grain protectants Cowpea seeds *C. maculatus* Nigeria Ivbijaro, 1990

Castor oil Grain protectant Cowpea seeds *C. rhodesianus* Zimbabwe Giga & Magnets, 1990

Olive oil
Sesame oil Grain protectants Cowpea seeds *C. chinensis* Egypt Zewar, 1988

Olive oil
Mustard oil Grain protectants Green gram seeds *C. maculatus* Pakistan Ahmed *et al*., 1988
Ether extract of
Annona squamosa Contact toxicant _ *C. chinensis* Japan Ohsawa *et al*., 1990

Leaves of Beguina
(*Vitex negundo*) Grain protectant Pulse grains *C. chinensis* India Prakash & Rao, 1990

Maize oil
Coconut oil Grain protectants Stored cowpea seeds *C. maculatus* Egypt El-Sayed *et al*., 1989

Oils from:
Navel orange
Sweet orange
Grapefruit Grain protectants Wheat grains *S. granarius* Egypt El-Sayed *et al*., 1989

Citronella oil *T. castaneum*
(Extract of *Cymbopogon nardus*) Insect repellent _ *C. chinensis* India Saraswathi & Rao, 1987

Himalayan cedarwood oil
(*Cedrus deodara*) Natural insecticide _ *C. analis* India Singh & Agarwal, 1988

Neem oil
Karanj oil (*Pongamia pinnata*) Natural insecticides _ *C. chinensis* India Khaire *et al*., 1987

3.5 Temperature

Temperature is a crucial environmental factor that influences the development of insects. There is always a minimum, optimum and a maximum range of temperature in which insects can survive. Insects differ in their tolerance to either low or high temperatures, however, a general pattern of population increase is shown on Figure 5. Most stored product pests would follow the same pattern of survival under a different range of temperatures. As temperature approaches zero, insect development, activity and movement decline to a minimum. Gradual increase in temperature will increase insect activity up to a certain range that differs among different species. Further increase in temperature above the optimum range will lead to increase in insect mortality and crashing of the population.

The use of high temperature is a well known technique to control stored product pests. For example, temperatures of above 40^0C are lethal for most stored food pests (Gwinner *et al*., 1996). Adult emergence of *Sitotroga cerealella, Sitophilus oryzae* and *Rhyzopertha dominica* can be totally suppressed after exposing their pupae to 45^{0}C for 72 hours (Sharma *et al*., 1997). However, low temperature treatment of grains may also provide a degree of control. Evans *et al*. (1987) stated that cold treatment, in combination with drying, is more useful for protecting grain from attack and deterioration than for disinfestation. In the USA, a prototype grain chiller was tested to determine its efficacy as a pest management tool in stored popcorn. Fewer *Plodia interpunctella* were trapped in the chilled aeration bins compared to the traditionally managed popcorn bins. Costs of chilled aeration (0.11 cents/kg) were competitive with the costs of conventional pest management practices such as fumigation and ambient aeration (Mason *et al*., 1997).

In Belgium, work has been done on using a combination of controlled atmospheres with an ice-forming preparation from a bacterium (*Pseudomonas syringae*), which is able to reduce freeze-resistance in insects (Desimpelaere, 1996). The combination resulted in 100 percentage mortality of *Sitophilus granarius* after exposure to 100 p.p.m. solution combined with $-10\ ^{0}$C for 24 hours (see also Mignon *et al*., 1995). Similarly, *Plodia interpunctella* larvae are known to be freeze susceptible. In winter, they avoid freezing by lowering their supercooling point. Feng *et al*. (1996) showed the possibility of elevating the supercooling point of the larvae using bacterial ice nucleators.

