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Pulses and their by-products as animal feed

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by

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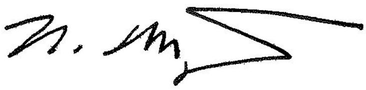
Foreword

The pulse sector is undergoing dynamic changes at global, regional and country levels, to meet the growing demand for protein. Projections indicate that demand for pulses will continue to increase in developing counties due to growing population and rising per capita incomes. Globally, the average share of pulses is only 5 percent of the total protein consumption, but in several developing countries their contribution ranges between 10 and 40 percent. Pulses are an important crop group in the cropping patterns of several developing countries. They are of particular importance for food and nutrition security, particularly in low-income countries. In these countries they are the major source of protein often consumed in the diet along with staples like wheat or rice. Pulses help to improve nutrition and thus health and contribute to reduce poverty and hunger. Moreover, pulses – and legume crops in general – are key components of sustainable, climate-resilient cropping systems.

Pulses further play an important role in providing valuable by-products for animal feeding and thus indirectly contribute to food security. There is considerable potential to use crop by-products (e.g. straw and other plant parts) left after harvesting the seeds as ruminant feed. Other by-products such as chunies (a mix of seed coats and endosperm fractions) and husks, obtained during processing of pulses for human consumption, are also good animal feeds. These by-products are valuable sources of protein and energy. They do not compete with human food, but contribute to decreasing cereals and soybean levels in the diets of livestock in intensive livestock production systems. They are used by smallholder farmers, particularly in Asia, in extensive or mixed crop-livestock production systems to extenuate the feed shortage. Also their feeding provides important economic, social and environmental benefits by saving grains used for feeding for animals.

There have been considerable research efforts on the use of pulses and their by-products as animal feed, which has resulted in a large body of published and unpublished data. However, an authoritative review in this area has been lacking. In order to fill this gap and to raise awareness on the use of pulses and their by-products as animal feed, we have collated and synthesized the available information in this comprehensive state-of-the-art document. It highlights the nutritional role of pulses and pulse by-products as animal feed and is a contribution to the legacy

of the 2016 International Year of Pulses. This document will further enhance the use of these feed resources in other continents, besides Asia, where many pulse by-products are simply dumped. It is also expected that the synthesis presented contributes to make the use of pulses and their by-products as animal feed more efficient. This document will be useful for extension workers, researchers, feed industry, policy-makers and donors alike.



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Glossary

Ad libitum. Unrestricted consumption of feed or water.

Anti-nutritional factors. Anti-nutritional factors are substances that when present in animal feed or water reduce the availability of one or more nutrients.

As fed. As consumed by the animal.

Bran. Refers to the pericarp or outer coarse coat of the grain, which is removed during processing.

Chuni. It consists primarily of the broken pieces of endosperm, including germ and a portion of husks obtained as a by-product during the processing of pulse grains for human consumption. The compound is valued as a concentrate feed, as it is comparatively low in fibre and high in energy and protein contents in comparison with roughages.

Concentrate. Any feed containing relatively low fibre (< 20 percent) and more total digestible nutrients (> 60 percent).

Crop residues. Refers to the materials left in an agricultural field or orchard after the crop has been harvested.

Dehulling. Process of removing the outer covering from grains or other seeds.

Dehulled grains. Grains from which the outer covering has been removed.

Digestibility. Refers to the extent to which a feedstuff is absorbed from an animal's gastrointestinal tract. It varies greatly with the type of feedstuff and type of animal in context.

Digestible energy (DE). Digestible energy provides an indication of the actual amount of energy from a feed that can be available for use by the animal.

Dry matter (DM). Represents everything contained in a feed sample except water; this includes protein, fibre, fat, minerals, etc. In practice, it is the total weight of feed minus the weight of water in the feed, expressed as a percentage.

Dry matter digestibility (DMD). Refers to the portion of the dry matter in a feed that is digested by animals at a specified level of feed intake.

Dry matter intake (DMI). Refers to the amount of dry matter consumed by the animal and is a central concept to any discussion of animal nutrition.

Forage. Refers to plants or plant parts other than separated grains fed to or grazed by domestic animals. Forage may be fresh, dry or ensiled (such as pasture, green chop, hay, haylage).

Haulms. Plant material above the ground level, harvested, dried and used for feeding livestock.

Hay. The aerial part of fine-stemmed forage crops that has been cut and dried for animal feeding.

Husks (Hulls). Husks are outer covering of grain or other seed, especially when dry.

***In sacco* degradability.** It is the same as *in situ* degradability, wherein a ground feed sample is incubated in a porous nylon bag placed within the rumen for a fixed time period; and loss in dry matter or nitrogen is measured and this loss is taken as degradability.

***In situ* digestibility.** *In situ* digestibility is determined by incubating a ground forage sample in a porous nylon bag placed within the rumen via a fistula or port in the animal's side (*in situ*) for a fixed time period.

***In vitro* digestibility.** *In vitro* digestibility of a feed is determined by incubating a ground feed sample with rumen fluid in a beaker or test tube for 24 to 48 hours, followed either by addition of acid and pepsin and further incubation for 24 hours or by boiling in neutral detergent fibre solution.

In vitro. *In vitro* (Latin for "within the glass") generally refers to the technique of performing a given biological procedure in a controlled environment outside of a living organism. In feed testing, *in vitro* refers to a feed sample that is digested in test tubes or tested outside the animal.

In vivo. Occurring in the living body.

Legume. A plant, member of the Leguminosae family, whose fruit is typically a pod and with a majority of the plants having the ability to form symbiotic nitrogen fixing nodules with bacteria on its roots.

Meal/*korma*. Meal is the main by-product of pulse industry, and rich in protein (40–45 percent, DM basis). It is a mixture of germs and hulls, having approximate ratio at 25:75 percent. Richer (50–55 percent, DM basis) protein meal is also called korma.

Mixed-farming systems. Livestock systems in which more than 10 percent of the dry matter fed to animals come from crop by-products or stubble, or more than 10 percent of the total value of production come from non-livestock farming activities.

Monogastric. Animals having a single compartment or simple stomach system (such as swine, horse).

Offal/Waste. The offal/waste is produced after splitting the seeds in a mill to remove the shells, winnowing to remove loosened testa and converting the cotyledons into fine flour by milling several times followed by sieving.

Palatability. Refers to the appeal and acceptability of feedstuffs to an animal. Palatability is affected by the feed's odour, texture, moisture, physical form and temperature. For forage to be considered "high-quality," it must be highly palatable because quality is related to intake, and palatability is required for high intake levels.

Pulse. The word "pulse" originated from the Latin word puls - meaning thick soup or potage. Pulses are important crops belonging to the Leguminosae family. They comprise annual and perennial leguminous crops of which edible seeds are used for both food and feed.

Roughage. Refers to bulky and coarse feed high in fibre (> ca 18 percent crude fibre) but lower in energy than most concentrates. Roughage includes hays, straws, silage, stover, legume plants, shrubs, tree foliage and grasses.

Ruminants. Ruminants are a class of animals that have multiple organs working together to accomplish digestion. The digestive tract consists of the reticulum (involved in rumination and in passage from the rumen to the omasum), rumen (large compartment used for fermentation), omasum (once called the manyplies, it removes excess liquid and nutrients moving out of the reticulo-omasal orifice), and abomasum (acid-pepsin digestion similar to a monogastric).

Screenings. Refers to the by-products of cleaning seeds, which can consist of whole and broken seeds, cereal grains, weed seeds, chaff and dust.

Silage. Refers to feed preserved by an anaerobic fermentation process in which lactic acid and volatile fatty acids (produced by fermentation) lower the pH of the silage.

Stovers. Stovers are by-products after harvesting grains. They are given to the livestock with various supplements. Stovers are much better roughages than straws.

Straw. Refers to the crop residue consisting of the dry stems and leaves left after the harvest of cereals, legumes and other crops.

Total digestible nutrients (TDN). A value that indicates the relative energy value of a feed for an animal.

Abbreviations and acronyms

ADF	Acid detergent fibre
ADL	Acid detergent lignin
BW	Body weight
Ca	Calcium
CF	Crude fibre
cm	Centimetre
CIAT	International Center for Tropical Agriculture
Co	Cobalt
CP	Crude protein
Cu	Copper
DM	Dry matter
DMD	Dry matter digestibility
DMI	Dry matter intake
EE	Ether extract
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
g/d	Gram per day
h	Hour
ha	Hectare
HCN	Hydrogen cyanide
ICARDA	International Center for Agricultural Research in the Dry Areas
IITA	International Institute for Tropical Agriculture
kg/d	Kilogram per day
m	Metre
LWG	Liveweight gain
masl	Metres above (mean) sea level
ME	Metabolizable energy
Mg	Magnesium
min	Minute (time)
MJ	Megajoule
mm	Millimetre
Mn	Manganese
N	Nitrogen
NDDB	National Dairy Development Board (India)
NDF	Neutral detergent fibre
nes	Not elsewhere specified
NFE	Nitrogen free extract
NRC	National Research Council (United States of America)

OM	Organic matter
OMD	Organic matter digestibility
P	Phosphorus
TIU	Trypsin inhibitor units
$W^{0.75}$	Metabolic body weight
Zn	Zinc

Chapter 1
Introduction

The word "pulse" originated from the Latin word *puls* – meaning thick soup or potage. Pulses are important crops belonging to the Leguminosae family. They comprise annual and perennial leguminous crops with edible seeds that are used for both food and feed. According to FAO (1994), the term "pulses" is limited to crops harvested solely for dry grain, thereby excluding those crops used mainly for oil extraction [e.g. soybean (*Glycine max* (L.) Merr.) and groundnut (*Arachis hypogaea* L.)] and for sowing purposes [e.g. seeds of clover (different species belonging to the genus *Trifolium* L.) and alfalfa (*Medicago sativa* L.)]. Likewise, legume species are not considered as pulses when they are harvested as vegetables [e.g. green peas (*Pisum sativum* L.); green beans (*Phaseolus vulgaris* L.)]. A list of pulse commodities (FAO, 1994), including the scientific names of the species, is presented in Table 1.1.

Pulses have been cultivated for millennia and have become essential for human and animal nutrition as well as for improving agronomic systems. Pulses are grown in virtually every corner of the globe. They are an important crop group in the cropping patterns of several developing countries in Asia, Africa, and Latin America. Globally, pulse production increased from 44.9 million tonne in 1981-1983 to 72.3 million tonne in 2011-2013. The area under production increased from 63 million hectare to 80 million hectare over the same time period (IFPRI, 2016). India is the world's largest pulse producer, accounting for 34 percent of area, and 24 percent of total production in pulses. Pulse production in India increased from 10.4 million tonne to 17.5 million tonne from 1981-1983 to 2011-2013, mainly due to increases in the area under production, from 22 million hectare to 27 million hectare (IFPRI, 2016). In 2011-2013 (average), the world's biggest producers of pulses were India (24.3 percent), Myanmar (7.3 percent) Canada (7.0 percent), China (6.3 percent), Nigeria (4.6 percent), Brazil (4.2 percent), Australia (4.2 percent), Russian Federation (3.2 percent), Ethiopia (2.9 percent), and United States of America (2.8 percent). Major international research centres working on various pulse crops are given in Appendix A. Global production of major pulse crops is given in Appendix B.

The pulse sector is undergoing dynamic changes at global, regional and country levels, to meet the challenge of growing demand in face of sluggish production growth. Projections indicate that demand for pulses will continue to grow in the short-to-medium term in developing counties due to growing population and rising per capita incomes. Globally, the average share of pulses is only 5 percent of the total protein consumption, but their contribution in several developing countries range between 10 and 40 percent (Joshi and Parthasarathy Rao, 2016). Pulses are an important crop group in the cropping patterns of several developing countries in Asia, Africa, and Latin America;

Table 1.1 Classification of pulses according to FAO (1994) and their global production for year 2014

FAO Code	Commodity	Remarks[1]	Production[2]
176	Beans, dry	This is an aggregated category that includes the following species: 1) Common bean (*Phaseolus vulgaris* L.) 2) Lima bean (*Phaseolus lunatus* L.) 3) Scarlet runner bean (*Phaseolus coccineus* L.) 4) Tepary bean (*Phaseolus acutifolius* A. Gray) 5) Adzuki bean [*Vigna angularis* (Willd.) Ohwi & H. Ohashi] 6) Mung bean [*Vigna radiata* (L.) R. Wilczek] 7) Mungo bean [*Vigna mungo* (L.) Hepper] 8) Rice bean [*Vigna umbellata* (Thunb.) Ohwi & H. Ohashi] 9) Moth bean [*Vigna aconitifolia* (Jacq.) Maréchal]	25 093 616
191	Chickpeas	This category includes only one species: 1) Chickpea (*Cicer arietinum* L.)	14 239 010
187	Peas, dry	This category includes only one species: 1) Pea (*Pisum sativum* L.)	11 332 772
195	Cowpeas, dry	This category includes only one species: 1) Cowpea [*Vigna unguiculata* (L.) Walp.]	5 588 947
201	Lentils	This category includes only one species: 1) Lentil (*Lens culinaris* Medik.)	4 885 271
197	Pigeon peas	This category includes only one species: 1) Pigeon pea [*Cajanus cajan* (L.) Huth]	4 858 102
181	Broad beans	This category includes only one species: 1) Broad bean (*Vicia faba* L.)	4 297 465
210	Lupins	This is an aggregated category that includes several species of the genus *Lupinus* L.: 1) *Lupinus albus* L. 2) *Lupinus luteus* L. 3) *Lupinus angustifolius* L. 4) *Lupinus mutabilis* Sweet	981 480
205	Vetches	This category includes only one species: 1) Vetch (*Vicia sativa* L.)	883 238
203	Bambara bean	This category includes only one species: 1) Bambara bean [*Vigna subterranea* (L.) Verdc.]	287 793
211	Pulses nes[3]	This is aggregated which includes species of minor relevance at international level: 1) Hyacinth bean [*Lablab purpureus* (L.) Sweet] 2) Jack bean [*Canavalia ensiformis* (L.) DC.] 3) Winged bean [*Psophocarpus tetragonolobus* (L.) DC.] 4) Guar bean [*Cyamopsis tetragonoloba* (L.) Taub.] 5) Velvet bean [*Mucuna pruriens* (L.) DC.] 6) African yam bean [*Sphenostylis stenocarpa* (Hochst. ex A. Rich.) Harms]	5 151 560

[1] Scientific names are sourced from the updated taxonomic database Tropicos (MBG, 2016).
[2] The unit of measurement is tonne.
[3] Stands for not elsewhere specified.

and in these regions, they are an important component of the diet along with staples like wheat and rice. They are of particular importance for food security – and more importantly nutrition security – particularly in low-income countries, where plant products are the major sources of protein. Pulse crops can potentially help improve health and nutrition, reduce poverty and hunger, and enhance ecosystem resilience.

The nutritional attributes of pulses for human nutrition are indisputable. In addition to contributing directly to food security, pulses also play an important role in providing valuable by-products for animal feeding and thus indirectly contributing to food security. There is also considerable potential to use crop by-products (crop residues) left after harvesting the seeds, as sources of dry fodder for livestock. These by-products are good animal feeds and play an important role in the feed-food security nexus. In addition, these by-products do not compete with human food, and contribute to decreasing cereals and soybean levels in the diets of livestock in intensive livestock production systems. In semi-intensive ruminant production systems, by-products such as pulse crop residues provide a good source of nutrients. They are used by small-scale farmers in extensive or mixed crop-livestock production systems to ameliorate feed shortage (Nigam and Blümmel, 2010). Pulse by-products are also used to fill feed gaps during periods of acute shortage of other feed resources and used as adjuncts to natural pastures and planted forages (Williams *et al.*, 1997).

The potential of pulses and their by-products as animal feed is governed by mainly two factors: 1) the contribution of nutrients to the diet, and 2) the presence of anti-nutritional factors. Pulse seeds are sources of energy, fibre, amino acids, minerals, vitamins and essential fatty acids. However, their contribution of energy and amino acids is what confers on them the greatest economic potential in animal feeding. Feeding of by-products in livestock production provides particularly important economic, social and environmental benefits by saving grains used for feeding for animals. It also encourages the return of the manure to farmland, thereby sparing use of chemical fertilizers. Pulse cultivation also fixes atmospheric nitrogen and increases soil nitrogen content, so playing also an important role in decreasing the use of nitrogen fertilizers.

There are various factors that may influence the feeding value of crop residues. Plant factors like species, stage of maturity at harvest, cultivar, and proportions of leaf, sheath and stem influence the nutritive value of crop residues (Agbagla *et al.,* 2001; Qingxiang, 2002). Factors also known to affect the composition and digestibility of straw are variety and cultivar (Mould *et al.,* 2001; Kafilzadeh and Maleki, 2012). The yield and composition of crop residues could be influenced by environmental factors, including location, climate, soil fertility and soil type (Qingxiang, 2002) and seasonal effects (Mathison *et al.,* 1999). Biological factors (genetic makeup of the crop) also have influence on yield and quality of crop residues. The utilization of crop residue nutrients is influenced by animal factors including species/genotype, live weight, age, body condition, type and level of production and diseases. The efficiency of utilization of crop residues is different among various breeds and types of animals. Besides, growing and harvesting condition, and threshing and storage methods could also affect their utilization by animals.

Legume straws, for example those of pulses, in general have high metabolizable energy concentrations and lower neutral detergent fibre (NDF) contents than cereal straws. This is because of their greater proportion of highly digestible cell contents. Furthermore, legume straws have higher dry matter digestibility than that of the cereal straws (López *et al.,* 2005). Legume straws also have higher concentrations of pectins than grasses, and these carbohydrates are important components of the intracellular spaces and degraded extensively by rumen micro-organisms. In addition, pulse crop residues (straw) contain lesser fibre and higher digestible protein than cereal straws (Solomon, 2004; Tolera, 2007).

The General Assembly of the United Nations declared 2016 as ***the International Year of Pulses.*** To create awareness on use of pulse by-products as animal feed, the National Dairy Development Board (NDDB) of India, with the support of the Food and Agriculture Organization of the United Nations (FAO), Rome produced this state-of-the art document on ***"Pulses and their by-products as animal feed"***. In this document, we have attempted to highlight the nutritional role of pulse by-products for domestic animals that provide milk, meat and eggs. The by-products covered are plant residues (plant remaining after harvesting pulse grains), *chunies* and husks. *Chunies* are a mix of seed coats and endosperm fractions, husk is only the seed coat, and these are obtained during processing of pulses for human consumption. Each pulse has been described under sub-headings such as common names, description, distribution, production, chemical composition, anti-nutritional factors and effect of feeding in ruminants, pig and poultry.

