PHASEOLUS BEAN

Post-harvest Operations

INPhO - Post-harvest Compendium

Food and Agriculture Organization
of the United Nations

PHASEOLUS BEAN: Post-harvest Operations

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1. Introduction

The common dry bean or *Phaseolus vulgaris L.*, is the most important food legume for direct consumption in the world. Among major food crops, it has one of the highest levels of variation in growth habit, seed characteristics (size, shape, colour), maturity, and adaptation. It also has a tremendous variability (> 40,000 varieties). Germplasm collection in beans compares well with other important commodities on a worldwide basis.

Phaseolus vulgaris is produced in a range of crop systems and environments in regions as diverse as Latin America, Africa, the Middle East, China, Europe, the United States, and Canada. The leading bean producer and consumer is Latin America, where beans are a traditional, significant food, especially in Brazil, Mexico, the Andean Zone, Central America, and the Caribbean. In Africa, beans are grown mainly for subsistence, where the Great Lakes region has the highest per capita consumption in the world. Beans are a major source of dietary protein in Kenya, Tanzania, Malawi, Uganda, and Zambia. In Asia, dry beans are generally less important than other legumes, but exports are increasing from China (25 and 37).

In Latin America, Africa, and Asia, the bean is primarily a small-scale crop grown with few purchased inputs, subjected to biological, edaphic, and climatic problems. Beans from these regions are notoriously low in yield, when compared to the average yields in the temperate regions of North America and Europe (26). Yet yields can be improved in all zones.

Beans are a nearly "perfect" food. Nutritionally rich, they are also a good source of protein, folic acid, dietary fibre and complex carbohydrates. Further, when beans are part of the normal diet, the use of maize and rice proteins increases since the amino acids are complementary. Beans are also one of the best non-meat sources of iron, providing 23 percentage-30 percentage of daily recommended levels (23) from a single serving. Consumption of beans is high mostly because they are a relatively inexpensive food (23). For the poor of the world, they are a means of keeping malnutrition at bay (36). Any advances in scientific research that benefit bean yields, particularly in developing countries, help to feed the hungry and give hope for the future.

1.1 Economic and social impact

1.2 World Trade

Statistics for dry bean production are vague. Figures for the biggest producers and consumers in developing countries are underestimated because beans are often intercropped and/ or grown in remote areas. As a result data are often imprecise. Political disturbances or war sometimes makes statistical analysis difficult or impossible to perform as in the case of Kenya, Rwanda, and Eastern Europe. Illegal trading also occurs across various borders. FAO figures for Asian countries include Vigna, of which there are 150 species in the tropics. A climbing or prostrate plant, Vigna is rarely erect and has various, small seeds that are not broad and flat. The most economic species is the cowpea Vigna unguiculata (L.) Walp. aggreg. whose dried seeds are an important pulse crop in the tropics and subtropics. Including Vigna in the statistics means that P. vulgaris has to be estimated. In short, for developing countries, it is best to take field experience into account when interpreting the statistics.

The centre of origin of the crop is attributed to the central Andes, Central America, and Mexico. Pre-Colombian times documented minor trade between regions. In the seventeenth century, returning colonists took beans to Spain. Thence the Portuguese introduced beans to Brazil and East Africa. Beans became useful for travellers both at sea and on land. European bean consumption began and increased to become one of the few foci of stable trade in the world. Other country to country trade is opportunistic and dependent on the vagaries of climate, causing a continually shifting pattern in world marketing. For example, Chile is now exporting only half the dry beans it did in 1990-92. Morocco has shifted from an exporter in the early 1990s to a big importer in the mid 1990s. Previously substantial exports from Tanzania to Europe have evaporated as Rwandan refugees obtain any surplus product (24). Over 12 million tons of dry beans are produced annually world-wide, with a total production value of US million $5717. Of this production, 81 percentage occurs in tropical countries. Today, Brazil remains the most important country for production and consumption of beans in the world (13), followed by Mexico. These two countries are nearly self-sufficient in the crop, but bean imports can be essential to supplement periodic production shortfalls. The United States has lost its position as top world exporter to China. Unlike rice and wheat, fundamental to the Chinese diet, dried beans are not government controlled in China. Farmers have a valuable cash crop with production almost wholly for export. This has made China the fastest growing supply source in the world although quality control is lacking (25). In 1994, South Africa imported 58,000 tons of beans to supplement its own production, which has been falling since 1990. China provided 89 percentage of these imports (18).

In East Africa and Central America, the bean is an important staple. Throughout sub-Saharan Africa mostly women farmers grow it traditionally as a subsistence crop. Yet the East Africa Bean Research Network's (EABRN) recent economic surveys show that approximately 50 percentage of producers sell part of their harvest, primarily to urban populations. The income-generating aspect of bean production is becoming more significant principally near urban markets, where populations increasingly rely on bean as an inexpensive source of protein (7).

Table 1. Major dry bean production and consumption by areas (Yearly average in 1000 tons) 1993-95.