3.6 Other methods

The search for other alternatives to pesticides is still going on, with the hope that one day, a competitive and economic method, or an integrated group of methods that can be widely applicable, will emerge. In search for other methods, Pradzynska (1982) treated different stages of *Sitophilus granarius* with ultrasonic waves. Treatment for 5 min at 14.5 W/cm2 resulted in 100 percentage mortality within 2 min when treated outside the grains and within 4 min in the kernels. Tests in Mexico, exposing of adults of *Tribolium confusum*, *T. castaneum*, *Sitophilus zeamais*, *Prostephanus truncatus* and *Oryzaephilus surinamensis* to argon or helio-neon lasers, resulted in shortening of the life span; anorexia and dehydration, melanization and sclerotization and reductions in the size of F1 generation adults which were sterile. Chemical analysis showed the nutritive value of the laser-exposed maize flour remained unchanged, and the germination of exposed grains was not adversely affected (Ramos *et al*., 1983). In Iran, an electrohydrodynamic (EHD) system which generated air ions within a strong electric field was used for the control of *Tribolium confusum*. Negative ions resulted in maximum mortality of pupa due to the body fluid losses caused by the electric wind of the system (Shayesteh & Barthakur, 1997).

In Iraq, releasing cytoplasmically incompatible males of *Ephestia cautella* reduced infestation rate of stored dates when the release ratio was 80:1:(incompatible males strain: wild strain) (Ahmed *et al*., 1994). While in an interesting experiment in the USA, half-filled kidney beans containers were rolled or tumbled every 8 h or 2-3 times/day for 2 weeks, which resulted in disturbing the alignment between stable bracing sites of *Acanthoscelides obtectus* and target beans, and prevented the larvae of from completing entrance holes. Populations of *A. obtectus* in all rolled or tumbled containers were reduced by about 97 percentage compared with stationary controls (Spencer *et al*., 1991).

The followings are different applicable methods that might provide potential alternatives for the wide use of pesticides. Though their application is still rather limited, however, an intensive amount of research is carried out to facilitate the use of each method, and to achieve a plausible degree of integration among the different methods.

3.7 Biological control

Biological control may provide a useful and safe alternative for the control of crop pests. However, the use of biological control against stored product pests is still limited, though recently gaining ground due to increasing health concerns. On a small scale, the use of natural enemies may become available as a degree of "filth" or a small number of insects can be tolerated. Moreover, natural enemies may minimise the number of insect pests carried to the store at the end of the season. The following is a brief listing of some promising trials against certain post-harvest pests through the use of natural enemies.

B.C. Agent Used against Ref Remarks

Uscana lariophaga C. chinensis Alzouma, 1995 The parasitoid was (Trichogrammatidae) present in stores throughout the dry season. Laboratory studies showed that it was an effective parasitoid of bruchids
in Niger.

Anisopterolamus calandrae C. chinensis Islam & Nargis 50 released pairs Pteromalidae (1994) resulted in almost 100% control in red lentil debris in Bangladesh

R. dominica Ahmed, 1996 Percentage parasitism reached almost 60% in the field, Saudi Arabia.

S. zeamais Wen & Brower Percentage 1994 suppression reached over 90% in maize stored in drums following parasitoid release.

Trichogramma evanescens E. Kuehniella Scholler *et al*., Females were able to (Trichogrammatidae) (1995) parasitize eggs at 55 cm depth in wheat.

Lyctocoris campestris O. surinamensis Trematerra & A fairly wide host Anthocoridae *T. castaneum* Dioli, 1993 range larval predator *E. elutella* recorded from wheat *S. cerealella* stores in central Italy.
Teretriosoma nigrescens P. truncatus Boye *et al*.,1995 releasing the predator Histeridae in the field resulted in quicker dispersal than in stores.

P. truncatus & Rees, 1991 Use of predator *R. dominica* reduced weight loss in maize caused by the bostrichids.

Dinarmus basalis C. chinensis Alzouma, 1995 The parasitoid (Pteromalidae) *B. atrolineatus* showed efficiency in the control of the two bruchids.

In addition to arthropod natural enemies, other bacterial and protozoan agents may also become applicable. McGaughey *et al*.(1987) reviewed the use of the entomopathogenic bacterium *Bacillus thuringiensis* against pests of stored grain and seed. *B. thuringiensis* proved to be ideally suited for use on stored grain and seeds, being compatible with other protectants and available in different formulations for convenient application. In bulk stores, dressing a 10 cm deep surface layer with *B. thuringiensis* at 125 mg/kg controlled both *Plodia interpunctella* and *Ephestia cautella*. *B. thuringiensis* retained its activity for up to 2 years in stored grains, where it was not exposed to ultraviolet radiation, but *P. interpunctella* developed resistance levels of over 100-fold in 15 generations on a *B. thuringiensis*-treated diet in the laboratory.