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Chapter 2
Beans

The word “bean” originates from the old German word *böna* (in modern German *Bohne*) and has been in use since the eleventh century. Bean originally meant the seed of the broad bean (*Vicia faba* L.), but was later broadened to include members of the genus *Phaseolus* L., such as the common bean or haricot (*Phaseolus vulgaris* L.) and the runner bean (*Phaseolus coccineus* L.), and other *Leguminosae* genera like *Vigna* Savi and *Glycine* Willd. Currently, the term is mostly applied to refer to the plant and seed of the allied genus *Phaseolus* (Proffitt, 2016). Indeed, the FAOSTAT category “dry beans” originally comprised only species of the genus *Phaseolus* (FAO, 1994). However, species delimitations in the genus *Phaseolus* have been revised through new taxonomic evidence and, consequently, five species originally included into this category are currently treated as *Vigna* (i.e. *Vigna angularis*, *V. radiata*, *V. mungo*, *V. umbellata* and *V. aconitifolia*) (FAO, 2016). In this chapter, the term beans is used to refer to the nine species classified by FAO (1994) as “dry beans”.

Beans of *Phaseolus* species are one of the most ancient crops of the New World, and they have been a dominant staple in the low-to-mid altitudes of the Americas for millennia. Beans are extremely diverse crops in terms of cultivation methods, uses, the range of environments to which they have been adapted, and morphological variability. They are found from sea level up to 3 000 m above mean sea level (masl), and are cultivated in monoculture, in associations, or in rotations. Beans are consumed as mature grain, as immature seed, as well as a vegetable (both leaves and pods).

Beans of *Vigna* species have a pantropical distribution and economically important pulses of this genus originated either from Africa or Asia. They are adapted to a broad range of environmental conditions and can be found up to 1 800 masl.

Beans, as an aggregate commodity comprising species of the genera *Phaseolus* and *Vigna*, are the most important pulses for direct human consumption in the world. Total production exceeds 23 million tonne, of which 7 million tonne are produced in Latin America and Africa (Broughton *et al.*, 2003). Bean seeds contain between 20 and 25 percent proteins, much of which is made up of the storage protein phaseolin (Ma and Bliss, 1978). Phaseolin is a major determinant of both quantity and nutritional quality of proteins in bean seeds (Gepts and Bliss, 1984). Like other seed proteins of the legume family, phaseolin is deficient in sulphur-containing amino acids such as methionine. Taxonomy and species information of beans are described below:

Table 2.1 Taxonomic affinities of dry beans

Rank	Scientific name and common name
Kingdom	Plantae – Plants
Subkingdom	Tracheobionta – Vascular plants
Super division	Spermatophyta – Seed plants
Division	Magnoliophyta – Flowering plants
Class	Magnoliopsida – Dicotyledons
Subclass	Rosidae
Order	Fabales
Family	Leguminosae – Pea family
Subfamily	*Papilionoideae*
Genus	*Phaseolus* L. and *Vigna* Savi – Beans
Species	*Phaseolus vulgaris* L. – Common bean
	Phaseolus lunatus L. – Lima bean
	Phaseolus coccineus L. – Scarlet runner bean
	Phaseolus acutifolius A. Gray – Tepary bean
Species	*Vigna angularis* (Willd.) Ohwi & H. Ohashi – Adzuki bean
	Vigna radiata (L.) R. Wilczek – Mung bean
	Vigna mungo (L.) Hepper – Mungo bean
	Vigna umbellata (Thunb.) Ohwi & H. Ohashi – Rice bean
	Vigna aconitifolia (Jacq.) Maréchal – Moth bean

2.1 Common bean

COMMON NAMES

Beans, bush bean, flageolet bean, French bean, garden bean, green bean, haricot bean, kidney bean, navy bean, pole bean, snap bean, string bean (English); haricot à couper, haricot, haricot commun, haricot pain, flageolet, haricot vert (French); judía, frijol comun, nuña, habichuela, poroto, vainita (Spanish); feijão, feijoeiro (Portuguese); gewone boon (Dutch); Gartenbohne (German); buncis (Indonesian); fagiolo (Italian); maharage (Swahili); fasulye (Turkish).

DISTRIBUTION

The common bean (*Phaseolus vulgaris* L.) originated in Central and South America. It is an ancient crop and archaeological evidence indicates that it was being cultivated as early as 6 000 BC. The crop was brought to Africa in the sixteenth century by Portuguese traders and carried to high-altitude regions by slave trading caravans and merchants. Domestication occurred in Central America (Mexico and Guatemala) and in South America (Peru) independently, leading to two distinct genepools. Today, common bean is a globally important crop, especially in North and South America, Europe, Africa and Asia.

DESCRIPTION

Common bean is widely cultivated for its delicious seeds which add flavour and protein to the diets of people throughout the world. This ancient crop belongs in the Leguminosae family and like many other legumes it has an ability to fix nitrogen from the air through a symbiotic relationship with bacteria housed in its root nodules. As a result, common bean is high in protein and in many parts of the world, it is considered as the *'meat of the poor'*. The impressive diversity of colours, textures and tastes of the common bean make it a popular choice for people everywhere.

Common bean is a highly polymorphic warm-season, herbaceous annual. There are two types of plant: (1) Erect herbaceous bushes, up to 20–60 cm high; and (2) Twining, climbing vines up to 2–5 m long (Ecocrop, 2013). It has a taproot with many adventitious roots. The stems of bushy types are rather slender, pubescent and many-branched. In twining types, the stems are prostrate for most of their length and

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*Photo 2.1.1 Seeds of common bean (*Phaseolus vulgaris *L.)*

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*Photo 2.1.2 Common bean (*Phaseolus vulgaris *L.) intercropped with maize (*Zea mays *L.)*

rise toward the end. The leaves, borne on long green petioles, are green or purple in colour and trifoliate. The flowers are arranged in pairs or solitary along the rachis, white to purple and typically papilionaceous. Once pollinated, each flower gives rise to one pod. Pods are slender, green, yellow, black or purple in colour, sometimes striped. The pods may contain 4 to 12 seeds. The seeds are 0.5–2 cm long, kidney-shaped and highly variable in colour depending on the cultivar: white, red, green, tan, purple, grey or black. Mature pods and seeds are dried. Crop residues, such as dried pods and stems (straw) and processing by-products (discarded pods) can be used as animal feed (Wortmann, 2006).

CLIMATIC CONDITIONS FOR CULTIVATION

Common bean grows well at temperatures ranging from 15 to 27 °C and withstands temperatures up to 29.5 °C. High temperature (close to or higher than 35 °C) and moisture stress during flower and pod setting results in abortion of large numbers of blossoms and developing pods. The ideal rainfall growing conditions are 350–500 mm rainfall during the growing season, combined with low relative humidity to minimize risk of bacterial and fungal disease (Salcedo, 2008). Most types of bean require a frost-free growing season of 85 to 120 days. Suitable soil types range is from light to moderately heavy and to peaty (with organic matter) soils with near-neutral pH and good drainage. Common bean is sensitive to salt.

SEED PRODUCTION

According to FAO (2013), production of dry beans (*Phaseolus* L. and *Vigna* species) was about 23 million tonne in 2012, cultivated on 29 million ha. Myanmar, India, Brazil, China, the United States of America, Mexico and the United Republic of Tanzania represented two-thirds of the world production of dry beans. China was the main producer of fresh beans (*Phaseolus* and *Vigna* species: 17 million tonne in 2011, 77 percent of total world production). Common bean is less known in Asia where other pulses are preferred.

COMMON BEAN AND ITS BY-PRODUCTS AS ANIMAL FEED

These beans are usually processed by cooking in water, before consumption,

Table 2.1.1. Chemical composition of common bean and its straw by-product (percent, DM basis)

Parameter	Seed	Straw
Crude protein	22.2–27.4	4.8–10.7
Ether extract	1.1–2.4	0.7–1.8
Crude fibre	43.3–7.9	38.1–45.2
NDF	16.1–25.8	51.1–86.4
ADF	4.8–9.9	37.3–56.9
Lignin	0.1–0.3	5.4–9.3
Ash	4.0–6.5	7.2–12.1
Calcium	0.12–0.51	0.68–1.15
Phosphorus	0.21–0.63	0.09–0.13

Notes: DM (as fed) is 84.5–92.7 percent and 81.2–94.4 percent, for seed and straw, respectively.
ADF = acid detergent fibre; NDF = neutral detergent fibre.
Source: Feedipedia (2016).

whereas, some beans are consumed after roasting or after milling into flour (Siddiq and Uebersax, 2012). Immature seed pods are consumed as vegetables in some regions, and straw from the plants is used as forage (Broughton *et al.*, 2003). Common bean pods can be harvested 25–30 days after flowering and yields up to 5–7.5 tonne/ha of green pods (Ecocrop, 2013). If common bean is grown for dry beans, another 23–50 days are required for seed-filling. The average yield of dried beans is 0.5–1.5 tonne/ha, but yields up to 2.8–5 tonne/ha have been reported by Wortmann (2006). A yield of 1.6 kg green biomass/m^2 (about 16 tonne green biomass/ha) has been reported (CNC, 2004).

Common bean crop residue (straw)

Bean crop residues (straw) can be fed to livestock fresh, or after ensiling. It can be mixed with grains in order to increase the protein content of the silage (Linn *et al.*, 2002). Intercropping common bean with maize (*Zea mays* L.) gives silage yields that are as high as with monocropped maize, but richer in protein (Dawo, Wilkinson and Pilbeam, 2009). The chemical composition of bean crop residues depends on the proportions of stems, pod husks and leaves. The stems and pod husks have low protein content (8 and 4 percent, DM basis, respectively), while the leaves are much richer in protein (20 percent, DM basis) (Pieltain *et al.*, 1996). Common bean straw (haulms) contains about 5–11 percent protein (DM basis) and is rich in fibre (38–45 percent, DM basis), as shown in Table 2.1.1. However, like other legume straws, it has a higher nutritive value than cereal straws due greater protein and lower fibre content.

Digestibility. The common bean residues such as stems, leaves and pods, contain metabolizable energy with 9.2 MJ/kg DM for stems, 8.5 MJ/kg DM for leaves and 10 MJ/kg DM for pods. These values are close to that of medium quality grass hay. Protein degradability in the rumen was very high (70 percent) (Pieltain *et al.*, 1996). Due to higher protein and lower fibre content, bean straw has a higher DM digestibility and metabolizable energy content than cereal straws. Leaf-rich straw has a higher *in vitro* DM digestibility than stem-rich straw (74 *vs* 68 percent) and a higher ME (8.0 *vs* 7.3 MJ/kg DM, estimated by the gas production method) (López *et al.,* 2005).

ANTI-NUTRITIONAL FACTORS

Common beans contain several anti-nutritional compounds, notably enzyme (trypsin, chymotrypsin, alpha-amylase) inhibitors, phytic acid, flatulence factors, saponins and lectins (Krupa, 2008). These anti-nutritional factors may affect the performance of monogastric animals or even be toxic; for example lectins are known to have caused food poisoning in humans who have eaten undercooked or raw beans. Therefore, it is highly recommended to process raw common beans before feeding to pigs, poultry and other monogastric livestock. Treatments such as heating, autoclaving, cooking or extruding have been shown to remove heat-sensitive anti-nutritional factors (Akande *et al.,* 2010). Biological treatments such as germination, ensiling, treatment with pancreatin or with chemicals can also be effective in removing anti-nutritional factors in common beans (Egli *et al.*, 2002). Lectin content may be reduced by cooking above 100 °C, but cooking at a lower temperature (80 °C) increased lectin content and toxicity (FDA, 2012).

FEEDING OF SEED AND ITS BY-PRODUCTS

Cattle

Buschinelli de Goes *et al.* (2013) evaluated productive performance, nutrient digestibility and ruminal fermentation parameters on the inclusion of common beans at 0, 13 and 26 percent in the diet of cattle. The study found that the addition of beans in the diet did not affect animal performance, dry matter intake (DMI) and feed efficiency. However, the digestibility of DM, OM, CP, EE and total carbohydrates decreased with the inclusion of 26 percent. The best digestibility was observed at the 13 percent inclusion level. Thus, common bean can be included up to 13 percent in the diet of feedlot cattle. Nunes (1998) also recommended including common bean at between 15 and 20 percent of the concentrate for growing cattle.

A study conducted by Patterson *et al.* (1999) in Eastern Colorado revealed that feeding raw beans to cattle reduced feed intake, due to a palatability problem. However, mixing the beans with sunflower meal eliminated the palatability problem in beef cows grazing native winter range. Body weight, body condition score, reproductive performance and calf performance were not affected by feeding raw beans.

Goats

Bean straw and maize stubbles included at 15 percent in goat diets resulted in lower body weight gains and feed efficiency than those obtained with a good quality, forage-based diet (Serrato Corona, Partida Rodríguez and López Martínez, 2004). Aredo and Musimba (2003) reported that bean haulms were poorly ingested and digested by low-producing goats in Ethiopia. Ramírez and Ledezma-Torres (1997) evaluated that feeding bean straw at 75 to 80 percent of the basal diet (up to 3.5 percent BW) did not affect nutrient intake and DM digestibility in goats.

Llama

López and Morales (2001) demonstrated that on feeding llamas (*Lama glama*) bean straw, the intake and protein digestibility were similar to those of ryegrass hay (29 g/kg $BW^{0.75}$/d and 35 percent, respectively). Similarly, the digestibilities of neutral detergent fibre (NDF) (54 percent) and acid detergent fibre (ADF) (52 percent) were similar to those of oat straw.

Pigs

Unprocessed common beans contain anti-nutritional factors that are deleterious to pigs. Therefore, it is recommended to process common beans before feeding to pigs. Raw beans included at 20 percent of the diet reduced weight of pancreas thymus and spleen weight, protein digestibility, nitrogen (N) balance and overall performance (Huisman *et al.,* 1990a). However, heat treatments (102 °C for 20 min or 136 °C for 1.5 min) were shown to have beneficial effects on the nutritive value of common beans as they almost completely inactivated anti-nutritional factors. Heating also enhanced the digestibility of dry matter, protein and lysine (van der Poel *et al.,* 1991a; van der Poel *et al.,* 1991b). However, in piglets, compared with maize-casein, common beans heated at 105 °C for 20 min were less readily eaten, and growth rate was reduced (van der Poel, 1990).

Poultry

A study conducted by Ofongo and Ologhobo (2007) in Nigeria, indicated that 50 percent soybean meal protein replacement with cooked kidney beans gave performance that was equally as good as feeding either soybean [*Glycine max* (L.) Merr.] meal or groundnut (*Arachis hypogaea* L.) cake as protein source. Chicken fed raw beans had no differences in spleen and thymus weights compared with those fed the control diet (Huisman *et al.,* 1990b). However, raw common beans increased weight of the intestine and decreased liver weight (Emiola and Ologhobo, 2006). Liver showed marked coagulative necrosis and degeneration of hepatocytes, while there was a severe congestion of glomeruli and distention of the capillary vessels with thrombi in the kidneys (Emiola and Ologhobo, 2006; Emiola, Ologhobo and Gous, 2007a; Emiola, Ologhobo and Gous, 2007b). Fermented common beans included at levels ranging from 5 to 20 percent in poultry diets reduced feed intakes, live-weight gains and feed efficiency. It was suggested to limit their inclusion to 5 percent in the diet (Siriwan, Pimsan and Nakkitset, 2005a; Siriwan, Pimsan and Nakkitset, 2005b).

Several experiments showed that aqueous cooking, in preference to toasting, or soaking-extruding improved the nutritive value of common beans in poultry diets, with satisfactory results compared with control diets (Emiola, Ologhobo and Gous, 2007a; Emiola, Ologhobo and Gous, 2007b). With boiled, cooked or extruded common beans, digestibilities of nutrients (protein, amino acids, ether extract, crude fibre, ash and N) were higher than with raw, toasted or dehulled beans (Arija *et al.*, 2006). Heat-processed common beans replaced up to 50 percent of the protein provided by soybean meal (Emiola, Ologhobo and Gous, 2007a; Emiola, Ologhobo and Gous, 2007b). Heat processed beans included at 20 percent of the diet replaced completely soybean and groundnut meal mixtures without loss of performance (Emiola *et al.*, 2003), but with soybean meal in a maize-soybean based diet, complete replacement was not satisfactory (Arija *et al.*, 2006). Common beans, boiled for 30 minutes under an uncontrolled temperature and pressure, could not satisfactorily replace meat meal and fishmeal at 11 percent of the diet for starters and at 14 percent for finisher broilers (Defang *et al.*, 2008). Roasted beans gave poorer results than full-fat soybean seeds, soybean meal or cottonseed meal for boilers (Poné and Fomunyam, 2004).

SUMMARY

Common beans can be mixed with other protein meals and incorporated at up to 20 percent in the ration of large ruminants. Due to presence of various anti-nutritional factors, it is recommended to process raw common beans before feeding to pig, poultry and other monogastric animals. Heat treatment increases the nutritive value of common beans. Up to 50 percent of the protein provided by soybean meal in poultry diet can be replaced by common beans.

2.2 Lima bean

COMMON NAMES

Butter bean, Java bean, Madagascar bean, sieva bean, sugar bean (English); haricot de Lima, haricot du Cap, pois du Cap (French); feijão de Lima, fava belém (Portuguese); frijol de luna, haba lima, judía de Lima, pallar, garrofón, guaracaro (Spanish); kacang kratok (Indonesian); Limabohne, Mondbohne (German); fagiolo di Lima (Italian); pwachouk (Haitian Creole); patani (Tagalog).

DISTRIBUTION

Lima bean (*Phaseolus lunatus* L.) originated in the Neotropics and has two main centres of domestication. The small-seeded genotypes were developed in Central America and the large-seeded types were cultivated in South America (mainly in Peru) as far back as 6 000 BC. After domestication, lima bean spread throughout the Americas, and the Spaniards imported it to the Pacific Islands and the Philippines. It later spread to South-East Asia, Western and Central Africa. Today, lima bean is cultivated throughout the tropics.

DESCRIPTION

Lima bean is a tropical and sub-tropical legume cultivated for its edible seeds, which are enjoyed by millions of people throughout the world. Also known as butter bean on account of its creamy taste, lima bean adds flavour, protein and important minerals such as manganese and iron, to a wide variety of dishes. It is also highly valued for its medicinal properties.