Region[a]	Production 1993-95	Value (US million $)[b]	Consumption 1993-95	Import(-)/Export(+) 1993-95	Comments
Brazil	2931	1260	3096	- 165	World's biggest producer & consumer
East Africa[c]	1696	644	1678	- 18	Uganda and Kenya biggest consumers/producers of area
East Asia[d]	1524	594	1918	+ 394	China world's leading exporter (+633), Japan imports increasing
N. America	1400	812	983	+ 417	Mainly USA, world's 2nd biggest exporter (+353).
South Asia[d]	1336	494	1296	- 40	Per capita consumption low
Mexico	1308	510	1275	+ 33	Exports recently increasing
Europe	581	407	825	- 244	W. Europe biggest importers, UK especially
C. America & Caribbean	420	214	459	- 39	Guatemala biggest consumer/ producer of area
South Africa	393	193	481	- 88	Imports increasing, mainly low-cost from China
W. Asia & N. Africa	364	204	373	- 9	Iran & Turkey chiefly for export, Egypt & Algeria importing
Southern Cone	311	196	97	+ 214	Chile & Argentina mostly for export
Andean	278	178	341	- 63	Venezuela biggest consumer/ producer of area
Australia	26	11	18	+ 8	Recent increase for export

Regions are in order of production and defined as:

East Africa	Burundi, Ethiopia, Kenya, Rwanda, Somalia, Sudan, Tanzania, Uganda, Zaire
East Asia	Cambodia, China, Indonesia, Japan, Korea Rep., Myanmar, Philippines, Thailand, Vietnam
South Asia	Bangladesh, India, Nepal, Pakistan, Sri Lanka
Europe	Albania, Austria, Benelux, Bulgaria, Czechoslovakia, France, Germany, Greece, Hungary, Ireland, Italy, Poland, Portugal, Romania, Spain, Sweden, United Kingdom, former USSR, Yugoslavia
C. America & Caribbean	Costa Rica, Cuba, Dominican Republic, El Salvador, Guatemala, Haiti, Honduras, Nicaragua , Panama
South Africa	Angola, Lesotho, Madagascar, Malawi, Republic of South Africa, Swaziland, Zimbabwe
W. Asia & N. Africa	Algeria, Egypt, Iran, Israel, Jordan, Lebanon, Morocco, Saudi Arabia, Tunisia, Turkey, Yemen
Southern Cone	Argentina, Chile, Paraguay, Uruguay
Andean	Bolivia, Colombia, Ecuador, Peru, Venezuela

Calculations based on implicit border prices.
Kenya figures calculated from area planted and expected yields, and probably underestimated.
Asian figures adjusted using scientists' information (FAO Asian data includes *Vigna* in dry beans).
SOURCE: Compiled by author from FAO databases
http://www.fao.org/WAICENT/Agricul.htm (9)
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Some high quality dry beans are exported to European markets and elsewhere, constituting a significant proportion of export crops in many countries, notably Ethiopia, Zimbabwe, and Tanzania. These crops have considerable foreign exchange value (23).

The Southern Cone countries of Latin America produce beans mainly for export. Argentina prefers meat protein and began producing beans only for export. Grain that is below export quality remains within a country to sell off cheaply. Thus a producer becomes a consumer as well. This is also the case for Bolivia, where local consumption has risen as a result of information campaigns on the nutritional value of beans.

Europe remains the world's biggest importer of high quality beans. In Asia, beans are less important than other pulses and the statistics are unreliable.

Clearly dry bean production and consumption continue to expand at greater and greater rates as populations increase. As a food crop for the poor, beans have big potential, particularly in developing countries.

1.3 Primary Product

Common bean is grown for its green leaves, green pods, and immature and/or dry seeds. The dry seeds of P. vulgaris are the ultimate economic part of the bean plant. They are appreciated throughout the developing world because they have a long storage life, good nutritional properties and can be easily stored and prepared for eating.

Traditional markets have accentuated local preferences in seed colour and size of seed coat, but dry beans have similar composition. The different bean classes give identical total calories per gram. So it is easy to interchange or substitute different bean types within a major seed-coat class in recipes that require milling mashing or mixing. The consumer may not readily discern the bean type.

There are some limits on the use of dry beans and research is finding ways to overcome them. The long preparation time can be inconvenient and expend much fuel. Changes in the product during post-harvest storage can damage the grain including seed hardening, hard shell, hard-to-cook effect, moisture absorption, mould growth, seed discoloration, flavour and odour. Anti-nutrients such as protease inhibitors and lectins can block the digestion process. Factors promoting flatulence are another undesirable effect (30). There is genetic variability for most of these factors.