Kroschel & Koch (1996) treated potato tubers with a mixture of *B. thuringiensis* and fine sand. Good results were obtained against the potato tuber moth *Phthorimaea operculella*. While Raman *et al*. (1987) showed that a dust formulation of *Bacillus thuringiensis* applied to potato tubers was most effective.

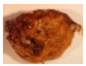
Figure 8: 
Potato Tuber

Figure 14: 
Potato Tuber

Nosema sp. can also be used for the control of certain pests. One example is the use of spores against *Lasioderma serricorne*. (Ghosh *et al*., 1995). Insect death is caused by severe damage to gut epithelial tissues and fat bodies.

Moreover, the use of transgenic plants is currently gaining ground in different parts of the world. (Bt) can be introduced to plant tissues and serve as protectants against infestation by certain pests. In a storage bioassay in Belgium, selected potato line tubers carrying the *Bacillus thuringiensis* CryIAb6 insecticidal crystal protein gene gave 100 percentage control of *P. operculella* damage (Jansens *et al*., 1995).

3.8 Irradiation

The use of varied short wave doses of about 0.2-0.5 Kilogray (kGy) provides another alternative in the control of pests in store. Combined treatments of radiation and carbon dioxide produced a higher mortality in *T. confusum* than did either treatment alone (Omar *et al*., 1988). This method has the advantage of leaving no residues in the product, though it might not be feasible due to the high costs involved in application. Other experiments involved the use of microwave energy against stored product pests. A special microwave unit was developed with a variable speed conveyor belt and tested for insect control in stored milled rice. Results indicated that *Tribolium confusum* and *Cryptolestes pusillus* can be killed economically with microwave energy (Langlinais, 1989).

3.9 Pheromones and trapping

The use of pheromones is one of the most promising techniques aimed at the control of stored product insects that may lead to a drastic reduction of chemical treatments against crop pests (Trematerra, 1997). Pheromone traps can be used to monitor the dynamics and occurrence of different stored product pests, such as *Phthorimaea operculella* (Trematerra *et al*., 1996). In Peru, mixtures of the pheromone components (4E,7Z)-4,7-tridecadien-1-ol acetate (PTM 1) and (4E,7Z,10Z)-4,7,10-tridecatrien-1-ol acetate (PTM 2) were evaluated for its attractiveness to *Phthorimaea operculella*. Ratios of PTM 1:PTM 2 of 9:1 or 1:15 gave the highest captures. ass trapping showed the feasibility of direct control in the field and stores. Microencapsulated pheromone sprays resulted in significant reduction of larval infestation in stored tubers (Raman, 1988).

In addition, certain compounds extracted from insect bodies may serve as attractants, repellents or arrestants to other insects of the same species. For example, hexane wash of *Lasioderma serricorne* females reduced egg laying by conspecific females in treated tobacco leaf disk stacks, therefore it may have use as an oviposition deterrent (Howlader & Ambadkar, 1995). In another experiment on *Callosobruchus chinensis*, crude extracts of females captured more than 60 percentage of males of in a laboratory culture using a pitfall trap, resulting in lower adult infestation levels in the following generation (Islam, 1994). In Japan, two arrestants of *Oryzaephilus surinamensis*, 13-oxo-(Z)-octadecenoic acid and 15-oxo-(Z)-11-icosenoic acid, were synthesised for the first time (Nakajima *et al*., 1997). The two compounds were previously extracted from wheat flour infested by this pest (Nakajima *et al*., 1996).

3.10 Cultivars

There is a wealth of information regarding the selection of resistant plants through intensive breeding programmes. Though host plant resistance is a promising strategy in pest control, insect populations are able to develop biotypes that can attack formerly resistant varieties, and there is evidence that improved varieties tend to perform poorly under low input conditions (CIMMYT, 1992). However, this strategy may result, along with other control methods, in a significant degree of pests population regulation.

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