Wild and cultivated types of lima bean are generally referred to as *Phaseolus lunatus* var. *silvester* Baudet and *P. lunatus* var. *lunatus*, respectively. Lima bean is a herbaceous plant with two main types of growth habit. The perennial form is an indeterminate, vigorous, climbing and trailing plant, up to 2–6 m tall, with axillary flowering only. It has swollen and fleshy roots up to 2 m long. Annual lima bean is a pseudo-determinate, bushy plant, 0.3–0.9 m tall with both terminal and axillary flowering. It has thin roots. The stems may be up to 4.5–8 m long. The leaves are alternate and trifoliate with ovate leaflets, 3–19.5 cm long × 1–11 cm broad. Inflorescences are 15 cm long and bear 24 white

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*Photo 2.2.1 Seeds of lima bean (*Phaseolus lunatus *L.)*

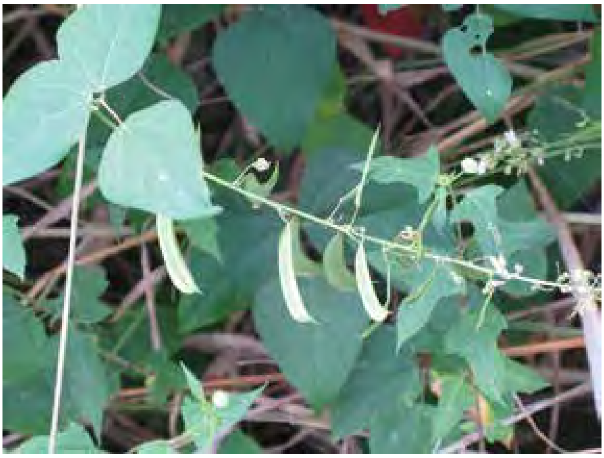

*Photo 2.2.2 Plant of lima bean (*Phaseolus lunatus *L.) with flowers and pods*

or violet bisexual flowers. The fruits are 5–12 cm long, dehiscent pods with 2 to 4 seeds (Ecocrop, 2011). Seeds are very variable in size, shape and colour. The vines, leaves and empty pods left after the harvest can serve as fodder, and can be made into hay or silage.

CLIMATIC CONDITIONS FOR CULTIVATION

Lima bean is found in humid, sub-humid and semi-arid tropical climates as well as warm temperate climates. In humid climates, it is often intercropped with cereal crops, root crops or other crops, while in drier climates it tends to be used as sole crop. Lima bean requires a dry period for the seeds to mature. Lima bean grows better in areas where temperatures range from 16 to 27 °C, with annual rainfall from 900 to 1 500 mm. Once well established, it can withstand rainfall as low as 500–600 mm. Perennial forms of lima bean are considered drought resistant. Lima bean is tolerant of a wide range of soils but prefers well-drained soils with a pH above 6. However, some cultivars do well in acid soils with a pH as low as 4.4 (Ecocrop, 2011).

LIMA BEAN AND ITS BY-PRODUCTS AS ANIMAL FEED

Lima bean seeds

Lima beans are relatively rich in protein (25 percent, DM basis) and starch (40 percent, DM basis), but low in fibre (5 percent, DM basis) and fat (<1.5 percent, DM basis), as shown in Table 2.2.1. The seeds of lima bean are sometimes used to feed livestock, but there is a risk of hydrogen cyanide (HCN) poisoning if used raw. Dry or moist heat treatment is an effective way to remove anti-nutritional factors in lima beans (Adeparusi, 2001). Soaking and cooking lima beans remove most of the HCN, and sub-lethal poisoning can be alleviated by supplements of iodine and sulphur amino acids (Barnes *et al.,* 2007)

Lima bean crop residue (straw)

The nutritive value of lima bean straw is comparable to that of cereal and grass hays. Therefore, it can be used as livestock feed for cattle and sheep. It is suggested that it can be fed in combination with alfalfa (*Medicago sativa* L.) hay in order to increase its protein content. Dairy cows can be fed on lima bean vines, with or without seeds. Vines should be chopped in order to enhance palatability.

Table 2.2.1 Chemical composition of lima bean and its by-products (percent, DM basis)

Parameter	Seeds	Vines (fresh)	Vines (dehydrated)
Crude protein	18.9–28.2	19.4	12.5
Ether extract	08.8–1.7	1.5	1.9
Crude fibre	41.1–6.6		29.3
NDF	13.3	38.2	45.8
ADF	6.0	17.0	34.7
Lignin		7.4	
Ash	4.0–5.5		11.6
Calcium	0.06–1.12		
Phosphorus	0.43–0.78		

Notes: DM (as fed) is 88.4 percent for seeds and 38.6 percent for fresh vines.
ADF = acid detergent fibre; NDF = neutral detergent fibre.
Source: Feedipedia (2016).

Silage can be made from young vines and can be fed to growing and milking cattle (Ishler and Adams, 2010). However, it is recommended to limit the feeding of bean silage to 60 to 80 percent of the usual intake of forage dry matter (Ishler and Adams, 2010). Ajayi (2011) reported that a silage made of young lima bean vines (before flowering), fresh Napier grass (*Pennisetum purpureum* Schumach.) and pineapple pulp has high dietary protein content, nutrient digestibility, nitrogen absorption and retention, and its feeding also reduced weight loss of goats during the dry season in Nigeria. Ajayi *et al.* (2012) also observed that in a comparison with silages made from the vines of either lima bean, pigeon pea [*Cajanus cajan* (L.) Huth] or African yam bean [*Sphenostylis stenocarpa* (Hochst. ex A. Rich.) Harms] the silage based on lima bean vines alone, produced the optimal growth rate and weight gain in goats.

ANTI-NUTRITIONAL FACTORS

Lima bean seeds and leaves contain cyanogenic glucosides (linamarin and phaseolunatin) and linamarase – an enzyme that turns cyanogenic glucosides into hydrogen cyanide (HCN). The level of HCN varies with maturity, stage of development, genotype and cultivation conditions. Young leaves and seeds have higher HCN production potential (Ballhorn, Lieberei and Ganzhorn, 2005), whereas, cultivated varieties contain much lower cyanoglucosides than wild varieties (100–120 ppm *vs* 2000–2400 ppm) (Baudoin, 2006). Lima bean foliage contains a wide range of anti-nutritional factors such as oxalate (5 percent), saponins (1.3 percent), phytic acid (1.8 percent) and tannins (6.5 percent) (Ajayi *et al.*, 2009).

FEEDING OF LIMA BEAN AND ITS BY-PRODUCTS

Cattle

Dairy cows can be fed on lima bean vines (with or without seeds). Vines should be chopped in order to enhance palatability. Young vines cut when the leaves were still green resulted in higher intake and were more nutritious. The

OM digestibility of lima bean foliage ranges from 56 percent (based on *in vitro* gas production) to 68 percent (*in vivo*), corresponding to ME values of 8.4 and 9.2, respectively (Ajayi *et al.,* 2009).

Sheep and goats

Ajayi (2011) in Nigeria studied the digestibility of fibre fractions of various beans and found highest digestibility in lima bean/grass silage, followed by that in pigeon pea/grass silage, and least in napier grass silage fed to goats. Nitrogen absorbed (69.7 percent) and nitrogen retention (54.8 percent) were highest in goats fed lima bean/grass silage and were significantly ($P<0.05$) different from other treatments. In another study Ajayi *et al.* (2012) also reported that the silage based on lima bean vines produced the optimal growth rate and weight gain in goats, as compared with silages made from the vines of either lima bean, pigeon pea or African yam bean.

Pigs

To the authors' knowledge, no study is available on the effect of feeding lima beans to pigs. It is likely that the presence of anti-nutritional factors limits the use of raw lima beans in pig diets. Heat treatment might allow the use of lima beans in limited amounts, at least in less sensitive adult pigs. Research is required to address these issues.

Poultry

Raw lima beans should not be used in poultry. They negatively affect growth and metabolism in broilers, mainly due to the presence of anti-nutritional factors such as lectins and trypsin-inhibitors (Achi, Adelanwa and Ahmed, 2007). However, thermal treatments can alleviate adverse effects (Akande *et al.,* 2010). Akinmutimi, Aligwara and Abasiekong (2008) reported that boiled and toasted lima beans included at 5 percent in broiler diets improved performance when compared with the soybean-based control diet. At higher levels, growth was reduced but feed efficiency was maintained due to a lower feed intake. It is reported that, after thermal treatment, lima beans can be used up to a maximum of 10 percent in broiler diets (Akande *et al.,* 2010). However, due to the potential long-term effects of anti-nutritional factors, it is not advisable to use lima beans in layer diets.

SUMMARY

Raw seeds of lima bean cannot be used as livestock feed, as they may cause hydrogen cyanide poisoning. Silage made from lima bean vines can be fed to cattle at up to 80 percent of the total forage DM intake. Silage can also be used in the diet of sheep and goats. Raw lima bean is not recommended for broilers; although, after thermal treatment, it can be incorporated to a maximum of 10 percent in the broiler diet.

2.3 Scarlet runner bean

COMMON NAMES
Case knife bean, multiflora bean, runner bean, or scarlet runner bean.

DISTRIBUTION
Scarlet bean is native to montane Central America, where it has been domesticated for over 2 000 years, and the wild type still grows in the region. Cultivars are widely grown for their ornamental flowers and edible seeds.

DESCRIPTION
Scarlet runner beans (*Phaseolus coccineus* L.) are notable among the world's many beans for several reasons. Unlike most beans the plant is perennial, albeit it is usually killed to the ground – or totally – by winter frosts. Also it is among the most productive of all beans. It is the only edible bean grown extensively as a mere ornamental, because of its gorgeous scarlet flowers. The flowers are large (around 2.5 cm or more wide), and are clustered like those of sweet-peas. So even if the big bean pods were not produced, or were inedible, this plant would be valued for its looks. It has been called the Flowering bean. The old name multiflorus alludes to its multitudes of flowers. The name *coccineus* means scarlet in Latin.

*Photo 2.3.1 Seeds of scarlet runner bean (*Phaseolus coccineus* L.)*

*Photo 2.3.2 Plant of scarlet runner bean (*Phaseolus coccineus* L.) with flowers and pods*

CLIMATIC CONDITIONS FOR CULTIVATION
Scarlet runner beans are best grown in consistently moist, fertile, organically-rich, well-drained loams in full sun. Runner beans are perennials in frost-free climates, but die to the ground at first autumn frost in temperate climates where they are grown as annuals. Runner

beans cannot tolerate frost at all, nor will they set fruit while temperatures are above 32 °C. Scarlet runner beans need abundant water during flowering and pod expansion.

The authors found no study available on the nutritive value of the scarlet runner bean by-products in animals.

SUMMARY

No information about effect of feeding scarlet runner bean and its by-products to animals was found available. More studies are required to explore the potential of their use in livestock rations.

2.4 Tepary bean

COMMON NAMES

Escomite, pawi, pavi, tepari, yori mui, yorimuni, or yori muni.

DISTRIBUTION

Tepary bean (*Phaseolus acutifolius* A. Gray) is native to the south-western United States of America and to Mexico, and has been grown there by the native peoples since pre-Columbian times. It is more drought-resistant than the common bean and is grown in desert and semi-desert conditions from Arizona through Mexico to Costa Rica. The water requirements are low and the crop grows in areas where annual rainfall is less than 400 mm.

*Photo 2.4.1 Seeds of tepary bean (*Phaseolus acutifolius *A. Gray)*

DESCRIPTION

The name tepary may derive from the Tohono O'odham phrase t'pawi or "It is a bean". The tepary bean is an annual and can be climbing, trailing, or erect with stems up to 4 m long. A narrow leafed, var. *tenuifolius*, and a broader leafed, var. *latifolius*, are known. In the Sonora desert, "the flowers appear with the summer rains, first appearing in late August, with the pods ripening early in the fall dry season, most of them in October" (Nabhan and Felger, 1978). The beans can be of nearly any colour. There are many local landraces. Beans vary in size but tend to be small. They mature 60 to 120 days after planting.

*Photo 2.4.2 Plant of tepary bean (*Phaseolus acutifolius *A. Gray) with pods*

CLIMATIC CONDITIONS FOR CULTIVATION

Tepary bean is grown as a sole crop or intercropped with cereals (sorghum, millet, maize), vegetables (Allium, Brassica, Capsicum, Cucurbita spp.), or other pulses. In the United States of America and Mexico tepary bean is sometimes sown in unsorted admixtures with common bean (*Phaseolus vulgaris* L.), thus providing greater yield stability than common bean alone and higher potential yields than tepary bean alone (Mogotsi, 2006a).

To the best of the authors' knowledge, no study is available on the nutritive value of tepary bean by-products in animals.

SUMMARY

No information about effect of feeding tepary bean and its by-products was found available. More studies are required to explore its potential as animal feed.

2.5 Adzuki bean

COMMON NAMES

Aduki, azuki, or English red mung bean.

DISTRIBUTION

Adzuki bean [*Vigna angularis* (Willd.) Ohwi & H. Ohashi] is an important grain legume in East Asia. In Japan, adzuki bean is the second most economically important grain legume, after soybean [*Glycine max* (L.) Merr.] Adzuki beans are small, usually red, and are popular in Japan and other parts of Asia. It is a traditional legume crop, grown throughout East Asia and the Himalayas for its small bean (Zong *et al.*, 2003).

DESCRIPTION

The plant is erect, 30 to 60 cm high, although some gardeners have reported them to be indeterminate, growing and producing until frost. The yellow flowers are followed by a cluster of several smooth, short, small, cylindrical pods. Leaves resemble those of cowpea while the pods are much like mung bean pods. The seeds are smaller than common beans but are two to three times larger than mung beans. Different coloured seeds, including dark red, green, straw coloured, black-orange, and mottled seeds are known. The most widely occurring seeds are of dark red colour. The round seeds have a hilum (seed scar) with a protruding ridge on the side.

The ripe seeds contain 25 percent protein on DM basis and are highly nutritious. The dry pods split open and scatter the seeds, so harvest the pods after the seeds are ripe but before they shatter. Little has been studied about Adzuki bean (Lee and Hong, 2000).

CLIMATIC CONDITIONS FOR CULTIVATION

Adzuki bean performs best in subtropical and warm temperate climates. It requires average temperatures of 15–30 °C for optimal growth. It tolerates high temperatures but is sensitive to frost. In the tropics it is more suitable for higher altitudes. Adzuki bean grows in areas with average annual rainfall of 500–1 750 mm. It is a quantitative short-day plant but day-neutral cultivars exist. Adzuki bean can

*Photo 2.5.1 Seeds of adzuki bean [*Vigna angularis* (Willd.) Ohwi & H. Ohashi]*

be grown on a wide range of soils (pH 5–7.5), provided they are well drained (Jansen, 2006a).

The authors have no knowledge of any study on the nutritive value of Adzuki bean by-products in animals. It is an area for further research.

SUMMARY

Adzuki bean is a highly nutritious food (25 percent protein, DM basis) for millions of people in East Asia. Research on feeding Adzuki bean and its by-products in livestock is required.

2.6 Mung bean

COMMON NAMES

Celera bean, golden gram, green gram, Jerusalem pea, moong bean (English); ambérique verte, haricot mungo (French); frijol mungo, judía mungo, poroto chino (Spanish); feijão-da-china, feijão-mungo (Portuguese); mungboon (Dutch); Mungbohne, Jerusalembohne (German); kacang hijau (Indonesian); kacang ijo (Javanese); fagiolo indiano verde, fagiolo mungo verde (Italian); monggo, munggo (Tagalog).

DISTRIBUTION

Mung bean [*Vigna radiata* (L.) R. Wilczek] has been grown in India since ancient times., It is now widely grown in south-east Asia, Africa, South America and Australia. It was apparently grown in the United States of America as early as 1835 as the Chickasaw pea (DAF&F, 2010).

DESCRIPTION

Mung bean is a fast-growing, warm-season legume. It is an annual crop, cultivated mostly in rotation with cereals. It is an erect plant which is highly branched and is about 60 to 76 cm tall. A bush or trailing plant that produces approximately 7.5 cm long pods containing about a dozen small green or gold-coloured seeds. It reaches maturity very quickly under tropical and sub-tropical conditions. Mung bean roots are deep rooted just like the roots of cowpea [*Vigna unguiculata* (L.) Walp.], and leaves are trifoliate like other legumes. The pale yellow flowers are borne in clusters of 12–15 near the top of the plant.

CLIMATIC CONDITIONS FOR CULTIVATION

The optimal temperature for mung bean growth is between 28 and 30°C. It can not withstand a temperature below 15 °C. It can be sown during summer and autumn. It does not require large amounts of water (600–1 000 mm rainfall/year) and is tolerant to drought. It is sensitive to waterlogging. High moisture at maturity tends to spoil the seeds, which may sprout before being harvested.

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*Photo 2.6.1 Seeds of mung bean [*Vigna radiata *(L.) R. Wilczek]*

The mung bean grows on a wide range of soils but prefers well-drained loams or sandy loams, with a pH ranging from 5 to 8. It is somewhat tolerant to saline soils (Mogotsi, 2006b).

PRODUCTION OF SEEDS

India is the largest producer of mung bean and accounts for 54 percent of world production and 65 percent of world hectarege. In India, mung bean is grown on about 3.70 million ha with annual production of 1.57 million tonne (Sharma *et al.,* 2011). China produces large amounts of mung beans, some 19 percent of its legume production. Thailand is the main exporter and its production increased by 22 percent between 1980 and 2000 (Lambrides and Godwin, 2006). Though it is produced in many African countries, mung bean is not a major crop there (Mogotsi, 2006b).

The nutritive value of mung bean lies in its high protein content and protein digestibility. Mung beans contain approximately 25–28 percent protein, 1.0 percent ether extract, 3.5–4.5 percent fibre, 4.5–5.5 percent ash and 62–65 percent carbohydrates on DM basis.

MUNG BEAN AND ITS BY-PRODUCTS AS ANIMAL FEED

Mung bean bran

Mung bean bran (called *chuni* in many Asian countries, including India) is a by-product of mung bean processing, and is the the residual by-product, containing broken pieces of endosperm including germ and a portion of husk. Mung bean bran is a good source of protein (19.2 percent, DM basis). Mung bean *chuni* can be included at 50 percent of the concentrates offered to buffaloes fed on a rice straw diet. It met maintenance requirements without any adverse effect on nutrient utilization (Krishna *et al.,* 2002).

Mung bean meal

Another by-product (mung bean meal), obtained during manufacturing of mung bean vermicelli, can be used as animal feed. The mung bean meal contains 11–23 percent crude protein, 0.4–1.8 percent ether extract, 13–36 percent crude fibre, 0.30–0.68 percent calcium and 0.17–0.39 percent phosphorus on DM basis, depending on the mung bean material (Sitthigripong and Alcantara, 1998).

Mung bean hull

Mung bean hull is the outer seed coat covering and is used as livestock feed. It is characterized by a moderate level of crude protein (12 percent, DM basis) and crude fibre (19 percent, DM basis) which makes it suitable for inclusion in diets of ruminants.

Mung bean forage

Mung bean is sometimes grown for fodder, to be used as hay, straw or silage (Mogotsi, 2006b). It is particularly valued as early forage as it out-competes

Table 2.6.1 Chemical composition of mung bean and its by-products (percent, DM basis)

Parameter	Seeds	Straw	*chuni*
Crude protein	19.5–29.4	8.7–11.6	19.2
Ether extract	0.2–3.7	2.3–2.4	2.2
Crude fibre	4.3–12.4	26.6–29.9	26.2
NDF	15.6	63.5	43.5
ADF	6.6–10.3	32.0–47.2	26.4
Lignin		4.8	4.3
Ash	0.9–14.0	6.1–12.1	4.8
Calcium	0.08–0.47	2.7	0.4
Phosphorus	0.36–0.62	0.2	0.3

Notes: DM (as fed) is 90.0 percent for seeds, 88.2 percent for straw and 95.3 percent for *chuni*.
ADF = acid detergent fibre; NDF = neutral detergent fibre.
Source: Feedipedia (2016).

other summer growing legumes such as cowpea or velvet bean [*Mucuna pruriens* (L.) DC.] in their early stages (Lambrides and Godwin, 2006). Mung bean forage yields range from 0.64 tonne/ha of green matter under unfertilized conditions to about 1.8 tonne/ha with the addition of fertilizer (FAO, 2012). Fresh mung bean forage has a moderate (13 percent, DM basis) to high (21 percent, DM basis) protein content. Garg *et al.* (2004) reported that mung bean forage can be incorporated up to 100 percent in the ration of sheep to maintain the adult sheep satisfactorily without any adverse effect.