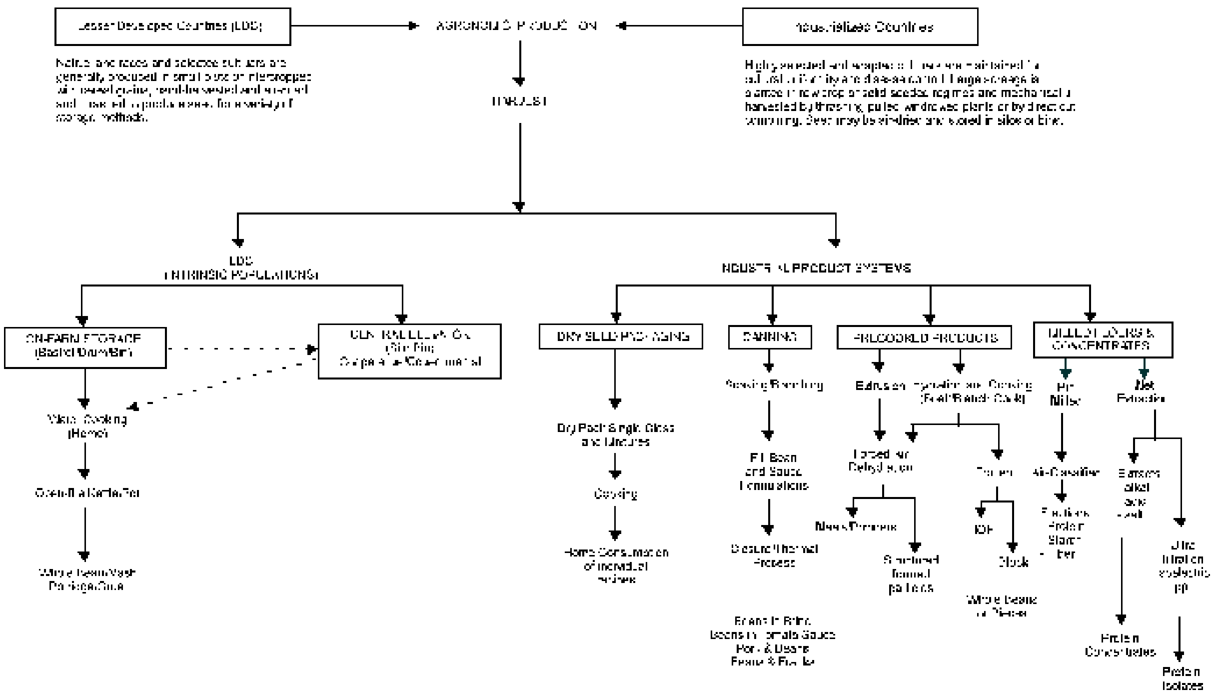
The major commercial processors of beans are developed countries. Some of their products are found on the supermarket shelves in the cities of developing countries. They are sold as "luxury" items for the middle and upper classes. This may eventually lead to commercial products being produced within developing countries. All have canning factories. South Africa produces a Bantu bean gravy and relish, Brazil a bean puree cake, Chile makes extruded products for infant foods using black beans and Guatemala pre-cooked flour. Mexico uses black beans for products similar to tempeh and pinto beans to manufacture tortillas and tacos (30). Manufacturing of bean products will increase as demands for convenience foods increase. This is a rapidly expanding market for dry beans.

1.4 Secondary and Derived Product

Dry leaves, threshed pods, and stalks are fed to animals and used as fuel for cooking, especially in Africa and Asia (30). In Peru and Bolivia, where high altitudes prolong cooking times and fuel costs, the ancient tradition of toasting grains comparable to corn and peanuts may be the reason why popping or "toasted" beans have been developed. They are cooked similarly to popcorn.

Dry beans are mostly eaten whole in cooked recipes. Some manufactured products use bean flour (see Figure 1). Roasted beans can be pin-milled to produce whole flour or cracked by corrugated rollers for easy removal of hulls by air aspiration. Hulls may be ground as high fibre (40 percentage) flour to desired particle size (30).

FIGURE 1. OUTLINE ILLUSTRATING PROCESSING STRATEGIES AND EDIBLE BY-PRODUCTS OF COMMON DRY BEANS IN LDC AND INDUSTRIALIZED COUNTRIES.



SOURCE: (30)

1.5 Requirements for export and quality assurance

Dry beans have numerous seed types, a wide spectrum of colours and colour patterns, varying degrees of brilliance and several seed shapes and classes (34). Of about 600 varieties grown in the world, 62 are commercial market classes and 15 of these are internationally recognised. The United States classifies dry beans as follows: Red Mexican, Pinto, Navy, Small White, Yellow Eye, Great Northern, White Marrow, White Kidney, Cranberry, Dark and Light Red Kidney, Pink and Black. These classes have become international.

Seed size is classified as small (>900 seed kg-1), medium (600 to 900kg-1) and large (>600 seed kg-1). Seed shape also varies among market classes and has become standardised (3).

Figure 1: Some of the great diversity of bean seed types

1.6 Consumer preferences

There is always a premium price for traditional, high quality bean varieties. Worldwide more sophisticated consumers are willing to pay for a quality product. In Latin America, colour preferences are still paramount. Local producers grow beans of the area's preferred colour, which they can sell at high prices. Imported beans of other colours will sell for low prices. At the cheaper end of the market, consumers have no strict criteria. In Africa where mixed varieties are preferred, bean colour is not as important as uniformity of cooking.
Cooking time varies regionally and can be a criterion for consumer acceptance. It is less of a factor where pressure cookers are used, as in many Latin American regions but may be more prominent where firewood is the main fuel source in Central Africa and Guatemala (30).
Producers are concerned about risk avoidance and yield of good quality beans. They recognise the importance of good adaptation of cultivars and resistance or tolerance to major negative characteristics. They are also concerned about culinary quality, taste and selected traits such as seed size, colour and plant growth habit (8).