Mung bean crop residue (straw)

Like other legume straws, mung bean straw is higher in protein (9–12 percent, DM basis) than cereal straws (Table 2.6.1). They are mixed with rice straw and wheat straw and fed to sheep and goats in the highlands of Afghanistan (Fitzherbert, 2007). Mung bean straw was found to be palatable to sheep and goat, with no deleterious effects on animal health. Dry matter digestibility of mung bean straw (64 percent) fed to ewes *ad libitum* was similar to that of the straws of groundnut (*Arachis hypogaea* L.), alfalfa (*Medicago sativa* L.) and cowpea and higher than that of pigeon pea straw (54 percent). Organic matter digestibilities were reported as 56 and 61 percent in sheep and goats, respectively (Khatik, Vaishnava and Gupta, 2007). Feeding ewes with mung bean straw increased overall DM intake from 12.6 to 18.9 g/kg live weight (LW)/day (McMeniman, Elliott and Ash, 1988).

ANTI-NUTRITIONAL FACTORS

Various anti-nutritional factors such as trypsin inhibitors, chymotrypsin inhibitor, tannins and lectins are present in mung bean. The level of anti-nutritional factors varies depending upon the type of beans. Various processing methods such as soaking and cooking can be used to reduce the effect of these anti-nutritional factors (Lambrides and Godwin, 2006; Mogotsi, 2006b).

FEEDING OF SEED AND ITS BY-PRODUCTS

Cattle

A study conducted by Zahera, Permana and Despal (2015) in Indonesia showed that mung bean fodder (produced in green house) had high digestibility and fermentability, indicating potential fodder for dairy cows. Supplementation of mung bean fodder increased nutrient intake.

Pigs

Mung bean meal has been tested in pig diets (purebred large white barrows) with satisfactory results; it could replace up to 75 percent of the rice bran in pig diets, with older pigs benefiting the most. Higher inclusion rates resulted in higher intakes but were detrimental to the feed conversion ratio (Sitthigripong, 1996). Amino acid supplementation failed to make diets based on this product as efficient as a maize-soybean-meal-based diet (Sitthigripong and Alcantara, 1998). Mung bean *chuni* was included at 15 percent level in the rations of finisher crossbred pigs (Ravi, Rao and Yedukondalu, 2005). Mung bean *chuni* can be included up to 7.5 percent without adverse effect in maize-soybean meal-based diet of nursery pig (Rungcharoen *et al.,* 2010).

Poultry

Mung bean has a higher energy value than many other legume seeds (Wiryawan *et al.,* 1995). The supplementation of broiler ration with 100 g mung bean during the starting to finishing period (15 to 35 days old) and during the finishing period (28 to 35 days old) had no effect on final weight, weight gain, feed intake, feed cost per kilogram broiler produced, feed efficiency and production efficiency of broiler (Binalay, 2012).

Broilers. Singh *et al.* (2013) observed that feeding of sprouted mung bean (10 g/bird/day) may provide protection in broiler chickens against coccidiosis-induced alteration in growth, haematological and parasitological parameters. Rungcharoen *et al.* (2010) conducted a series of experiments to determine the apparent metabolizable energy of mung bean waste (mung bean hull) in broilers and effects of its inclusion in broiler diets on growth performance and nutrient digestibility. This study recommended that the inclusion of mung bean hull in the broiler diets should be less than 5 percent to achieve optimum growth performance and nutrient digestibility of broilers.

Layers. Raw mung beans introduced at levels of 15 percent or 30 percent in the diet did not reduce egg production or feed efficiency. However, egg production was significantly depressed at a 45 percent inclusion level. Pelleting diets had no effect at the 15 percent or 30 percent inclusion rate, but had a positive effect on production at the 45 percent level (Robinson and Singh, 2001). In all cases body weight was slightly depressed by the inclusion of mung beans in the diet. The general recommendation is to use mung beans at levels up to 30 percent in layer diets, provided that the diet is properly balanced, especially with amino acids. Vinh, Tuan and Hang (2013) conduced experiments to evaluate the effect of mung bean hulls in maize-based diets for pre-laying (10–19 weeks of age) and laying (20–38 week-old) performance of Ri × Luong Phuong hens. The studies found that inclusion of 14 and 18 percent mung bean hulls in the diet at pre-laying stage were not affected from 10 to 16 weeks, but were reduced by 12 and 26 percent during the period from 16 to 20 weeks (Vinh, Tuan and Hang, 2013). It was reported that inclusion of 14 or 18 percent mung bean hulls in the laying period did not affect egg production or egg quality.

SUMMARY

Mung bean is widely grown in tropical and temperate climates. Mung bean bran (*chuni*) can be included at up to 50 percent of the concentrates for buffaloes fed cereal-straw-based diets. It can be included at up to 15 percent in crossbred pigs finisher diet. Mung bean fodder can be fed solely to sheep without any adverse effect. It is recommended to use mung beans up to 30 percent in layer diets, provided that the diet is properly balanced. To achieve optimum growth and nutrient digestibility, it is advisable to use a maximum of 5 percent mung bean hulls in broiler diet.

2.7 Mungo bean

COMMON NAMES

Black gram, black lentil, black matpe bean, mungo bean, urd bean, urad bean (English); ambérique, haricot urd (French); feijão-da-India, feijão-preto (Portuguese); frijol mungo, fréjol negro, frijol negro, lenteja negra, urd (Spanish); Urdbohne, Linsenbohne (German); fagiolo indiano nero, fagiolo mungo nero (Italian); mchooko mweusi (Swahili).

DISTRIBUTION

Mungo bean [*Vigna mungo* (L.) Hepper] was domesticated in central Asia (India) and is now widely grown in many tropical areas of Asia, Africa and Madagascar. It is cultivated in the United States of America and in Australia as a fodder crop (Jansen, 2006b). Archaeological studies have shown that it was cultivated in India as far back as 2 200 BC.

DESCRIPTION

Mungo bean is an erect, sub-erect or trailing, densely hairy, annual herb. The tap root produces a branched root system with smooth, rounded nodules. The pods are narrow, cylindrical and up to 6 cm long. The plant grows to 30–100 cm, with large hairy leaves and 4–6-cm long seed pods (Nitin, Ifthekar and Mumtaz, 2012). The leaves are trifoliate with ovate leaflets, 4–10 cm long and 2–7 cm wide. The inflorescence is borne at the extremity of a long (up to 18 cm) peduncle and bears yellow, small, papilionaceous flowers. The fruit is a cylindrical, erect pod, 4–7 cm long x 0.5 cm broad. The pod is hairy and has a short hooked beak. It contains 4–10 ellipsoid black or mottled seeds (Ecocrop, 2011). Mungo bean is easily distinguished from mung bean (*Vigna radiata* L.) by its much shorter, stout, very hairy pods and larger oblong seeds that vary in colour from blackish to olive green.

CLIMATIC CONDITIONS FOR CULTIVATION

Mungo bean grows optimally at temperatures ranging from 25 to 35 °C and annual rainfall of 600–1 000 mm. It cannot tolerate wet tropical climates but it can be grown during the dry period in high rainfall areas. Rich black vertisols or loamy soils, well-drained soils with a pH 6–7 are more suitable for mungo bean cultivation (Baligar and Fageria,

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*Photo 2.7.1 Seeds of mungo bean [*Vigna mungo* (L.) Hepper]*

2007). However, it can also withstand acidic soils (down to pH 4.5) if lime and gypsum are added to the soil (Baligar and Fageria, 2007). It is drought-tolerant and thus suitable for semi-arid areas. It is sensitive to saline and alkaline soils (Sharma *et al.,* 2011).

SEED PRODUCTION

India is the largest producer and consumer of mungo bean in the world. It is grown on about 3.24 million ha with annual production of 1.52 million tonne (Sharma *et al.,* 2011). Other producing countries are Myanmar, Thailand, Pakistan, Sri Lanka, Japan, Bangladesh, Canada, The Islamic Republic of Iran, Greece and East African countries.

ANTI-NUTRITIONAL FACTORS

Mungo bean seeds contain trypsin inhibitors and condensed tannins, sometimes in larger amounts than chickpeas (*Cicer arietinum* L.), broad beans (*Vicia faba* L.) or peas (*Pisum sativum* L.). This could limit their use if they are not processed before feeding to monogastric species. However, experimental results are inconsistent. The seeds are free from glucosides (Wiryawan, Miller and Holmes, 1997).

MUNGO BEAN SEED AND ITS BY-PRODUCTS AS ANIMAL FEED

Mungo bean seeds

Mungo bean seeds contain approximately 25–28 percent protein, 1.0–1.5 percent ether extract, 3.5–4.5 percent fibre, 4.5–5.5 percent ash and 62–65 percent carbohydrates on dry weight basis (Sharma *et al.*, 2011).

Mungo bean *chuni*

Chuni is the by-product of mungo beanmungo beanmungo bean processing, and contains broken pieces of endosperm including germ and a portion of husk, and is called *chuni* in India. The crude protein value of *chuni* ranges from 15 to 26 percent (DM basis), based on amounts of seed coats and endosperm fractions (Islam, Chowdhury and Alam, 1997). It is a potential feed resource and large quantities are available in India and other Southern Asian countries where mungo bean is a popular food (Reddy *et al.,* 2000). Swain *et al.* (2015) observed that mungo bean/mungo bean *chuni* is the best in terms of available protein among the *chunies* studied of various pulses namely mung bean, chickpea and pigeon pea [*Cajanus cajan* (L.) Huth].

Mungo bean forage

Mungo bean is also grown for forage and hay. Its crop residues are an important feed for livestock in some regions of India (Sandeep *et al.,* 2000). Fodder is derived mainly from the leaves and stems, but seeds, pods and pod husks are also used. It is usually fed to cattle as a fodder but the plant, the seeds and the by-products are also consumed by other livestock species (Fuller,

Table 2.7.1 Chemical composition of mungo bean and its by-products (percent, DM basis)

Parameter	Seeds	Straw	Pods	Husk	*Chuni*
Crude protein	20.8–26.8	8.9–17.2	9.0	18.2	20.7
Ether extract	09.9–2.2	0.4–2.8	2.3	1.4	2.2
Crude fibre	3.7–14.5	28.6	29.9	20.3	13.1
NDF	14.2–22.4	54.5–56.9		48.2	
ADF	5.2–8.4	31.9–36.4		37.4	
Lignin	0.1–0.5	4.6		9.6	3.0
Ash	3.7–7.4	8.8–12.6	12.2	5.5	11.7
Calcium	0.10–0.43	1.74	2.71	0.51	
Phosphorus	0.39–0.65	0.16	0.19	0.26	

Notes: DM (as fed) is 86.6–89.6 percent for seeds, 90.0 percent for straw and 93.1 percent for *chuni.*
ADF = acid detergent fibre; NDF = neutral detergent fibre.
Chuni: residues containing broken pieces of endosperm including germ and a portion of husk.
Husk: outer covering of grain or seed, especially when dry.
Source: Feedipedia (2016); Arulnathan, Murugan and Balakrishnan (2013).

2004). Fresh bean forage is rich in protein (18–19 percent, DM basis) and fibre (crude fibre 25–27 percent, DM basis; NDF 45 percent, DM basis).

In India, mungo bean yields up to 15.6 tonne green fodder/ha and 340–1500 kg dry seeds/ha (Ecocrop, 2011). In Bangladesh, mungo bean is also grown as a pasture feed along with other legumes such as grass pea (*Lathyrus sativus* L.) in a no-tillage system. It is then rotationally grazed by cattle which should be offered straw to prevent diarrhoea or bloat (Islam, Sarker and Islam, 1995). In Bangladesh, some dairy cattle feeding systems are based on legume pastures, combining mungo bean and grass pea herbage with copra-meal-based concentrates. Supplementing such diets with straw (2.5 kg/head/day) did not change DMI but increased milk production (up to 8.64 litre/day) and was more profitable (Islam, Sarker and Islam, 1995).

Mungo bean crop residue (straw)

Mungo bean straw and haulms have a variable composition, depending on the proportion of stems, leaves, and pods. Reported protein values range from 8.9 to 17.2 percent, DM basis and NDF values range from 54 to 57 percent, DM basis (Reddy, 1997), with low starch content (4.5 percent, DM basis) (Singh *et al.*, 2002, Table 2.7.1). The crude protein of mungo bean straw was found to be more degradable than that of leucaena [*Leucaena leucocephala* (Lam.) de Wit] leaves (Singh *et al.*, 2002). Dry matter is also highly rumen-degradable (Reddy, 1997). OM digestibility of the roughage was good (68 percent), and ME (9.1 MJ/kg DM) was higher than that of rice straw and groundnut (*Arachis hypogaea* L.) straw (Krishnamoorthy *et al.*, 1995).

Hossain *et al.* (2015) observed that the supplementation of straw-based diets with different levels of mungo bean hay (0, 106, 212 and 318 g DM) improves feed intake, nutrient digestibility and live weight gain of indigenous bull calves (age 2–3 years and average 83.4 kg live weight). However, use of mungo bean straw as a sole feed *ad libitum* did not meet the nutritional requirements (and particularly the protein requirement) of Murrah buffalo heifers (Sanjiv and Garg, 1995). Mungo bean straw offered to sheep at 60 percent of the diet supported growth in sheep (average live-weight gain of 60–62 g/h/day), and was equivalent to wheat straw in terms of feed efficiency and feeding cost (Jadhav and Deshmukh, 2001). Effect of feeding complete rations comprising sorghum straw, maize stover, pigeon pea straw and mungo bean straw as roughage sources showed that DMI (kg/day) was similar in all groups. Venkateswarlu, Srinivas kumar and Narendranath (2013) observed that feeding complete ration (mungo bean straw and concentrates 60:40) to buffalo bulls had no effect on DMI, when compared with complete ration based on other roughages (sorghum straw, maize stover. However, the digestibility coefficients of DM, OM, CP, EE, CF, NDF, ADF, cellulose and hemi-cellulose were significantly ($P<0.01$) lower in buffalo bulls fed mungo bean in comparison with other groups (Venkateswarlu, Srinivas kumar and Narendranath, 2013).

Mungo bean husk

In India, mungo bean husk (outer covering of grain or seed) is available in substantial quantity, as this pulse is grown as a cash crop in vast areas of the country. It contains 18.2 percent CP, 1.4 percent EE, 20.3 percent of 54.6 percent NFE and 5.5 percent total ash. Its fibre contains 48.2 percent NDF, 37.4 percent ADF, 10.8 percent hemicellulose, 26.6 percent cellulose and 9.6 percent lignin. It also contains 0.51 percent CA, 0.26 percent P, and 0.014 percent Mg. The Cu, Zn, Co and Mn levels were 13.16 ppm CU, 37.47 ppm ZN, 0.97 ppm CO and 53.75 ppm MN. It is considered that carbohydrate could be the main component bound by tannin in mungo bean husk, which is protected from rumen fermentation but digested in the small intestine (Sreerangaraju, Krishnamoorthy and Kailasb, 2000). In Bangladesh, mungo bean is a valuable supplement, resulting in greater protein intake and higher weight gain (57 *vs* 31 g/day in goats fed grass alone) (Islam, Chowdhury and Alam, 1997).

FEEDING OF SEED AND ITS BY-PRODUCTS

Cattle

Dey, De and Gangopadhyay (2016) observed that partial (50 percent) or complete replacement of wheat bran with mungo bean foliage improved daily feed intake, fibre digestibility and milk production in crossbred lactating cows. Reddy *et al.* (2000) recommended inclusion of up to 40 percent of *chuni* in the concentrate diets of male buffaloes, fed a rice-straw-based diet, with no adverse effect on OM, DM and CP digestibilities and with a positive effect on fibre digestibility. At a 40 percent level, the degradability of DM was 55.6 percent and CP was 71.6 percent (Reddy *et al.,* 2002).

Pigs
The inclusion of mungo bean *chuni* at the 15 percent level in the rations of growing and finishing crossbred barrows did not affect growth rate or carcass characteristics (Ravi *et al.*, 1999).

Poultry
Mungo bean *chuni* could partially replace fish meal and maize grain in layer diets. However, diets containing 5 or 20 percent *chuni* resulted in lower (but not significantly different) egg production, digestibility and N and Ca retention (Khulbe and Singh, 1973).

SUMMARY

India is the largest producer and consumer of mungo bean in the world. Therefore a large quantity of its by-products such as *chuni*, husk, forages, crop residues and hay are available for feeding to livestock. About 40 percent of concentrates can be replaced with *chuni* in the diet of male buffaloes. The inclusion of mungo bean *chuni* up to the 15 percent level is recommended for pig diets, without affecting growth and carcass characteristics. Feeding mungo bean forage (50 or 100 percent of roughage) improved feed intake, fibre digestibility and milk production in lactating cows.

2.8 Rice bean

COMMON NAMES

Climbing mountain bean, mambi bean, oriental bean, red bean, rice bean (English); haricot riz (French); feijão-arroz (Portuguese); fríjol mambé, fríjol rojo, frijol de arroz (Spanish); Reisbonhne (German); kacang uci (Indonesian).

DISTRIBUTION

Rice bean's [*Vigna umbellata* (Thunb.) Ohwi & H. Ohashi] distribution pattern indicates great adaptive polymorphism for diverse environments, with its distribution ranging from humid tropical to sub-tropical, to sub-temperate climate. The presumed centre of domestication is Indo-China (Tomooka *et al.*, 2011). It is thought to be derived from the wild form [*V. umbellata* var. *gracilis* (Prain) Maréchal, Mascherpa & Stainier], with which it cross-fertilizes, and which is distributed from Southern China through the north of Viet Nam, Lao People's Democratic Republic and Thailand into Myanmar and India (Tomooka *et al.*, 1991).

DESCRIPTION

Rice bean is an annual legume with an erect to semi-erect vine that may grow to more than 3 m in height. It shows profuse branching. Leaves are tri-foliate with entire, 6–9 cm long leaflets. Flowers are conspicuously bright yellow and borne in clusters. Research in India has shown that rice bean has very high growth efficiency and low respiratory loss of seed reserves (Sastrapradja and Sutarno, 1977). Rice bean is a diploid (2n=22) and there is some evidence of natural out-crossing. It has elongated, slightly curved and beaked seeds of variable size and colour with prominent hilum.

CLIMATIC CONDITIONS FOR CULTIVATION

Rice bean can be grown in diverse environments due to its wide adaptation. A temperature range of 25–35 °C and average rainfall of 1 000–1 500 mm per annum are optimal for healthy vegetative growth and proper pod development. Most varieties are photoperiod-sensitive, tend to be late in flowering, and produce vigorous vegetative growth when grown under conditions of ample water and warm tem-

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*Photo 2.8.1 Seeds of rice bean [*Vigna umbellata *(Thunb.) Ohwi & H. Ohashi]*


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Photo 2.8.2 Plants of rice bean [Vigna umbellata (Thunb.) Ohwi & H. Ohashi]

perature in the subtropics. Rice bean is best adapted to drought-prone sloping areas and flat rainfed areas. Rice bean can be grown in different types of soil including grey, black, yellow or cream coloured soils. However, red soil, which is moderate in fertility, is considered best for rice bean cultivation (Khanal and Poudel, 2008). Though rice bean can better tolerate harsh conditions (including drought, waterlogging and acid soils), it remains an underutilized legume and there is no breeding programme to improve this crop. Farmers must rely on landraces rather than on commercial cultivars (Joshi *et al.*, 2008).

RICE BEAN AND ITS BY-PRODUCTS AS ANIMAL FEED

Rice bean seeds

Rice bean seed is rich in protein (18–25 percent, DM basis), low in fibre (4 percent, DM basis) and fat (2 percent, DM basis) (Table 2.8.1). It is rich in lysine (more than 6 percent of the protein) but poor in sulphur-containing amino acids.

Rice bean is useful for livestock feeding. In India, it is fed to buffalo calves and sheep to provide energy. Rice beans can replace 50 percent each of cereals and de-oiled cake in the concentrate mixture offered to buffalo calves (Ahuja, Kakkar and Gupta, 2001). In sheep, replacing 50 percent of the metabolizable energy from oat hay by rice bean seeds had no deleterious effect on sheep N balance, which remained positive (Krishna *et al.*, 1989).

Rice bean forage

The crop residue from rice bean is a valuable and palatable fodder which is known to increase milk production. It has been promoted in India as a cattle fodder (Mukherjee, Roquib and Chatterjee, 1980), and has also been suggested as a crop with potential for use as a feed for livestock production. This might lead to an increased market for rice bean, but could also lead to the crop being stigmatized as `livestock fodder´. Rice bean, despite its grain yield potential, comparable to major pulse crops, and excellent nutritional qualities, has failed to emerge as an important pulse crop in India. Rice bean forage is relatively rich in protein (17–23 percent, DM basis), and minerals (10 percent, DM in the fresh forage), particularly in Ca (up to 2 percent in DM in the fresh forage).

Table 2.8.1 Chemical composition of rice bean and its by-products (percent, DM basis)

Parameter	Seeds	Hay	Straw
Crude protein	18.1–25.2	15.6	13.6
Ether extract	0.7–4.2	4.6	1.4
Crude fibre	2.2–7.4	30.2	26.3
NDF	54.6	51.2	
ADF	39.2	30.7	
Ash	3.8–4.9	9.9	22.2
Calcium	0.26–0.67	1.31	2.91
Phosphorus	0.21–0.39	0.26	0.12

Notes: DM (as fed) for seeds is 81.0–95.0 percent.
ADF = acid detergent fibre; NDF = neutral detergent fibre.
Source: Feedipedia (2016).

Due to high fodder production potential (35 tonne/ha, fresh basis), rice bean is now attracting attention as a leguminous fodder crop in India. In Bengal (India), fodder yields were reported to range from 5–7 tonne DM/ha in May and June, to 8–9 tonne DM/ha in November and December. In India, rice bean grown with Nigeria grass (*Pennisetum pedicellatum* Trin.) yielded 7.6 tonne DM/ha after the application of 20 kg N/ha (Chatterjee and Dana, 1977).

In Pakistan, rice bean grown with sorghum (50:50 mix.) yielded up to 12 tonne DM/ha (Ayub *et al.*, 2004). However, lower yield (5–6 tonne DM/ha) have been reported in Myanmar (Tin Maung Aye, 2001), and in the sub-humid Pothwar plateau of Pakistan (2.9 tonne DM/ha; Qamar *et al.*, 2014).

An experiment conducted by Singh, Saha and Singh (2000) revealed that *ad libitum* feeding of rice bean forage and sorghum sudan green fodder mixture (46:54 fresh basis) could support a growth of 456 g/day in crossbred calves (age 22–23 months). Similarly, Joshi *et al.* (2008) also observed that farmers in Nepal prefer rice bean fodder for livestock feeding due to its softness and palatability.

Rice bean crop residue (straw)

Rice bean straw contains 16 percent protein (DM basis) and large amounts of minerals (more than 20 percent, DM basis). Chaudhuri, Gupta and Singh (1980) observed that rice bean straw had a low OM digestibility, ranging from 31 to 47 percent, and recommended to supplement it with energy-rich feed materials, such as cereal grains or bran.

Rice bean hay

Rice bean hay is generally used as a protein source (Table 2.7.1) to supplement poor quality roughage-based diets in ruminants. In an experiment with rice bean hay in India, bullocks consumed it hesitantly at first, but within a few days were accustomed to it, and DM consumption increased, indicating that the hay was palatable (Gupta, Singh and Chatterjee, 1981). Holstein ×Friesian crossbred dairy cows receiving rice bean hay mixed with Ruzi grass

[*Urochloa ruziziensis* (R. Germ. & C.M. Evrard) Crins] tended to have higher digestibility of DM, OM and CP, higher milk yield and fat corrected milk (Wanapat *et al.,* 2012). Foiklang, Wanapat and Toburan (2010) concluded that rice bean hay has potential to be used as protein source in high quality feed blocks and its feeding resulted in improved rumen fermentation efficiency and digestibility in swamp buffaloes.

ANTI-NUTRITIONAL FACTORS

Rice bean contains phytic acid, polyphenol, tannins, trypsin inhibitors, other anti-nutrients, and flatus-producing oligosaccharides. However, the contents of all these compounds are lower than in many comparable pulses. Rice bean forage contains variable amounts of condensed tannins (0.1–2.8 percent, DM basis) (Chanthakhoun and Wanapat, 2010; Wanapat *et al.,* 2012). Saikia, Sarkar and Borua (1999) reported that rice bean contains trypsin inhibiting contents of 2456 to 2534 TIU/g, phytic acid levels of 1976 to 2170 mg/100 g and tannins of 513 to 572 mg/100 g. Cooking, namely 15 min. pressure cooking and 50 min. boiling showed a considerable decrease in anti-nutritional factors.

FEEDING OF RICE BEAN AND ITS BY-PRODUCTS

Cattle

Thang, Sanh and Wiktorsson (2008) observed higher daily weight gain (609 g/day), better feed efficiency and reduced feeding cost in growing crossbred heifers fed on a mixture of cassava hay and rice bean hay (3:1 ratio) replaced with 60 percent of concentrate in a forage-based diet (*Pennisetum purpureum* Schumach. + urea-treated rice straw). Supplementation of rice bean hay at 600 g DM/head/day was beneficial for swamp buffaloes fed with rice straw as a basal roughage, as it resulted in increased DMI, reduced protozoal and methane gas production in the rumen, increased N retention as well as better efficiency of rumen microbial protein synthesis (Chanthakhoun *et al.,* 2011). Chanthakhoun and Wanapat (2010) also reported that supplementation of rice bean hay in the diet of buffalo increases cellulolytic rumen bacteria, thus improving the utilization of high fibre content feeds.

Goats

Das (2002) reported that local goats fed with grass and rice bean hay (15 percent of diet DM) did not increase grass intake, while total DMI and nutrient digestibility were increased. Increasing the level of rice bean level above 15 percent had no further effect on digestibility.

Poultry

Rice beans are rich in protein but contain trypsin inhibitors and other anti-nutritional factors that limit their use in poultry feeding. Raw rice beans fed to broilers at 20 or 40 percent of the diet decreased growth. However, roasted rice beans gave better results and were included at 40 percent without hampering growth, but weight gain was lower than that with the control diet (Gupta, Yadav and Gupta, 1992).

SUMMARY

Rice bean is a useful livestock feed. It can replace 50 percent of concentrates in the ration of buffalo calves and sheep. Supplementation of rice bean hay at 600 g DM/head/day resulted in increased dry matter intake, and reduced protozoal and methane production in rumen of swamp buffaloes. For goats, the level of rice bean hay should not be more than 15 percent of diet dry matter. Raw rice bean should not be fed to poultry, although roasted rice bean can be included at up to 20 percent of the diet.

2.9 Moth bean

COMMON NAMES

Dew bean, haricot mat, Indian moth bean, mat bean, mattenbohne, math, moth, moth bean, matki, or Turkish gram.

DISTRIBUTION

The moth bean [*Vigna aconitifolia* (Jacq.) Maréchal] is probably a native of India, Pakistan and Myanmar, where it grows wild and appears to have been recently domesticated. It is a drought resistant legume, commonly grown in arid and semi-arid regions of India and Pakistan (Maréchal, Mascherpa and Stainer, 1978).

DESCRIPTION

Moth bean is one of the underutilized legumes of the tropics and sub-tropics, grown mostly in dryland agriculture. It is a herbaceous creeping annual which grows to approximately 40 cm high. On account of its mat-like spreading habit, it has been given the name of mat bean in some parts of the world, particularly in the United States of America. Yellow flowers on its hairy and densely packed branches develop into yellow-brown pods, 2 to 3 inches in length.

The seeds contain approximately 22–24 percent protein, DM basis (Table 2.9.1). The pods, sprouts and protein rich seeds of this crop are commonly consumed in India. Due to its drought resistant qualities, its ability to combat soil erosion and its high protein content, moth bean could play a more significant role as a food source in the future. It has been suggested that its suitability as a grain legume in semi-arid Africa should be further investigated.

Moth bean is cultivated on about 1.5 million ha, mainly on arid, sandy tracts of Rajasthan, India's driest state. It is found growing wild from the Himalayas to Sri Lanka, from sea level to 1 500 masl. It is a well-established commercial crop on the Indian subcontinent. Rajasthan has 85 percent of the total area and 55 percent of the total production of the country (Om and Singh, 2015). Uttar Pradesh, Punjab, Haryana and Madhya pradesh are the other states where moth bean is grown on marginal lands.

*Photo 2.9.1 Seeds of moth bean [*Vigna aconitifolia* (Jacq.) Maréchal]*

Table 2.9.1 Chemical composition of moth bean and its by-products (percent, DM basis)

Parameter	Seeds	Haulm	Hay	Pods
Crude protein	26.6	9.6	8.9–17.2	9.6
Ether extract	0.6	2.9	1.7–1.9	2.9
Crude fibre	5.3	19.4	26.8–29.4	19.4
Ash	5.6	14.1	12.0–14.4	14.4
Calcium	0.35	3.0	2.0–2.3	2.01
Phosphorus	0.38	0.24	0.12–0.18	0.25

Notes: DM (as fed) for hay is 86.2 percent.
Source: Feedipedia (2016).

CLIMATIC CONDITIONS FOR CULTIVATION

The moth bean is the most drought-tolerant pulse crop grown in India. Moth bean can grow well in hot climates with 500–750 mm of annual rainfall; with as little as 50–60 mm rainfall, as three to four showers during the growing period, a good yield can be obtained. It can be successfully cultivated on well drained sandy plains and sand dunes with poor organic matter and poor fertility in Northern-western mid regions of lndia. Moth bean, with its deep and fast penetrating root system, can survive up to 30–40 days in open fields, experiencing fast depletion of soil moisture, with air temperature peaking to more than 35 °C.

MOTH BEAN AND ITS BY-PRODUCTS AS ANIMAL FEED

The moth bean shows good promise for supplying quality forage under arid and semi-arid conditions. Fields of moth bean make valuable pastures and have been cultivated for this purpose in India, California and Texas. At the end of the hot season, when other crops have succumbed to the heat, the leaves and vines are still green – even after the seeds and pods are ripe – and they remain succulent until the arrival of cold weather. They are palatable and are relished by livestock. Yields of over 60 tonne/ha of green forage have been achieved.

Moth bean hay

Moth bean hay is readily eaten by livestock and has a feeding value almost equal to that of alfalfa (*Medicago sativa* L.) hay. The stems are small and the leaves do not easily fall off when the plant is dried.

ANTI-NUTRITIONAL FACTORS

Various anti-nutritional factors, such as phytic acid, saponin and trypsin inhibitor, are present in moth bean. Soaking the seeds in plain water and mineral salt solution for 12 hours decreased phytic acid by up to 50 percent, whereas sprouting for 60 hours had the most pronounced saponin lowering effect (44–66 percent). The processing methods involving heat treatment almost eliminated trypsin inhibitor activity, while soaking and germination partly removed the activity of the trypsin (Khokhar and Chuhan, 1986).

To the best of the author's knowledge, little information is available about effects of feeding moth bean and its by-products.

SUMMARY

Moth bean fodder is palatable, and relished by livestock. Green forage can be obtained at up to 60 tonne/ha, which provides quality fodder to livestock under arid and semi-arid conditions. Little information about effect of feeding moth bean and its by-products is available. More research is required to explore its potential use in animal feeding.

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Chapter 3
Broad bean

COMMON NAMES

Bell bean, English bean, faba bean, fava bean, field bean, horse bean, tick bean, Windsor bean (Mejía, 1984) (English); féverole, féverolle, fève (French); gourgane (French/Canada); haba, habas, haba común, jaba (Spanish); fava, fava-comum (Portuguese); tuinboom (Dutch); Ackerbohne (German); kara oncet (Indonesian); bakla (Turkish).

DISTRIBUTION

Information about the exact origin of Broad bean (*Vicia faba* L.) is very limited. This reflects the fact that broad bean varieties found in the field are domesticated, and until now neither wild relatives nor closely related species have been found (Maxted, Khattab and Bisby, 1991). Therefore, the origin of broad bean has been debated and some authors have proposed that the species was domesticated in the Fertile Crescent, in what is Iraq today (Ladizinsky, 1998). However, very recent research found 14 000-year-old seeds of broad bean in Mount Carmel, Israel, which suggest that the species' origin is in the Lower Galilee area (Caracuta *et al.,* 2016).

Broad bean had been cultivated in the Middle East for 8 000 years, before it spread to Europe, North Africa, and Central Asia. It spread to China over 2 000 years ago via traders along the Silk Road, to South America in the Columbian period, and more recently to Canada and Australia (Stoddard, 1991). Broad bean was first grown commercially for grain in South Australia in the early 1980s, and is now cultivated in Victoria, New South Wales and Western Australia. Small areas are grown in Tasmania and southern Queensland (Somerville, 2002).

DESCRIPTION

Broad bean is a free-standing, upright annual legume crop that is sown in winter or spring and, even though primarily grown for its edible seeds (beans), it can also be used as a whole-crop. Broad beans show a wide range in the size and shape of their seeds. Those with the largest and flatter seeds (*Vicia faba* var. *major*) are called broad beans (fava beans in United States of

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*Photo 3.1.1 Split broad beans (*Vicia faba* L.)*

America) and are cultivated as a vegetable for human consumption. Broad beans are generally harvested while still immature, and typically have a 1 000 seed weight of over 800 g. Those used as an animal feed in Ireland are smaller and rounder, and are interchangeably referred to as field, horse or tick beans. More strictly, intermediate-sized seeds (*Vicia faba* var. *equina*) are horse beans (500–800 g/1 000 seeds) and the smaller-sized seeds (*Vicia faba* var. *minor*) are tick beans (<500 g/1 000 seeds) (O'Kiely, Stacey and Hackett, 2014).

CLIMATIC CONDITIONS FOR CULTIVATION

Broad bean can not only be grown successfully under various agro-climatic conditions, but it can also be produced on residual soil moisture, is relatively tolerant of biotic and abiotic stresses, with minimum input (Singh and Prevesh, 2009; Singh and Bhatt, 2012). It can be grown as a winter or a spring crop in wetter areas, but requires a cool winter for optimal growth. It can survive frost during the vegetative stage but frost damages flowers and immature pods if it occurs during spring. Broad bean can grow optimally in temperatures ranging between 18 and 27 °C (Matthews and Marcellos, 2003), with annual rainfall ranging from 700 to 1 000 mm (Muehlbauer and Tullu, 1997). In the tropics and sub-tropics, broad bean can be grown above 1 200 masl and up to an altitude of 2 500 masl (FAO, 2016a). It does better on deep, well-structured clay soils, but can grow on a wide range of soils provided they are not too acidic or saline. Acidic soils with high levels of aluminium and manganese can be detrimental to growth of broad bean (Matthews and Marcellos, 2003).

PRODUCTION OF SEEDS

Broad bean is among the oldest crops in the world (Duc *et al.,* 2016). Globally, it is the third most important feed grain legume after soybean [*Glycine max* (L.) Merr.] and pea (*Pisum sativum* L.) in area and production (Mihailović *et al.,* 2005). Currently, 58 countries grow this bean on a large scale (FAO, 2016b). Global production of broad bean for food and feed was 4.5 million tonne in 2012 (Feedipedia*,* 2016). The major producing countries are China, Ethiopia, Australia, France and United Kingdom, and they account for more than 75 percent of world production. China alone produced 34 percent of all broad beans in 2013 (FAO, 2016b). In the EU, broad bean ranks second after field peas for legume seed production and is mostly used for animal feed (FAO, 2016b).

BROAD BEAN AND ITS BY-PRODUCTS AS ANIMAL FEED

Broad bean seeds

Broad bean seeds are a valuable source of protein and energy for livestock, as they contain 25–33 percent protein, 40–48 percent starch and 7–11 percent crude fibre on DM basis (Table 3.1). It contains about 1 percent lipid (DM basis) with a high proportion of linoleic (60.7 percent) and linolenic (14.3 percent) acids, followed by palmitic acid (11.6 percent). Broad beans contain

Table 3.1 Chemical composition of broad bean and its by-products (percent, DM basis)

Parameter	Seeds	Aerial part, fresh	Straw
Crude protein	25.2–33.5	14.3–20.7	5.0–10.9
Ether extract	0.9–2.1		1.0–1.5
Crude fibre	7.1–11.2	14.7–32.2	23.9–50.3
NDF	12.4–22.1	46.9	42.0–74.5
ADF	8.5–12.8	29.7	30.0–71.5
Ash	3.3–4.6	5.9–12.8	3.3–18.4
Lignin	0.2–2.6		4.9–15.9
Calcium	0.08–0.27		0.94–1.40
Phosphorus	0.44–0.68		0.09–0.15

DM (as fed) is 83.4–89.8 percent for seed, 10.5–30.0 for aerial part and 88.6–90.7 percent for straw.
ADF = acid detergent fibre; NDF = neutral detergent fibre.
Source: Feedipedia (2016).