Figure 2: Mixed varieties are preferred in Africa

2. Post Production Operations

Traditional high-yielding (> 1000 kg ha^{-1}) bean environments are in subtropical regions like those in Chile, Argentina, the Pacific coast of Mexico, the United States, and in some Asian and European countries. In these areas the crop is often irrigated and sole cropped, so diseases and insect problems are few. Bean farmers in these regions are more affluent than those in the tropics and grow crops to sell to large cities within the country or to export to other nations. However, an estimated 90 percentage of world dry bean production occurs under stress conditions where average yields are low (< 600 kg ha^{-1}). Such regions are found in tropical and subtropical Latin America and Africa, where small-scale farmers often intercrop beans for subsistence and apply few or no inputs because they have limited

resources. Diseases, insects, adverse climatic and edaphic factors, and other problems cause severe yield loss (28).
Wherever beans are grown on a small-scale, the whole family becomes involved in the harvesting and cleaning of the crop in most of Africa. Women are primarily responsible for bean production in Kenya, Rwanda, Burundi and Uganda. The bean is one of the few crops a woman can grow and be allowed to market for cash. Thus Ugandan women groups are targeting beans as one of the crops to be produced on a large scale (17 and 21). In fact, women make substantial contributions to the agricultural labour, household income generation, choice of crops planted and choice of seeds. Women also assume a large role in Peru, Ecuador, and Bolivia (Andean zone).
Latin America is the part of the world where women help the most by picking, threshing, and cleaning crops. In Africa, women help during all stages, or may be the only ones who do the work. This profile changes when machinery is used. Women are not usually involved in mechanical harvesting.

2.1 Pre-harvest operations

Pre-harvest operations are diverse. Developed countries use highly mechanised techniques. In Latin America, except Argentina where beans are produced on large holdings with high technical input, small holders usually produce beans. Mexico, Brazil, Chile, and Cuba have three types of bean producers, large-, medium-, and small-scale. Colombia, Venezuela, Dominican Republic, Peru, Guatemala, and Costa Rica have limited areas of large-scale, highly mechanised production (33). For mechanised harvesting, the plant needs to be uniform and upright with pods off the ground. Breeding for an improvement in plant architecture would help mechanised harvesting become more efficient and cut down on losses.
At harvest, the variety needs to be ready all at the same time. If plants are too mature pods open. Breeding for uniform ripening is being pursued. Some disease and insect resistant varieties are available but dissemination of new varieties is slow. Networks such as PROFRIZA (Proyecto Regional de Frijol para la Zona Andina) and PROFRIJOL (Proyecto Regional de Frijol para Centro América, México y el Caribe) in Latin America, and ECABREN (Eastern and Central Africa Bean Research Network) and SADC (Southern Africa Development Community) in Africa are helping in this aspect. They encourage small holders to produce seed and develop improved varieties (10).

2.2 Harvesting

Once harvested and separated from the plant, the bean seed continues to ripen, thus biochemical reactions occur, which deteriorate the quality. Therefore at harvest, humidity content, temperature, and climate affect or modify the deterioration agents (12).
There are two types of mechanised dry bean harvesting: conventional undercutting, rodding, or winnowing then combining; and the direct harvest system requiring only one pass of the combine. The latter system has some problems associated with it, such as high header losses and the difficulty of threshing immature plants and weeds. The reduced harvest cost, and lower risk from high winds and water staining, more than compensate. Moisture levels should be about 13 percentage-15 percentage (26). Depending on the size and type of machinery used, 1 hectare of beans may be harvested in 1-2 hours.
In developing countries, harvesting is mostly manual. Plants are pulled up and placed in rows (if a threshing machine is used), or more commonly in piles, very early in the morning to avoid pods opening. When harvesting is done totally by hand, 1 hectare requires 50-80 men hours. Climbing species have to be harvested pod by pod as they mature upwards. Humidity should be about 12 percentage-13 percentage (12). Unthreshed beans are not left long,

usually removed for shelter by nightfall for fear of rain. Careful harvesting is important to the bean yield. Mistakes at this point could undo all the benefits of earlier proper practices. Small-scale farmers need equipment they can use in their fields, thus small-scale technology needs to be developed.

2.3 Transport

Problems of transport do not usually affect small-scale farmers. On the farm, distances are short and covered often on foot. Most of the crop does not leave the farm; some is kept for seed and the rest eaten. Although farms are usually distant from markets, and roads may be in poor condition, the time taken to transport dry beans is not as consequential as it is for green foods. Intermediaries usually take the cost of transport and make the profit on it. There is price duplication on beans between the original seller and the buyer to cover the cost of storage and transport. In theory, small holders could accomplish this themselves in a co-operative. This has not worked in some Latin American countries because the intermediary is also usually the supplier of other goods to the farmer (e.g., chicken feed). The farmer, who does not sell the crop to the intermediary, loses the complementary services. Intermediaries often use the price differential for different grain types to quote farm-gate prices for new varieties.

Large volumes of beans are transported by truck or semi-trailer for domestic markets and by intermediary bulk containers for export. In both cases, handling is kept to a minimum and the more advanced procedures have moisture gradients and temperature controls. Sanitation of containers must be carefully inspected and controlled (31).

2.4 Threshing

Once harvested, the bean plants are either left in the field or taken elsewhere to dry. Bigger producers use drying silos or dryers designed for sacks. Plants must not be piled too high, as air must pass through them to avoid the risk of heating. Smaller amounts may be dried on patios, wooden platforms, under house pilings, in ceiling spaces, hung from wires under a roof and in fine weather, directly on fences or bars around the house.

Threshing methods vary widely. Big-scale producers use moving machinery, which require calibration to avoid losses. Standing machinery can be used for smaller production, carried to the field and run on diesel oil or gasoline. Usually the dried plants are piled on plastic sheets or jute bags then beaten with sticks or run over by animals, tractors, or even light trucks. Beans used for seed are best threshed by hand as this causes least damage but is only suitable for small amounts. In Guatemala and El Salvador, a thin walled box is used on a table made of strips of bamboo, wood, or 12-mesh wire. Separations are wide enough for beans to pass through; the chaff remains on the table. This method has the advantage of less beating of the seed and is useful in areas of small production (12).

Photo 3: Hanging beans to dry under patio roof

Figure 4: Threshing by beating with sticks

2.5 Drying

Drying can be done artificially or naturally (see Table 2). The artificial methods are used for larger production. Natural methods prevail in developing countries and women help in the operation.

The object in drying the seed is to achieve a final humidity of 11 percentage-12 percentage for better storage. Three practical rules should be observed: for each 1 percentage humidity reduced, double the storage potential; for every 5 _C lower temperature of seed, double the storage potential; if the sum of the temperature (in _C) and humidity (in wb) is less than 45, storing conditions are adequate (12).

Table 2. Some different systems for drying beans

Drying systems	Examples	Conditions required	Recommendations
Artificial:			
Stationary	False-bottomed drier - air flow forced through perforated floor from open chamber below	Continuous air flow	Temperature not to exceed 40_ C, RH 40% at start, 70% at end
	Tunnel system - forcing air over seeds packed in hemp sacks		Do not use more than 4-9 _C temp. differential above air supply temperature Do not dry below 13%
Intermittent	Silo modifications of brick or wood (700-800 kg capacity)	Fast - air temp. < 70 _ C Slow - < 60 _C (0.25% per hour)	
	Drying wagons or trailers		
Natural:			
Sun and wind	On patios and roads in wave form < 10 cm thick	Immediately after cleaning. Early hours before sun heats concrete/asphalt	Use plastic sheeting under and cover with jute or cloth to absorb humidity
	Suspended trays with wire netting base	Seeds piled < 10 cm high, periodically stirred	Trays suspended 50 cm from ground and parallel to it, or slightly angled (23_) in direction of wind and sun
	Coffee dryers	< 60 _C, well ventilated	

SOURCE: Compiled by author from (12) and (14).

2.6 Cleaning

Big-scale producers use air and sieving machinery with padded equipment to clean the crop. The distance and number of drops is kept minimal to avoid damaging the seed. The finished product is then bagged (14).
Most small-scale methods of cleaning use sieves and air, then a manual pick through for damaged or discoloured seed. Sieves usually have a metal mesh, with mesh size according to seed size, smaller particles falling through. In windy areas, natural air currents are used, the seed being allowed to fall onto the ground or onto sackcloth from the height of a person with arms raised. The wind takes away the lighter material. Alternatively, electric fans may be used or a motor pump.
The small-scale farmer might use the portable cleaner type Clipper 3W (bicycle), which works with an electric motor, petrol, or with foot pedals, like riding a bicycle. Manual sorting is traditionally done on a table. It is more efficient if the surface is painted pale blue for better contrast and the seed placed in a box with a slanted bottom and an exit at the end (12).

Women play a major role in cleaning seed. Their hands are smaller and defter for this kind of work.

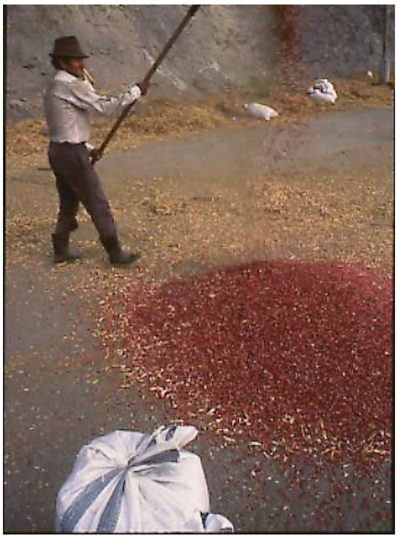


Figure 5: Sieve method of cleaning **Figure 6: The wind blows away lighter material**

Figure 7: Manual sorting of beans

2.7 Packaging

Commercially, beans are often transported direct in container trucks. Various types of bags are used by the bean industry-laminated paper, burlap, and polypropylene are most used in shipments (2).

Beans are usually sold loose in open sacks or in clear plastic bags so that the colour and quality can be easily seen.

Figure 8: Beans for sale in open sacks

2.8 Storage

Farmers have three main reasons for storing bean seed: to keep it safe for consumption; to keep it safe for the next harvest; and to speculate the selling price. When everyone harvests at the same time prices go down, so some farmers reserve seed for later sale at a higher price. The condition of dry beans going into storage and the storage conditions they experience affect their final quality (26). Conventional storage types for quantities over 1 ton have temperature and humidity controls. The traditional storage methods follow the same principal to keep seed with fewer than 12 percentage humidity and in dry ventilated conditions. Small-scale farmers lower the moisture content of stored bean seed to less than 12 percentage without necessarily understanding the reasons behind it. They just know from experience that humidity will rot the seed.