0.12 percent calcium, 0.44 percent phosphorus and 0.18 percent magnesium. Broad beans are a poor source of vitamins such as biotin, choline, niacin, pantothenic acid and riboflavin; however, the level of thiamine is higher than that of soybean meal or rapeseed meal (Blair, 2007). Dehulled broad beans have a higher nutritional value than non-dehulled beans, as they contain more protein and starch and much less fibre (Ferruzzi *et al.*, 2009).

Although broad beans are a good source of protein, they are low in the sulphur-containing amino acids such as methionine and cysteine. The amino acid profile will limit inclusion of broad beans in high density diets of monogastrics. In addition, the availability of amino acids is influenced by the presence of various anti-nutritional factors (Froelich, Pallmer and Christ, 1976).

Small-seed varieties with low tannin, vicine-convicine and trypsin inhibitor contents of broad bean are preferred for livestock feeding (McVicar *et al.*, 2013). Broad bean can be used as an alternative protein source to soybean for livestock in Europe (Jezierny, Mosenthin and Bauer, 2010; Smith *et al.*, 2013).

Digestibility of seeds. Broad beans are usually quite palatable for ruminants, and are an excellent source of both protein and energy for ruminants. The protein is extensively and rapidly degradable in the rumen and provides degradable protein for microbial protein synthesis. A part of protein that escapes ruminal degradation is accessible later in the intestinal tract as undegradable protein. Levels of undegradable protein can be increased by heat treatment (Yu *et al.*, 2004). Extrusion of broad beans can also provide much higher rumen undegradable protein than soybean meal (more than 12 percent, DM basis), which is higher than for other raw or processed legume seeds such as pea or lupin (Masoero, Pulimeno and Rossi, 2005). Extrusion did not affect amino acid composition. Similarly, Yu, Goelema and Tamminga (2000) stated that extrusion of beans at 136 °C for 15 min yielded the highest values of rumen undegradable protein and, at the same time, it maintained a sufficient amount of degradable protein for microbial protein synthesis.

The energy value of broad beans is at least as good as cereal grains such as barley. They have a high content of starch, some of which can bypass the rumen and be digested at a later stage of the digestive tract. Their content of fibre is relatively low, with much of it being in the hull (seed coat). Oil concentration is also low, but the oil that is present has a high content of linoleic and linolenic acids. The effective starch degradability of broad bean grains in the rumen of lactating cows was above 58 percent (Aleksić, Grubić and Pavličević, 1999). Crépon *et al.* (2010) observed lower *in vivo* digestibility with tannin-rich broad beans, but higher protein and amino acid digestibilities with tannin-free cultivars in pigs and poultry.

Broad bean hull

Broad bean hulls contain 14.3 percent crude protein and a high level of crude fibre (39.6 percent, DM basis). Higher protein content may be the presence of some broken seeds in hulls. It also contains high fibre fractions, especially of cellulose (50.2 percent, DM basis) and ADF (53.0 percent, DM basis). Content of condensed tannins was 6.75 mg/kg DM of the hulls. It is suggested that broad bean hulls can be used as a feed for ruminant animals (Minakowski, Skórko-Sajko and Fałkowska, 1996).

Broad bean forage

Broad bean is a multipurpose crop used for both food and fodder (Prolea, 2014). Fresh broad bean forage contains a relatively good quality of protein (14 to 20 percent, DM basis), with the highest protein content at full flowering stage, and thereafter it decreases.

Good quality silage can be made from broad bean plants (McVicar *et al.*, 2013). Silages have a high crude protein (18–22 percent, DM basis), which is highly soluble and degradable (Mustafa and Seguin, 2003). Ruminal degradability of DM, NDF and CP decline as broad bean crops become progressively more mature (Louw, 2009). Silages made from whole-crop are relatively stable when exposed to air during feedout (Pursiainen and Tuori, 2008). However, management during feedout needs care to prevent conditions that cause aerobic deterioration of silage. Baddeley and Walker (2014) recommended that crops of broad bean should be harvested when pods are fully formed and the beans are flexible with soft texture.

Broad bean crop reside (straw)

Broad bean straw is considered to be a cash crop in Egypt and Sudan (Muehlbauer and Tullu, 1997), as it contains 5–11 percent protein (DM basis). Voluntary DMI and digestibility of DM, OM and energy of broad bean straw by sheep were significantly ($P<0.05$) higher than those of wheat straw, but were not significantly different from those of medium quality alfalfa + brome hay.

ANTI-NUTRITIONAL FACTORS

Broad bean seeds contain various anti-nutritional substances such as tannins, lectins, glycosides (vicine and convicine), phytates, oligosaccharides, and inhibitors of enzymes (trypsin, chymotrypsin, alpha-amylase). The most undesirable anti-nutritional factors are tannins and glycosides.

Tannins

Tannins present in the seed coat of broad beans have a negative effect on the availability of both amino acids and energy in monogastric diets. However, the problem is readily addressed by dehulling. In addition, tannin-free genotypes are now available. The whole seed of traditional varieties contains tannin at the level of 0.02 to 0.05 percent (Minakowski, Skórko-Sajko and Fałkowska, 1996). Tannins are resistant to heat and dry heating. In normal conditions tannins may form poor digestibility tannin-protein complexes, which reduce the susceptibility of proteins to degradation in the rumen and decrease nutrient digestibility in the whole gastro-intestinal tract of ruminants (Frutos *et al.,* 2004).

Glycosides

Glycosides (vicine and convicine) are mainly located in the embryo and their content ranges from 0.58 to 1.04 percent (DM basis), depending on the genotype (Minakowski, Skórko-Sajko and Fałkowska, 1996). Vicine and convincine are not toxic *per se*, but are hydrolysed by beta-glycosidase in the intestine into divicine and isouramil. These glycosides were not shown to affect broad bean digestibility in pigs, but they were reported to be responsible for lower egg weight in laying hens (Grosjean *et al.,* 2001; Lessire *et al.,* 2005; Gatta *et al.,* 2013). New cultivars of broad beans having very low level of vicine and convicine contents are now available in the market.

Some level of processing is required to facilitate adequate digestion of the protein and starch of the beans. This processing can be: rolling/cracking or coarse grinding, or more intensive processing such as micronizing (infrared heating), extrusion, steaming and autoclaving; or dehulling, flaking, soaking, and germinating. Some of these processes can reduce the activity of anti-nutritional factors in the beans or contribute to repartitioning some of the protein and/or starch digestion from the rumen to later in the gastro-intestinal tract (Crepon *et al.,* 2010).

FEEDING OF SEED AND ITS BY-PRODUCTS

Cattle

Broad beans have been successfully used as a substitute for soybean meal or rapeseed meal in dairy cow rations. The animals offered soybean meal or broad beans with balanced diets had similar feed intakes, milk yields, milk composition, growth rates and carcass composition (Crepon *et al.*, 2010; Tufarelli, Khan and Laudadio, 2012). Becker *et al.* (2012) considered the maximum inclusion rate of broad bean to be 30 percent in the ration of dairy cows. Various studies show that replacing rapeseed meal with broad beans in iso-energetic and iso-proteic diets did not affect voluntary total intake, milk production and milk composition (Brunschwig and Lamy, 2002; Trommenschlager *et al.*, 2003; Brunschwig *et al.*, 2004). A study conducted by Melicharova *et al.* (2009) indicated that anti-nutritional factors present in broad bean did not affect milk production, milk composition, cow health, rumen digestion and mineral metabolism in high-yielding cows (25–30 kg milk/day) fed a concentrate containing 20 percent broad beans. Benchaar *et al.* (1992) reported that feeding extruded beans improved ruminal digestibility of the starch fraction compared with that of the untreated beans (72 *vs* 58 percent) and their subsequent utilization in the small intestine (1.61 *vs* 0.98 kg/day).

Sheep

Surra *et al.* (1992) found that substituting soybean by broad bean (50 or 100 percent) had no effect on digestibility or performance of growing lambs. In another study, El Maadoudi (2004) reported that the inclusion of broad bean in the ration of lambs (replacing 18 percent lupin seeds of the diet) had no significant effect ($P > 0.05$) on weight gain, intake, feed efficiency or carcass yield. Lanza *et al.* (2007) also reported that inclusion of broad beans in the diet of lambs (50 percent) did not affect meat quality compared with soybean meal. Mauro *et al.* (2002) reported that feeding broad bean seeds (50–60 percent of the diet), as the sole protein source to supplement cereal straw in growing lambs had a daily weight gain of 250 g/d, with an average DMI of 1.18 kg/day (0.65 kg/d of broad bean). Feeding broad beans with supplementation of lysine and methionine did not increase the growth rate in growing lambs, which clearly demonstrates the high protein value of broad beans (Mauro *et al.*, 2002).

Goats

Effects of feeding formaldehyde-treated broad bean seeds to goats have been evaluated in India. Virk *et al.* (1994) observed that feeding formaldehyde-treated broad beans (1.0 percent formaldehyde) increased DM and protein digestibility and N retention in goat kids. However, Tewatia *et al.* (1995) observed that formaldehyde (0.4–0.5 percent of formaldehyde)-treated broad beans (0.4 kg/day) did not improve significantly total milk yield, milk fat, total solids, DM and fibre digestibility, N balance or rumen profile in low yielding goats.

Pigs

Broad beans are palatable to pigs, but their use is limited due to presence of anti-nutritional factors, particularly tannins (Garrido *et al.*, 1991; Van der Poel, Gravendeel and Boer, 1991). However, zero-tannin broad beans could be included at rates of up to 30 percent in pig diets, without affecting feed intake (Lopetinsky and Zijlstra, 2004). Other anti-nutritional factors such as trypsin inhibitor, lectins, vicine and convicine are not a concern in pig diets at low levels of inclusion (Grosjean *et al.,* 2001; Blair, 2007). Low-tannin broad beans did not affect voluntary feed intake and carcass quality when included at 30 percent of the diet to replace soybean meal in growing pig diets (Zijlstra *et al.,* 2004). Royer *et al.* (2010) also observed that low-tannin broad beans can be included at higher rates (35 percent) against 20 percent level for the high-tannin beans in fattening pig diets.

Maximum inclusion rate of broad bean in the diet of growing and fattening pig was recommended at 20 percent. Though rates up to 30 percent have been tested without any adverse effect on feed intake, feed conversion ratio and carcass quality of growing pigs, there was a slight reduction effect on the average daily gain of finishing pigs (Gatta *et al.,* 2013; Smith *et al.,* 2013). Kasprowicz, Frankiewicz and Urbaniak (2005) also observed increasing daily weight gains and better feed conversion ratios when fed up to 30 percent broad bean, replacing 25, 50 or 75 percent soybean meal in growing pigs. Partial replacement of soybean meal with broad bean (18 percent of the diet) did not affect health and metabolic parameters of fattening pigs (Gatta *et al.,* 2013; Giuliotti *et al.,* 2014).

It has been reported that feeding pigs with broad bean had a positive effect on the omega 3:omega 6 ratio of the fat. The pigs fed on broad bean yielded hams with more intense taste than those fed on soybean meal or field peas (Prandini *et al.,* 2011). Blair (2007) recommended maximum inclusion rate of broad beans for sows to be 10 percent.

Poultry

Broilers. Processed (dehulled, extruded or pelleted) broad bean can be included up to 25 percent in broilers diets without affecting growth performance (Métayer *et al.,* 2003). Brévault *et al.* (2003) reported that low-tannin broad beans included at 20 percent in broiler diets resulted in higher live-weight gain and feed intake than those obtained with high-tannin beans. However, Métayer *et al.* (2003) reported no differences in performance when high- or low-tannin seeds were included at 25 percent in broiler diets, even though the metabolizable energy value of the high-tannin beans was lower. Recent work carried out in New Zealand (Ravindran *et al.,* 2005) showed that when diets are formulated on the basis of metabolizable energy and apparent ileal digestibility of amino acids, broad beans can be used successfully in broiler diets up to levels of 20 percent.

Layers. Layer hens are more sensitive to the presence of vicine and convicine in broad beans, with reduced egg size and feed intake commonly reported for birds fed diets containing broad beans (Fru-Nji, Niess and Pfeffer, 2007). However, Dänner (2003) reported that broad beans with 0.69 percent vicine and convicine could be used without negative effects on egg production and feed intake at levels of up to 30 percent in laying hen diets. Fru-Nji, Niess and Pfeffer (2007) also reported that broad beans (with a vicine and convicine content of 0.88 percent) could be included in layer hen diet at levels of up to 16 percent without a significant reduction in production or egg quality. It was recommended that inclusion rates for varieties free of vicine and convicine can be up to 20 percent with no detrimental effect on laying performance (Lessire *et al.*, 2005; Magoda and Gous, 2011).

SUMMARY

Small-seeded varieties of broad bean with low tannins, glycosides and trypsin inhibitor contents are preferred for livestock feeding. Seeds are a valuable source of protein and energy; and can be used up to 30 percent in the ration of dairy cows, replacing soybean meal or rapeseed meal. Feeding broad bean seeds at up to 50–60 percent of the diet did not affect feed intake, feed efficiency or carcass quality in lamb. Processed broad bean seeds can be used in monogastrics. Zero-tannin broad beans can be included up to 30 percent in growing and finishing pig diets. The maximum inclusion level of broad bean should not be more than 10 percent in sow diet. Processed or glycosides-free varieties of broad beans can be included up to 20 percent in layer and broiler poultry diet. Broad bean hulls can be used as feeding for ruminants. Good quality silage can be made from broad bean plants.

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Chapter 4
Pulses nes[1]

4.1 Hyacinth bean

COMMON NAMES

Batao (The Philippines); bataw bonavist bean, caroata chwata (Venezuela); chicarros, dolichos bean, dolique d'Egypte (France); Egyptian kidney bean, field bean, fiwi bean (Zambia); frijol de adorno (El Salvador); frijol jacinto (Colombia); frijol caballo (Puerto Rico); gallinita (Mexico); hyacinth bean (Brazil); lablab, lablab bean (Australia); lab-lab bean, lubia (Sudan); pig-ears, poor man's bean, poroto de Egipto (Argentina); quiquaqua, rongai dolichos, seim bean, Tonga bean (England);wal (India); frijol jacinto, quiquaqua, caroata chwata, poroto de Egipto, chicarros, frijol caballo, gallinita, zarandaja, judía de egipto, frijol de adorno, carmelita, frijol caballero, tapirucusu, chaucha japonesa (Spanish); Labe-labe, feijão cutelinho, feijão padre, feijão da India, cumandatiá (Portuguese); Helmbohne, Indische Bohne (German); komak, kacang komak, kacang bado, kacang biduk (Indonesian); dolico egiziano (Italian).

DISTRIBUTION

Hyacinth bean [*Lablab purpureus* (L.) Sweet][2] is an Old World food crop that is thought to have originated in Africa (Cook *et al.*, 2005) or India (Murphy and Colucci, 1999). It has been successfully grown in the Southern United States of America (Texas, Florida, Georgia), Puerto Rico, and as far north as the Great Lakes and Canada. In India, hyacinth bean is a field crop mostly confined to the peninsular region and cultivated to a large extent in Karnataka and adjoining districts of Tamil Nadu, Andhra Pradesh and Maharashtra. Karnataka contributes a major share, accounting for nearly 90 percent in terms of both area and production in the country. Karnataka state records production of about 18 000 tonne from an area of 85 000 ha (Prabhavathi and Khadri, 2014).

DESCRIPTION

Hyacinth bean is one of the most ancient crops among cultivated plants. It is a bushy, semi-erect, perennial herb. It is mainly cultivated either as a pure crop or

[1] Category of pulses comprising species of minor relevance at international level; nes stands for "not elsewhere specified".

[2] Hyacinth bean was formerly treated as *Dolichos lablab* L. and many research results are reported under this name.


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*Photo 4.1.1 Seeds of Hyacinth bean [*Lablab purpureus *(L.) Sweet]*

mixed with finger millet, groundnut, castor, maize, pearl millet or sorghum in Asia and Africa. It is a multi-purpose crop grown for pulse, vegetable and forage. The crop is grown for its green pods, while dry seeds are used in various vegetable food preparations. It is also grown in home gardens as annual crop or on fences as perennial crop. It is one of the major sources of protein in the diet in southern states of India. Consumer preference varies with pod size, shape, colour and aroma (pod fragrance). It is also grown as an ornamental plant, mostly in United States of America for its beautiful dark-green, purple-veined foliage with large spikes clustered with deep-violet and white pea-like blossoms.

Hyacinth bean is a herbaceous, climbing, warm season annual or short-lived perennial with a vigorous taproot. It has a thick, herbaceous stem that can grow up to 90 cm, and the climbing vines can stretch up to 7.6 m from the plant (Valenzuela and Smith, 2002). It has trifoliate, long-stemmed leaves. Each egg-shaped leaflet widens in the middle and is 7.5–15 cm long. The surface of the leaflet is smooth above and shorthaired below. The flowers grow in clusters on an unbranched inflorescence in the angle between the leaf and the main stem. It may have white, blue, or purple flowers depending on cultivar. Seedpods are from 4 cm (Cook *et al.,* 2005) to 10 cm long (Valenzuela and Smith, 2002), smooth, flat, pointed, and contain 2 to 4 seeds. Seeds can be white, cream, pale brown, dark brown, red, black or mottled, depending on cultivar.

CLIMATIC CONDITIONS FOR CULTIVATION

Hyacinth bean is remarkably adaptable to wide areas under diverse climatic conditions, such as arid, semi-arid, sub-tropical and humid regions where temperatures vary between 22–35 °C, lowlands and uplands and many types of soils, and with soil pH varying between 4.4 and 7.8. It does not grow well in saline or poorly-drained soils, but it is able to grow well under acidic conditions (Valenzuela and Smith, 2002). It can continue to grow in drought or shaded conditions, and grow in areas with an average annual rainfall of 630–3 050 mm (Cook *et al.,* 2005). It is more drought resistant than other similar legumes such as common bean (*Phaseolus vulgaris* L.) or cowpea [*Vigna unguiculata* (L.) Walp.] (Maass *et al.,* 2010), and can access soil water

6 feet deep. Being a legume, it can fix atmospheric nitrogen, to the extent of 170 kg/ha besides leaving enough crop residues to enrich the soils with organic matter. It is a drought tolerant crop and grows well in drylands with limited rainfall. The crop prefers relatively cool seasons (temperature ranging from 14 to 28 °C) with the sowing done in mid to late summer. It starts flowering in short days (11–11.5 hour day length) and continues indeterminately in spring. It flowers throughout the growing season.

HYACINTH BEAN SEED AND ITS BY-PRODUCTS AS ANIMAL FEED

The protein content of hyacinth bean seeds varies from 23 to 28 percent (DM basis; Table 4.1.1), depending upon cultivars or genotypes. It contains a high level of lysine (6.3 percent protein), but the levels of methionine and cystine are lower. The starch content is relatively high (45 percent, DM basis) while the fibre content is rather low (less than 10 percent, DM basis) in hyacinth bean seeds. Adebisi and Bosch (2004) reported that hyacinth bean grown for seeds, yields 2.5–5 tonne/ha of green pods, 0.45 tonne/ha of dry seeds when grown as an intercrop and up to 1.5 tonne/ha of dry seeds in sole cropping.