Bean moisture control, storage temperature, and relative humidity strongly influence dry bean quality and the final product. High moisture and high temperature during storage results in "bin burn", a defect that gives the beans a brown discoloration and an off-flavour. Beans given bad storage conditions may result in defective cooked grain texture. Bean grains that do not soften enough because they fail to absorb water during soaking are called "hard shell". Those that absorb enough water but do not soften enough during a reasonable cooking time are called "hard-to-cook".

Hard grain is both genetically and environmentally controlled. The incidence of hard shell increases as seed moisture content decreases experienced under conditions of high

temperature and low relative humidity. Hard shell has been found by most researchers to be highly heritable, with relatively few genes involved. Natural reversibility under high relative humidity occurs.
In contrast, hard-to-cook defect is irreversible and develops during storage under high temperatures (> 21 ºC) and high relative humidity. The mechanism by which the hard-to-cook defect develops is still not clearly understood. The inheritance and genetic variability of hard-to-cook has not been determined (27).
Small-scale farmers usually store bean seed for less than 6 months. They sell their surplus as soon as possible because they need cash and are afraid of losing seed to weevils. They leave the risks of storage for intermediaries. Beans being kept for seed can be treated with insecticides and stored safely for longer periods.
Types of storage range from sophisticated silos to pits in the ground, with all kinds of containers being used on a small scale. Ensuring that containers are clean before use is important.

Table 3. Examples of storage facilities for dry beans

Type	Examples	Storage period	Storage purpose	Storage conditions	Comments
Bulk	Silos - wood, steel, or concrete	3-6 m > 6 m	Marketing Later sale	14%-15% humidity 12%-14% humidity	Heated air temp not to exceed 45 ºC, RH < 40% Protect from contamination of other crops, chemicals, etc.
200-1000 kg	Containers - plastic, metal, wood, aluminium	3-6 m	Consumption, some marketing, some seed	11%-12% humidity	Hermetically sealed containers best
< 200 kg	Earthenware pots, straw baskets, sacks, gallon tins	< 3 m	Consumption, some seed	< 12% humidity	Containers mostly stored in farmer's house.

Source: Compiled by author from many of sources cited.

3. Overall Losses

This is a troublesome concept when dealing with beans. In the United States, with conventional harvest systems, losses average 4 percentage of yield, ranging from 1 percentage to 12 percentage. It mostly happens during the combining operation, with about half of this loss attributed to header and half to threshing loss (26).
Where beans are grown on a small scale or for subsistence, losses are much higher. Only rough estimates can be made and they are unreliable. Losses may be zero when beans are harvested by pulling plants from small plots and transporting bundles immediately to the threshing place, as performed by women in Uganda as no pod shattering occurs. When pulled and heaped for field drying before threshing, pod shattering depends strongly on weather conditions, and if these are adverse, losses can be heavy (20 percentage-30 percentage).
See under 4.1 for storage losses to bruchids.

4. Pest Control

4.1 Relative status of major pest species

Many species of insect pests attack beans both before and after harvest. The living bean plant can often recover after insect attack has been controlled, but stored dry beans cannot. There are two major post-harvest pests of dry beans world wide-the Mexican Dry Bean Weevil, *Zabrotes subfasciatus* (Boheman), and the Bean Weevil, *Acanthoscelides obtectus* (Say). Both belong to the order Coleoptera and the family Bruchidae, commonly known as bruchids. Indirectly, these insects force the rapid sale of post-harvest grain and short storage periods in granaries, thus causing post-harvest price collapse and marked seasonal price fluctuation (32).

Most of the many other insect species that attack stored beans migrate from other products (e.g., maize, sorghum, or rice) stored in the same warehouse. They only cause minor damage to their secondary host, beans (4).

In general, when beans are stored at 14 percentage-15 percentage moisture content or less, mould is not a problem. Since farmers are aware of this, losses caused by mould are negligible. Damage caused by rodents has not been reported. This is probably because dry beans in their raw state are highly toxic to warm-blooded animals.

4.1.1. Details of each major pest

Z. subfasciatus predominates more in warmer areas and *A. obtectus* at higher altitudes in the tropics and throughout temperate climates in general (4). In Africa, however, this differentiation is less marked (1). *Z. subfasciatus* does not attack beans in the field. Fresh eggs are attached to the testa of bean seed. The adults exhibit strong sexual dimorphism. Females are large and have four characteristic cream-coloured spots on the elytra. The male is entirely brown. *A. obtectus* scatters its eggs among stored seed and oviposits in maturing bean pods in the field. It is difficult to distinguish between male and female as size and colouring are the same (32).

4.1.2 Life history

In storage, the life histories of *Z. subfasciatus* and *A. obtectus* are similar. Larvae of both species moult four times before pupating. During the last larval instar, the feeding and pupation cell becomes externally visible as a circular window in the seed where the larvae feed on the lower testa surface. After pupation, the adult may remain in the cell for several days before pushing or biting out the window with its mandibles. Adults are short-lived, and mate and oviposit soon after emergence (4).

For the Mexican bean weevil, the egg stage lasts 5-6 days, different larval instars 14 days, pupal stage 6-7 days; adults live 10-13 days; and females lay an average of 36 eggs. For the bean weevil, the egg stage lasts 6-7 days, combined larval and pupal stage 23 days; adults live 14 days; female lay about 45 eggs. Sex ratios tend to be 1:1 in both species (4).

Figure 9: Bean Weevil and characteristic "window" left in seed

4.1.3 Damage symptoms and levels of loss

Losses correlate directly with length of storage, the longer the beans are stored, the greater the loss. There are two types of losses: quantitative, or the number of seeds or parts of seeds eaten by insects; and qualitative, or the grains contaminated by excrement or insect bodies. These losses may be augmented by subsequent attacks from fungi or bacteria because larval stage completion elevates temperature and relative humidity, inviting secondary rotting by micro-organism attack.

Damage shows in the circular holes or "windows" left in the bean when bruchids emerge. Losses caused by bruchids are known to be substantial on all continents. In Ethiopia, stored bean damage by bruchids reached up to 38 percentage with a corresponding weight loss of about 3.2 percentage (20). Burundi and Rwanda losses to bruchids are commonly about 30 percentage (19). Estimates in Mexico and Central America have been as high as 35 percentage (32).

Unclean storage conditions are the main cause of bruchid infestation. Storing beans with other grains, or newly harvested beans with the infested residue from other harvests, encourages bruchids to flourish (33).

4.2 Pest Control

Plant resistance as a principal method of insect control is effective, practical, and of low cost to farmers. Cultivars with genetic resistance to the Mexican bean weevil have been identified (15). High levels of resistance to these weevils have recently become available in commercial bean types (5). The resistance is a simply inherited dominant gene that can be rapidly backcrossed into local varieties.

Strict cleanliness in storage sites should be maintained. Control may be effected at two levels: domestic and small-scale farmer level, and large commercial level.

Domestic and small farm level

Reducing storage temperature to < 10 º C significantly affects bruchid growth and reproduction because most are adapted to higher temperatures of 20-32 º C. So storing beans in the freezer compartment of a refrigerator completely eliminates the insect in any of its stages.

A mechanical control is to store the beans mixed with ashes, which fill the spaces between seeds making it hard for bruchids to infest. The optimal mix of ash is 20 percentage of the

weight of bean seed being treated. This method only works before infestation. Sand, lime, or other fillers can be substituted for ash.
Coating with edible vegetable oils (e.g., peanut, maize, or soybean) is a relatively effective control permitting storage for at least 6 months without fear of insect damage. It also makes the seed look more attractive. The oil penetrates bruchid eggs and destroys them. It reduces oviposition and increases adult mortality. In general it should be applied at a rate of 5 mL per kg of seed. Control by oil is inexpensive and simple.
Some control of *Z. subfasciatus* is achieved by storing beans in their pods as *Zabrotes* prefer laying their eggs on shelled beans. For control of *A. obtectus* early harvest reduces exposure time to the insect in the field. Beans should then be shelled and cleaned immediately to eliminate eggs and insects coming from the field on pods.

Commercial level

Curative control in warehouses is possible by disinfestation and/or protection. Several chemical products are available for both.
Disinfestation eliminates at the time of treatment and leaves no residue so beans can be eaten immediately after. For the same reason, beans are liable to reinfestation. Phosphine (aluminum phosphide) and methyl bromide are the most used disinfestants. Phosphine eliminates all stages of the insect, including those within the seed. Methyl bromide leads to ozone depletion and its use will be phased out (35). It can affect germination when temperatures are high so is not recommended for use on seed to be planted. Both phosphine and methyl bromide are very toxic to humans and should be applied only by experts. Bean sacks should be completely covered with a plastic sheet and the edges sealed against the ground to prevent gas escape. Beans should be kept covered thus for 1-2 days after fumigation for gas to penetrate seed.
Protection is done by mixing seed with an insecticide that has residual effects. This is suitable for seeds for planting only. They cannot be reinfested once treated. Malathion kills 85 percentage-99 percentage of *Zabrotes* adults in the first 24 hours after application. Lindane gives longer protection but is toxic to humans and must only be used for seeds for planting. Pyrethrins are a more promising product as they are not toxic.
Application of insecticides must always be carried out with adequate knowledge of the product and potential dangers. It is not the best means of control in many situations. Oil treatments are just as effective at the smaller scale level (32).

Figure 10: Disinfestation in warehouse

4.2.1 Residue problems

Residues are not a major problem in dry beans because the pods absorb insecticides. In the tropics, the sun's radiation is perpendicular therefore loss of residues is high. Bush-type beans have a growth period of about 90-95 days in the tropics and 100-120 days in cooler regions. Ideally, farmers fumigate 3 to 5 times beginning at 15 days and finishing at about 60 days. This would leave at least a 2-month margin between last application and consumption. Climbing beans have a longer growing period of 150-180 days, and in the Andes (2700 m) of 180-270 days. Again preferably farmers should fumigate about 8 times over this longer period still leaving a 2-month margin at the end. However, in some areas of Latin America, farmers may spray as late as one week before harvesting. Residue problems will still not be as serious for dry beans as for fruit and vegetables that are eaten raw. In storage, insecticides are not used on beans for consumption. Given the above factors, it is highly unlikely that residues remain in dry beans (César Cardona, 1997, personal communication). There is a need to research this aspect.