Hyacinth bean forage

Hyacinth bean is used as forage, hay, and silage. As forage, it is often sown with sorghum or millet. The leaf is very palatable but the stem not. Overall, it is one of the most palatable legumes for animals (Valenzuela and Smith, 2002). Hyacinth bean forage has an average protein content of about 18 percent (DM basis), which varies from 13 to 24 percent depending on local conditions and stage of harvest (Mudunuru *et al.*, 2008; Linga, Lukefahr and Lukefahr, 2003). The protein is highly degradable in the rumen. Compared with tropical forages, hyacinth bean forage was found to have lower rumen protein degradability than rye-grass (*Lolium multiflorum* Lam.), but higher than the legume forage butterfly pea (*Clitoria ternatea* L.) and tropical C_4 grasses (Bowen, Poppi and McLennan, 2008).

Table 4.1.1 Chemical composition of hyacinth bean and its by-products (percent, DM basis)

Parameter	Seeds	Aerial part, fresh	Hay
Crude protein	23.3–28.8	12.5–24.3	12.2–19.9
Ether extract	0.9–4.2	1.7–3.9	1.6–2.9
Crude fibre	7.6–12.1	22.0–36.1	27.7–37.1
Ash	3.3–4.8	7.1–16.2	5.6–15.2
NDF	22.5–51.4	36.0–53.8	25.5–71.8
ADF	11.5–17.1	22.8–41.4	18.0–49.9
Lignin	0.5–1.8	4.6–10.7	1.0–13.1
Calcium	0.04–0.99	0.74–2.18	0.95–2.08
Phosphorus	0.11–0.79	0.19–0.55	0.11–0.54

Notes: DM (as fed) is 87.0–93.3 percent for seeds, 12.6–40.4 percent for fresh plant and 81.6–93.9 percent for hay.
ADF = acid detergent fibre; NDF = neutral detergent fibre.
Source: Feedipedia (2016).

The leaves contain 21 to 38 percent (DM basis) crude protein. The leaves make excellent hay for cattle and goats, but the stem is difficult to dry, and must be mechanically conditioned through crushing (FAO, 2012). Silage made from a mix of hyacinth bean and sorghum raised the protein content by roughly 11 percent with a 2:1 mixture of hyacinth bean:sorghum (FAO, 2012).

Hyacinth bean is a fast growing legume that can provide fodder in less than 3 months after sowing (ILRI, 2013). The green forage remaining after seed harvest can be sun-dried but its protein content is lower (13–14 percent, DM basis; Iyeghe-Erakpotobor and Muhammad, 2007). Adebisi and Bosch (2004) reported that Hyacinth bean grown for forage yields up to 9 tonne DM/ha/year.

ANTI-NUTRITIONAL FACTORS

Hyacinth bean seeds are reported to contain significant quantities of anti-nutritional factors such as tannins, phytate, and trypsin inhibitors, which limit its use in monogastric animal feeding (Murphy and Colucci, 1999). Suitable processing of hyacinth bean seeds is required to eliminate or reduce these anti-nutritional factors. Heat treatment is a common technique employed to reduce or totally eliminate the anti-nutritional factors contained in legume seeds (Tuleun and Patrick, 2007). Other methods include chemical treatment or decortication, fermentation and sprouting .

FEEDING OF SEED AND ITS BY-PRODUCTS

Cattle

Hyacinth bean forage. Hyacinth bean forage is a valuable source of protein for ruminants fed on low quality roughages. Juntanam *et al.* (2013) observed that sorghum forage intercropped with hyacinth bean forage had a better nutritive value than sorghum forage alone and resulted in greater LWG, DMI and milk yield in Holstein×Friesian crossbred cows. Eduvie *et al.* (2002) also observed that supplementing suckling Bunaji cows grazing natural pasture with hyacinth bean forage (2 kg/day) increased performance and farmer incomes in Nigeria. Abule *et al.* (1995) observed that increasing the level of legume forage in the diet of crossbred calves increased the rumen degradation rate, decreased retention time in the rumen and resulted in a higher DMI.

Hyacinth bean hay. Excellent hay can be made from hyacinth bean fodder, if the leaves are adequately preserved (FAO, 2014). However, due to a coarse and fibrous stem, it is difficult to dry and it has to be mechanically conditioned to hasten curing. Crossbred cows fed hyacinth bean hay at 0.52 percent (maize and hyacinth bean hay combined diet) or 0.85 percent (oats-vetch -hyacinth bean hay combined diet) of body weight resulted in optimum milk production. However, increasing the level of hyacinth bean hay resulted in no further improvement of animal performance, probably due to an energy deficit in the diet (Mpairwe *et al.,* 2003a; Mpairwe *et al.,* 2003b). Tibayungwa, Mugisha and Nabasirye (2011) observed that supplementation with hyacinth bean hay in a low-protein diet (napier grass – *Pennisetum purpureum* Schumach.) gave a higher growth rate in heifers.

Hyacinth bean silage. Good quality silage can be prepared with hyacinth bean forage alone or by mixing with other forages, such as sorghum or millet (FAO, 2014). Amole *et al.* (2013) found optimal results using maize + hyacinth bean silage for growth performance of crossbred calves with 70:30 maize:hyacinth bean (DM basis), which significantly improved animal performance during the dry season, compared with sole maize silage and natural pasture. Silage made from a mix of hyacinth bean and sorghum raised the protein content by roughly 11 percent with a 2:1 mixture of hyacinth bean:sorghum (FAO, 2012).

Hyacinth bean as pasture. Hyacinth bean should not be heavily grazed. Grazing can begin 10 weeks from planting and animals can be grazed 2 to 3 times per season, if the plant is not eaten below 25 cm (FAO, 2012). Cutting the plant lower will result in delayed re-growth. Hungry animals should not graze the crop as it may cause bloat, if eaten in large amounts (FAO, 2014). To avoid bloat, supplement the animal's diet with grasses. In Australia, hyacinth bean is particularly valuable during late summer and autumn, as it produces more biomass than cowpea because of its higher growth rates, has superior tolerance to trampling and better survival and recovery after grazing (Mullen, 1999).

Sheep and goats

Hyacinth bean seeds. Hyacinth bean seeds can be included in sheep and goat diets. hyacinth beans replaced groundnut meal as a protein source in a concentrate mixture for kids with positive effect on roughage intake, nutrient utilization, rumen fermentation and body growth with better N utilization (Singh *et al.,* 2010). In Australia, a comparison of mixtures of hyacinth beans or lupin seeds (*Lupinus angustifolius* L.) with roughage (hay + oat straw) fed to Merino lambs resulted in comparable dietary intakes but the hyacinth bean-based diets gave lower values for digestibility, weight gain and wool growth (the latter at 60 percent hyacinth beans inclusion) (Garcia *et al.,* 1990).

Hyacinth bean hay. Hyacinth bean hay is valuable forage for sheep and goat, and can supplement forage-based diets of low quality. Mupangwa *et al.* (2000) observed that supplementing hyacinth bean hay to low quality Rhodes grass hay (*Chloris gayana* Kunth) fed *ad libitum* with maize grain (100 g/day) resulted in increased DMI (42 percent), nutrient digestibility (DM, OM and NDF) and live-weight gain in growing goats. Compared with other forage legumes [*Centrosema pubescens* Benth., *Stylosanthes guianensis* (Aubl.) Sw. and *Aeschynomene histrix* Poir.], the mixture of hyacinth bean with Guinea grass (*Panicum maximum* Jacq.) in diets for West African Dwarf goats resulted in higher dietary metabolizable energy and organic matter digestibility (Ajayi and Babayemi, 2008). They also reported that hyacinth bean supplementation gave the highest nitrogen utilization and the highest weight gain.

Hyacinth bean silage. Various studies evaluated the positive effects on DMI in sheep fed silage made from hyacinth bean and maize, sorghum or millet (Adeyinka *et al.,* 2008; Ngongoni *et al.,* 2008). Babayemi *et al.* (2006) also observed that silages containing equal amounts of pearl millet and hyacinth bean, or Guinea grass and hyacinth bean, resulted in better feed intake and digestibility in sheep and goats.

Pigs

Hyacinth beans are used in pig feeding as a source of protein and energy. However, due to the presence of anti-nutritional factors (trypsin inhibitors, phytic acid, and condensed tannins), their use is limited in monogastric animals (Singh, Barneveld and Ru, 2005). Laswai *et al.* (1998) observed improved nitrogen digestibility for raw (50 percent), toasted (65 percent) and boiled beans (74 percent) in growing-finishing pigs by processing (cooking, toasting, boiling) of seeds. The palatability of raw hyacinth bean seeds is low to moderate in pigs, depending on the cultivar (Martens *et al.,* 2012). Pig diets can contain up to 10 percent of raw hyacinth bean seeds and processing (boiling, toasting, steam pelleting) could increase the maximum recommended level at up to 20–30 percent (Martens *et al.,* 2012).

Poultry

Hyacinth bean seeds are considered as valuable feed for poultry. However, the high fibre content and presence of anti-nutritional factors (tannins and trypsin inhibitors) limit the digestibility of protein in the absence of appropriate treatment.

Broilers. The supplementation of raw hyacinth bean seeds in the diet of broilers depressed feed intake and growth performance (Abeke *et al.,* 2007a; Rasha and Abdel Ati, 2007; Abeke *et al.,* 2008b). However, Elamin *et al.* (2013) reported that thermal treatment helps in reducing the negative impact of hyacinth bean, with a higher efficiency from boiling (optimum duration 30 min) compared with dry processing. The effect of hyacinth bean depended on the inclusion level. Young birds seem to be much more sensitive to hyacinth bean than finishers, in which growth was slightly reduced by supplementing 5 to 10 percent hyacinth beans in the diet (Abeke *et al.,* 2008a; Abeke *et al.,* 2008b; Abeke *et al.,* 2008c). It is recommended to use processed hyacinth bean seeds up to 5 percent maximum in the diet of poultry.

Layers. The supplementation of boiled hyacinth bean seeds in layer diets resulted in lower performance, with a direct effect from the level of inclusion (Ragab *et al.,* 2012). Although weak, this depressive effect was registered at relatively low levels (5 to 7.5 percent hyacinth bean in the diet). Feed intake was little affected by moderate inclusion levels, but the reduction in laying egg numbers led to a lower feed efficiency. In pullets, growth performance was slightly depressed, as with broilers (Abeke *et al.,* 2007a; Abeke *et al.,* 2007b). There was no major effect of using hyacinth bean in pullets on their subsequent laying performance, except at inclusion levels higher than 30 percent (Abeke *et al.,* 2007b). The recommendation is to use hyacinth bean with care in layers, as performance can decrease even at low inclusion levels. Only processed seeds (thermal treatment) should be used. It is advised not to exceed 5 percent unprocessed hyacinth bean seeds in diets.

SUMMARY

Hyacinth bean contains high protein (23–28 percent, DM basis) and low fibre (8–10 percent, DM basis), but the presence of anti-nutritional factors limits its use in monogastric diets. Heat treatment of raw seeds helps in reducing anti-nutritional factors. Forage is palatable for animals and a valuable source of protein (18 percent, DM basis), and good quality hay can be made from hyacinth bean forage. Raw and processed (boiling, toasting, steam pelleting) seeds can be included at up to 10 and 30 percent, respectively, in pig diets. A maximum 5 percent of unprocessed seeds are recommended for inclusion in poultry diets.

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4.2 Jack bean

COMMON NAMES

Brazilian broad bean, chickasaro lima bean, horse gram, jack bean, one-eye-bean, overlock bean, sword bean (English); feijão-de-porco (Portuguese); fève Jacques (French); frijol espada (Spanish); Jackbohne, Madagaskarbohne, Riesenbohne (German); Kacang parang (Indonesian); Pwa maldyòk (Haitian Creole).

DISTRIBUTION

Jack bean [*Canavalia ensiformis* (L.) DC.] is found in the tropical and sub-tropical regions of West Africa, Asia, South America, India, and South Pacific. It is also grown in the south-western states and Hawaii in the United States of America. *Canavalia* Adans. is a pantropical genus that is believed to have originated in the New World based on the large genetic diversity of species in the fossil record.

DESCRIPTION

The jack bean is an annual or weak perennial legume with climbing or bushy growth forms. It is woody with a long tap root. The 20 cm long and 10 cm wide leaves have three egg-shaped leaflets, wedge-shaped at the base, and tapering towards the tip. The flowers are about 2.5 cm long and are of rose-colour, purple, or white with a red base. It has about a 30 cm long, 3.8 cm wide, sword-shaped seedpod. Seeds are white and smooth with a brown seed scar that is about one-third the length of the seed. Its roots have nodules that fix nitrogen.

CLIMATIC CONDITIONS FOR CULTIVATION

Jack bean has an ability to continuously grow under severe environmental conditions (Udedibie and Carlini, 1998), including in nutrient-depleted, highly leached, acidic soils. It can also grow in poor, droughty soils, and does not grow well in excessively wet soil. It is drought-resistant and resistant to pests (FAO, 2012). It drops its leaves under extremely high temperatures, and may tolerate light frosts (Florentin *et al.*, 2004). It tolerates a wide range of rainfall (650–2 000 mm) evenly distributed throughout the year; and

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*Photo 4.2.1 Seeds of Jack bean [*Canavalia ensiformis *(L.) DC.]*

grows best at altitudes up to 1 800 masl, temperature of 15–30 °C, soil pH of 4.5–8.0, and tolerates a wide range of soils.

NUTRITIONAL VALUE

Jack bean is a good source of protein (23 to 34 percent, DM basis; Table 4.2.1) and carbohydrate (55 percent, DM basis). It is also a good source of calcium, zinc, phosphorus, magnesium, copper and nickel. Methionine and cystine are considered limiting amino acids in jack bean (Akpapunam and Sefa-Dedeh, 1997). The whole plant, the pods and the seeds are used to feed animals.

ANTI-NUTRITIONAL FACTORS

Jack bean seeds and foliage contain several anti-nutritional factors such as concanavalin A (a lectin protein), canavanine (a structural analogue of arginine) and canatoxin. Fresh forage and its by-products are generally detrimental to livestock and monogastric animals. Affected animals have a clear nasal discharge, become lame and cannot rise. Mucous membranes become muddy in appearance and clear urine is passed more frequently than usual. Heat-treatment overcomes this toxicity. Meal prepared from jack bean seed is more palatable to cattle if molasses is added to it. For non-ruminants, extended boiling with one or two changes of water and peeling off of the seed-coat is required before the mature seeds are edible.

It is recommended to process (by cooking or boiling) the seeds before feeding them to animals in order to reduce the anti-nutritional factors. However, autoclaving alone is not sufficient to mitigate deleterious effects of jack bean. It may thus be useful to combine soaking and autoclaving with boiling, soaking and shaking (Belmar *et al.,* 1999).

FEEDING OF SEED AND ITS BY-PRODUCTS

Cattle and sheep

Jack bean seeds. The supplementation of jack bean seeds at 30 percent in the diet of cattle reduced average daily gain by 8.3 percent (Chee *et al.,* 1992). Paredes and Escobar (1984) reported that supplementing grazing dairy cows with ground pods of jack beans had no depressive effect on milk yield. Troccoli, Escobar and Gonzalez (1989) also observed lower daily live-weight gain with jack bean seed supplementation compared with soybean meal and maize-based diets in pre-weaning calves. Adding molasses to jack bean seed meal may help increase its palatability (FAO, 2012). Mora, Parra and Escobar (1986) observed lower rumen fermentation by on increasing the inclusion rate of jack beans from 22 to 32 percent in the diet of sheep.

In the United States of America, jack bean is grown mainly as animal feed. Average yield of jack beans range from 800 to 1 000 kg/ha, depending on rainfall distribution. However, as high as 6 000 kg/ha has been recorded in highly intensive agriculture (Chee *et al.,* 1992).

Table 4.2.1 Chemical composition of jack bean and its by-products (percent, DM basis)

Parameter	Seeds	Aerial part, fresh	Leaves, fresh	Straw	Pod husk
Crude protein	20.5–36.3	14.9–24.8	20.3–24.8	27.3	4.5
Ether extract	1.6–3.1	1.18–2.2	2.2		1.5
Crude fibre	2.8–12.9	27.4–45.4	34.3		48.1
Ash	2.8–9.7	6.7–14.1	11.2	9.3	3.8
NDF	32.3–36.4	32.4–62.6	32.4–38.9	46.0	
ADF	13.8	17.2–43.2	27.1–27.2	32.9	
Lignin	1.1–2.0	8.2–12.1	8.2–10.2	8.0	
Calcium	0.10–0.32	1.48–3.34	2.54–2.82	1.41	0.30
Phosphorus	0.27–0.71	0.23–0.31	0.31	0.25	0.01

Notes: DM (as fed) is 85.3–96.0 percent for seeds, 21.0–38.5 percent for fresh plant, 21.0 percent for leaves, 89.1 percent for straw and 90.5 percent for pod husk.
ADF = acid detergent fibre; NDF = neutral detergent fibre.
Source: Feedipedia (2016).

Jack bean foliage. Fresh forage is not palatable to ruminants and is eaten only in small amounts. However, cattle can gradually get used to it and acquire a taste for it (Chee *et al.*, 1992). Drying of the forage results in higher intake. In goats, jack bean forage has been found worth considering for a dry season feed strategy in Nigeria (Akinlade *et al.*, 2007). Forage DM yields of up to 23 tonne/ha have been obtained in Hawaii and green fodder yields may exceed 50 tonne/ha (Chee *et al.*, 1992). The plant has also been used as silage.

Pigs

A negative effect on average daily weight-gain was observed when feeding jack bean seeds to growing pigs. For the processed seeds (alkali-treated, autoclaved or extruded), the level of inclusion could be up to 15 percent (Risso and Montilla, 1992). Michelangeli *et al.* (2004) also observed that diets containing up to 20 percent toasted seeds (at 194 °C for 18 minutes) were not detrimental to feed intake and weight gain.

Poultry

Broilers. Mendez, Vargas and Michelangeli (1998) observed that feed intake and weight gain of broiler chickens were reduced significantly by feeding a diet (maize + soybean meal) containing 10 percent raw jack bean seeds. However, a diet containing toasted jack bean seeds supported adequate chick performance. Esonu *et al.* (2000) observed that feeding jack bean meals (20, 25 and 30 percent of the diet) soaked with trona solution ($Na_2CO_3.NaHCO_3.2H_2O$ at 3 percent of the weight of jack bean) significantly depressed performance of broiler finishers at all levels. It has also been observed that raw seeds, even at inclusion levels as low as 5 percent, have negative effects on broilers, including decreased weight gain, increased feed conversion ratio (decreased feed use efficiency), and alterations in the liver, pancreas and kidneys (Akinmutimi, 2006; Akanji, Ologhobo and Emiola, 2007).