4.2.2 Discussion on pest control

In Latin America, small holders hardly used insecticides before 1985 but have since taken quickly to their use, despite the implied cost. All use pesticides, fungicides, and insecticides to some extent and cannot be prevented from using these products. Intercropping reduces the need for pesticides. Some research would be useful, not only for residue problems, but to determine the effect that using insecticides has on the farmer.

In Africa, pest control is left to Nature, as small-scale farmers cannot afford pesticides. Ideally, integrated pest management (IPM) principles can be applied and information is reaching the farmers. Research should focus on low-input IPM approaches that include current farming practices, host-plant resistance, and natural biological control (1).

Many pest control technologies have been developed over the years but few have reached the end-users. In collaboration with farmers, these techniques should be refined. Collaboration with social scientists is urged for this effort. Dissemination of resistant and/or high yielding varieties to small-scale farmers would increase yields.

5. Economic and Social Considerations

All important constraints are not biological in origin. Socio-economic factors related to farmer adoption of new technologies, seed distribution, and market requirements may also restrict bean production. New technology development is limited by the degree of organisation, resources, and the number of trained personnel within national programs (36). Networks such as PROFRIZA and SADC have proved to be a most efficient way of introducing new technologies to the small-scale farmer. Network participants include international organisations, national research institutions, state and private universities, ministries of agriculture, and nongovernmental organisations. But the most important partners are the small holders. They share their knowledge with scientists and play an active role in research aimed at developing and evaluating new technologies (10).

The small-scale farmer's main cost and biggest problem is often the purchase of high-quality seed. Network members have supported small holders by supplying high-quality seed at low cost, by developing strategies for its production and distribution, and by providing training for technicians and farmers. Seed systems need to be tailored for specific agroecological and socio-economic environments. The small seed packet technique of distribution through a diversity of channels is simple and has impressive potential for impact. In Rwanda, calculations show that 100,000 or just fewer than 10 percentage of all farmers can be reached (29).

Figure 11: Small seed packet distribution

Breeding for resistance to diseases and pests, and for better yields, is important. The bruchid-resistant commercial bean type will make a great difference to the small-scale farmer once he has access to it. Farmers can get better prices for their beans if they can store them until the lean months when prices are highest; and this storage would also stabilise bean prices in general by providing a more continuous supply (32). The small-scale farmer would also benefit from small technology, portable, and suitable for use in his fields. Breeding of upright plants for machine harvesting would increase efficiency of commercial production. A main constraint to expanding crops in Brazil is the lack of a bean cultivar with a suitable plant type for mechanical harvest. Uniformity of maturity is also needed (6).

The introduction of improved technology has increased small-scale farming production in many areas, thus improving family nutrition and income. For example, in the Great Lakes region of Africa, the population is increasing rapidly and farms are tiny (0.5-1.0 ha) with no land for expansion. Climbing beans were introduced here 8 years ago. Now about half a million Rwandan farmers grow climbing beans on 20 percentage of the country's bean land, increasing yields (8). Another example is that of the area around Santa Cruz, Bolivia, where small-scale farmers used to leave their farms and go out to find work during the winter months. They now plant beans, a new crop for them, thanks to newly introduced varieties. This has given them access to the Brazilian market in urban areas. They have improved income and have fewer weeds, as the land is not left fallow. Women in Bolivia choose the bean seed and they have also promoted increased consumption.

Storage problems (bruchids, and discoloration, hard-shell, and hard-to-cook defects) cause the greatest post-harvest losses in beans. These problems have management solutions such as control of relative humidity and temperature for the defects, and various disinfestation and protection controls for bruchids. Genetic solutions are also available. They are cheaper in the long run but have not been exploited.

Other means of adding value to the produce are to increase different kinds of consumption, and to commercialise the end product. Beans: can be eaten as cooked dry grain, immature beans, green pods, or popped. In Africa, the young tender leaves are also eaten (22). Not all bean-consuming areas take advantage of these different uses of beans. In Peru, large quantities of seed of a single variety of popping bean are now being multiplied, which will open potential markets for snack foods in urban areas (11). Dietary habits are changing in high-income countries, as illustrated by estimates of 12,000,000 vegetarians in the USA. Because of these changes in preference, major food companies are now developing a new array of bean-based processed foods, including microwave products (23).

All evidence points to a continuing increase in total demand for beans in Latin America and Africa, and an increasing market opening in Asia. Agricultural research can make a vital contribution to improving bean production, thus helping to narrow the growing food gap. In this effort, improvements to stress tolerances, both biotic and abiotic, are likely to be far more important than increases in yield potential (23).

Beans, often a subsistence or small-farmer crop, do not receive the research attention that cash crops, such as coffee or cotton, enjoy (33). The crop offers a low-cost alternative to beef and milk. One hectare planted to traditional bean varieties in Latin America produces 123 kg of protein compared to 3-4 kg for beef cattle on the same amount of land. Donor funds for bean research are decreasing at a time when world demand is increasing for this cheap source of protein and calories. Research by international institutions is reaching the small farmer through established networks. Funding such research helps feed the poor of the world, especially women, who are often the first to suffer when food supplies are scarce.

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