Layers. Udedibie (1991) reported that the optimal dietary level of boiled jack beans for layers was about 10 percent. Udedibie (1991) also reported that boiled jack beans along with urea-ensiling could be incorporated in layers' diets at up to 20 percent with good results.

SUMMARY

Jack bean is a good source of protein, carbohydrate and minerals. However, seeds and its by-products contain concanavalin A, canavanine and canatoxin as anti-nutritional factors, which limit its use in ruminant and monogastric diets. Processed seeds of jack bean can be included up to 15 percent in pig diets. Raw seeds are not recommended for poultry diet; although toasted/boiled seeds can be incorporated up to 10 percent in broiler and layer diets. Dried jack bean forage can be used in the diet of ruminant animals.

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4.3 Winged bean

COMMON NAMES

Asparagus pea, calamismis, four-angled bean, four-cornered bean, Goa bean, goabohne, Haricot dragon, Manila bean, Mauritius bean, pois carré, princess pea, or winged bean.

DISTRIBUTION

The origin of winged bean [*Psophocarpus tetragonolobus* (L.) DC.] remains in dispute. At least four sites have been suggested as possibilities: Papua New Guinea, Mauritius, Madagascar (the Malagasy Republic), and India. The centres of greatest diversity of the species are Papua New Guinea and Indonesia, although numerous new varients have recently been discovered in Thailand and Bangladesh.

The winged bean is a tropical legume plant native to New Guinea. It is a poor man's crop that, until recently, was found mainly in rural areas of Papua New Guinea and Southeast Asia. It grows abundantly in hot, humid equatorial countries, from the Philippines and Indonesia to India, Myanmar, Malaysia, Thailand and Sri Lanka. It is widely known, yet grown on a small scale in Southeast Asia and Papua New Guinea. The winged bean is an underutilized species but has the potential to become a major multi-purpose food crop in the tropics of Asia, Africa and Latin America (Khan, 1982).

TAXONOMY

The winged bean is a species in the genus *Psophocarpus* Neck. ex DC., a genus of 6–9 varying species (Khan, 1982). All but the winged bean appear to be indigenous to Africa. Only the species *Psophocarpus tetragonolobus* and *P. palustris* have been used for food. The other species have never been cultivated. Even *P. palustris* remains a semi-wild plant, used in West Africa mainly in times of famine. Species in the *Psophocarpus* genus are perennial herbs grown as annuals (Hymowitz and Boyd, 1977). *Psophocarpus* species are capable of climbing by twining their stems around a support. Species in the *Psophocarpus* genus have tuberous roots and pods with wings (NRC, 1975).

DESCRIPTION

Some researchers hailed the winged bean as "a possible soybean [*Glycine max* (L.) Merr.] for the tropics" (Berry, 1977; Garcia and Palmer, 1980; NRC, 1981). Currently, winged bean is appreciated by farmers and consumers in the Asian region for its variety of uses and disease tolerance. Winged bean is nutrient-rich, and all parts of the plant are edible. Leaves can be eaten like spinach, flowers can be used in salads, tubers can be eaten raw or cooked, and seeds can be used in similar ways as the soybean.


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*Photo 4.3.1 Seeds of winged bean [*Psophocarpus tetragonolobus *(L.) DC.]*

The winged bean plant grows as a vine with climbing stems and leaves, 3–4 m in height. It is a herbaceous perennial, but can be grown as an annual. It is generally taller and notably larger than the common bean. The bean pod is typically 15–22 cm long and has four wings with frilly edges running lengthwise. The skin is waxy and the flesh partially translucent in the young pods. When the pod is fully ripe, it turns an ash-brown colour and splits open to release the seeds. Winged beans contain a high level of protein (30–39 percent, DM basis; Table 4.3.1), which is similar to that of soybean.

The shape of winged bean leaves ranges from ovate, deltoid, ovate-lanceolate, lanceolate to long lanceolate (Khan, 1982). The leaves of winged bean also vary in colour, appearing as various shades of green. Stem colour is commonly green, but can vary from shades of green to shades of purple. Pod shape is most commonly rectangular, but can also appear flat. Pod colour may also vary from shades of cream, green, pink to purple. The exterior surface of the pod also varies in texture. Pods can appear smooth or rough depending on genotype. Seed shape is often round, but oval and rectangular seeds are also found. Seed colour changes based on environmental factors and storage conditions. Seeds may appear white, cream, brown or dark tan in appearance. The shapes of winged bean tuberous roots also show variation.

CLIMATIC CONDITIONS FOR CULTIVATION

Winged bean thrives in hot humid weather, but it is an adaptable plant. It can also adjust to the climate of the equatorial tropics (Khan, 1982), but is susceptible to waterlogging and moisture stress. Ideal growing temperature is reported to be 25 °C. Lower temperature is reported to suppress germination, and extremely high temperatures are detrimental to the yield of the plant.

Moderate variations in the growing conditions of winged bean can result in variations in yield. It is reported that growing winged bean in lower than favourable temperatures can increase tuber production. It is also reported that leaf expansion rate is higher in a warmer climate. In addition to adequate temperature, winged bean requires sufficient soil moisture at all stages of growth to produce high yields (Khan, 1982). Although the winged bean plant is indigenous to the humid tropics, it is possible for the plant to yield in drier

Table 4.3.1 Chemical composition of winged bean and its by-products (percent, DM basis)

Parameter	Un-ripe seeds	Ripe seeds	Immature pods	Leaves	Tubers
Crude protein	10.7	39.0	4.3	7.6	15.0
Ether extract	10.4	20.4	3.4	2.5	1.1
Crude fibre	2.5	16.0	3.1	4.2	17.0
Ash	1.0	4.9	1.9	2.9	1.70
Calcium		0.37	0.33	0.26	0.04
Phosphorus		0.61	0.07	0.10	0.06

Notes: DM (as fed) is 12.0 percent for un-ripe seeds, 76.0 percent for ripe seeds, 24.0 percent for immature pods, 15.0 percent for leaves, and 35.0 percent for tubers.
Source: NRC (1981).

climates with adequate irrigation (NRC, 1975). High yield has been recorded when the maturity of the plant and the drier part of the growing season correspond.

PRODUCTION OF SEED, POD AND TUBER

The winged bean is capable of producing more than 2 tonne of seeds/ha (Vietmeyer, 1978). Pod yields for the green (immature) pods harvested as a fresh vegetable was reported up to 35 tonne/ha. Tubers yield has been recorded to be 11.7 tonne/ha when grown in the traditional manner by village farmers in the Highlands of Papua New Guinea (Khan, 1980).

ANTI-NUTRITIONAL FACTORS

Winged bean seeds are known to contain several anti-nutritional factors such as trypsin and chymotrypsin inhibitors (NRC, 1981). Other anti-nutritive factors are amylase inhibitors, phytohaemagglutinins, cyanogenic glycosides, and perhaps saponins (Claydon, 1978). The winged bean seed-inhibitor activity can be safely eliminated only by using moist heat; for example by steaming the seeds in an autoclave at 130 °C for 10 minutes. The same result can be achieved by soaking seeds for approximately 10 hours and then boiling them for 30 minutes.

WINGED BEAN SEED AND ITS BY-PRODUCTS AS ANIMAL FEED

Winged bean seeds

The winged bean seed has high protein content (32–39 percent, DM basis; Table 4.3.1) and the amino acid composition of winged bean is similar to that of soybean, except that methionine and cysteine are limiting (Wyckoff, Mar and Vohra, 1983). Heat treatment (autoclaved at 120 ºC for 45 minutes) significantly improved amino acid digestibility of winged bean. However, overheating (90 minutes of autoclaving) destroyed lysine, cysteine and arginine of winged bean (Mutia and Uchida, 1994).

To the authors' knowledge, no study is available on feeding winged bean or its by-products to mammalian livestock.

Poultry

Benito *et al.* (1982) reported that replacing soybean (0, 19, 44, and 74 percent on protein basis) with autoclaved winged bean (submerged in water for 30 minutes at 121 °C) had no adverse effect on metabolizable energy, nitrogen retention, broiler performance and feed conversion. However, replacing soybean with autoclaved winged bean at 75 and 100 percent decreased metabolizable energy and led to poorer broiler performance. Smith, Ilori and Onesirosan (1984) also reported high nutritional merit of the winged bean, and suggested that farm processed winged bean can effectively partially replace soybean and groundnut cake in broiler diets.

The dry pod residue left after the seeds have been threshed out has 10 percent protein and has been tested satisfactorily in animal feeds. In Thailand, this pod residue is being used successfully as a medium for growing straw mushrooms.

SUMMARY

Winged beans contain a high level of protein (32–39 percent, DM basis) with an amino acid composition similar to that of soybean. It contains several anti-nutritional factors such as trypsin and chymotrypsin inhibitors, amylase inhibitors, phytohaemagglutinins, cyanogenic glycosides, and saponins. Steaming and soaking of seeds help reduce these anti-nutritional factors. Autoclaved winged bean can partially replace soybeans in broiler diets. More research is required to optimize the level of feeding seeds and by-products in the ration of ruminant and monogastric diets.

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4.4 Guar bean

COMMON NAMES

Calcutta lucerne, cluster bean, clusterbean, guar, Siam bean (English); guar, goma guar (Spanish); cyamopse à quatre ailes (French); guarplant, guarstruik, guarboon (Dutch); Guarbohne (German).

DISTRIBUTION

Actual place of origin is not known, but it is believed that guar bean [*Cyamopsis tetragonoloba* (L.) Taub.] originated in the hot and arid areas of Africa or the deserts of Middle East. It was domesticated in India by the Arab people (Ecoport, 2010). It is mainly grown in the semi-arid and sub-tropical areas of North and North-West India (Rajahstan) and East and South-East Pakistan. It later spread to other Asian countries, including Indonesia, Malaysia and the Philippines, and is now grown in many parts of the drier tropics and subtropics.

DESCRIPTION

Guar bean is an upright, coarse-growing summer annual legume known for its drought resistance. Its deep tap roots reach moisture deep below the soil surface. Most of the improved varieties of guar bean have glabrous (smooth, not hairy) leaves, stems and pods. Plants have single stems, fine branching or basal branching (depending on the cultivar) and grow 45 to 100 cm tall. Racemes are distributed on the main stem and lateral branches. Pods are generally 2.5 to 10 cm long and contain 5 to 12 seeds each. Seeds vary from dull-white to pink to light grey or black. Guar bean yields up to 45 tonne/ha of green fodder, 6–9 tonne/ha of green pods and 0.7–3 tonne/ha of seeds (Ecocrop, 2010; Ecoport, 2010).

CLIMATIC CONDITIONS FOR CULTIVATION

Guar bean is a photosensitive crop. It grows in specific climatic conditions that provide a soil temperature of around 25 °C for proper germination. It is mostly grown in arid, unirrigated areas, and does not require much fertilizer to grow. It is a rainfed monsoon crop, requiring 200–400 mm of rain in 3–4 spells and is harvested in autumn. Guar bean is an

© NDDB

*Photo 4.4.1 Plants of guar bean [*Cyamopsis tetragonoloba* (L.) Taub.] cultivated for fodder* annual, summer legume and requires warm weather and a relatively long growing season of 20–25 weeks. The crop is harvested in early winter. It is sown immediately after first monsoon showers say in July and harvested around November each year. Heavy rains, producing waterlogged condition or more compact soils disturb its root system because of its surface feeding nature, and reduces nitrogen fixing bacterial activity.

The guar bean prefers a well-drained sandy loam soil. It can tolerate saline and moderately alkaline soils, with pH ranging between 7.5 and 8.0. Heavy clay soils, poor in nodulation and bacterial activity are not suitable for this crop. Soils with medium to light constituents without excessive moisture are suitable for its cultivation. Even soils with poor fertility and depleted plant nutrients are suitable for growing guar bean as a green manure crop. Pasture lands receiving little care can also be used for growing guar bean mixed with grasses.

NUTRITIONAL VALUE

Guar bean meal is the main by-product of guar bean gum production. It is a mixture of germs and hulls with circa 25 percent germs and 75 percent hulls (Lee *et al.,* 2004). Guar bean meal is a protein-rich material containing about 40 to 45 percent protein (DM basis; Table 4.4.1). It is used as a feed ingredient, but may require processing to improve palatability and remove anti-nutritional factors. In addition to the regular guar bean meal, some Indian manufacturers sell a high-protein guar bean meal called *korma*, which contains 50–55 percent protein (DM basis). Guar bean *chuni* contains about 30–35 percent protein (DM basis), depending on the ratio of germs and hulls. Guar bean meal and *korma* are usually suitable for ruminants and to some extent can replace other protein sources, but their use in monogastrics is more limited.

ANTI-NUTRITIONAL FACTORS

Guar bean meal contains various anti-nutritional factors such as trypsin inhibitors, saponin, haemagglutinins, hydrocyanic acid and polyphenols (Gutiérrez *et al.,* 2007). However, Lee *et al.* (2004) observed that anti-trypsic activity of guar bean meal was found to be lower than that in heat-treated soybean meal, and therefore caused no adverse effects in poultry. Presence of gum residue (12 percent) in guar bean meal increases viscosity in the intestine and reduces digestibility and growth (Lee, Bailey and Cartwright, 2009). The large saponin content of guar bean seed (up to 13 percent, DM basis) could have both a negative anti-nutritional effect and a positive anti-microbial activity (Hassan *et al.,* 2010). Heat treatments (autoclaving) and enzyme treatment of guar bean meal improved feed utilization (Lee *et al.,* 2004, Lee *et al.,* 2005; Lee, Bailey and Cartwright, 2009). Autoclaving enhanced the stickiness of droppings, whereas addition of hemicellulase prevented it (Patel and McGinnis, 1985).

Table 4.4.1 Chemical composition of guar bean and its by-products (percent, DM basis)

Parameter	Seeds	Guar meal	Guar korma	Forage, fresh	Forage, dry	Crop residue
Crude protein	28.0	40.0–44.3	55.1–56.6	16.0	23.9	8.8
Ether extract	3.7	4.2–7.5	4.3–5.1	1.9	2.2	1.3
Crude fibre	6.9	7.2–16.1	6.3–8.0	22.7	11.8	32.9
Ash	5.0	4.7–8.8	5.3–5.5	17.0	15.5	7.9
NDF		20.5–21.0	25.6			
ADF			12.9			
Lignin		0.3	5.3			
Calcium		0.45–1.26		1.80	2.42	1.17
Phosphorus		0.46–0.98		0.10	0.27	0.27

Notes: DM (as fed) is 92.4 percent for seeds, 93.4–96.7 percent for guar bean meal, 92.0 percent for guar bean *korma*, 21.5 percent for fresh forage, 85.8 percent for dry forage, and 91 percent for crop residues.
ADF = acid detergent fibre; NDF = neutral detergent fibre.
Source: Feedipedia (2016).

GUAR BEAN SEED AND ITS BY-PRODUCTS AS ANIMAL FEED

Cattle

Guar bean seeds. Based on the protein and *in vitro* DM digestibility, guar bean seeds can efficiently replace other protein meals, such as cottonseed, in the ration of livestock animals (Rao and Northup, 2009). Tiwari and Krishna (1990) reported that growth rate and nutrient utilization were adequate with a diet containing wheat straw and overnight boiled (slow heat) guar bean seed in the ratio 60:40 (ME basis).

Guar bean meal. In dairy cows, lower palatability has been reported when more than 5 percent guar bean meal was included in the diet. However, dairy cows and heifers fed rations containing 10–15 percent guar bean meal became accustomed to its odour and taste after a few days. Raw guar bean meal can constitute up to 25 percent of cattle rations, whereas, heat treated guar bean meal can be used as the sole protein component in cattle diets (Göhl, 1982). A field study conducted by Garg et al. (2003) in India revealed that feeding formaldehyde treated (to reduce degradability of protein in the rumen) guar bean meal (1.0 kg/head/day) resulted in improved yields of milk, up by 7.3 percent and milk fat, up by 4.5 percent, compared with feeding untreated guar bean meal in crossbred cows.

Various studies showed that replacing guar bean meal at 50 percent of metabolizable energy, and protein supplement with groundnut meal in growing male buffalo calves gave a better growth rate and feed conversion efficiency (Mandal *et al.*, 1989a; Mandal *et al.*, 1989b). Lohan *et al.* (1989) also observed a positive response with respect to sperm motility, plasma luteinizing hormone and testosterone on feeding guar bean meal, compared with animals fed groundnut meal.

Guar bean crop residues. Patel and Shukla (1972) reported that guar bean crop residues containing the stems, leaves and immature pods left after threshing can be fed to lactating cows, and their nutritive value is comparable with that of pigeon pea .

Sheep and goats

Guar bean seeds. Inclusion of crushed guar bean seeds (150 g/head/day) in the diet of Marwari ewes grazing sewan grass (*Lasiurus scindicus* Henrard) increased DMI and digestibility (Thakur, Mali and Patnayak, 1985), suggesting that feeding 150 g crushed guar bean seeds has potential for improving DMI and DM digestibility, without any adverse effects on health.

Guar bean meal. Huston and Shelton (1971) observed that diets containing guar bean meal had reduced growth rates of lambs in the initial period of the study, but animals tended to overcome initial, poor performance and make compensatory gains toward the end of the feeding period. Rohilla, Khem Chand and Jangid (2007) also observed better meat yield in sheep fed diets containing 50:50 guar bean meal and maize (*ad libitum* diets alone or *ad libitum* diets combined with grazing). Mathur and Mathur (1989) reported that formaldehyde-treated guar bean meal supplemented with urea resulted in higher growth than raw or unsupplemented guar bean meal in Magra lambs.

Guar bean hay. Patnayak *et al.* (1979) reported that guar bean hay prepared at flowering stage was able to maintain the body weight of rams for 45 days with a DMI of 2.44 percent BW. Similarly, Pachauri and Upadhyaya (1986) reported that, in goats, guar bean hay prepared at pod formation was also able to maintain intake and digestibity of nutrients, when fed together with crushed oats. Feeding guar bean hay (2 kg/day/head) improved body weight and milk yield in goats, and the authors concluded that guar bean hay could be used to improve the overall productivity of goats (Zahid *et al.,* 2012).

Guar bean crop residues. Guar bean crop residues (straw) can be incorporated up to 70 percent in the maintenance ration without any adverse effects (Singh *et al.*, 2008). Bhakat, Saini and Pathak (2009) reported that guar bean straw can also be used for feeding camels.

Pigs

Tanksley and Osbourn (1967) observed lower growth rate in growing pigs, fed a diet containing 7.5 percent guar bean meal, compared with the control diet (sorghum + soybean meal). There was no negative effect on growth performance in growing-finishing pigs fed a diet with 6 percent guar bean meal. However, Heo *et al.* (2009) observed reduced growth rate at the 12 percent inclusion level, without affecting pork quality.

Poultry

Broilers. Conner (2002) observed that an inclusion rate of 2.5 percent untreated guar bean meal can support growth, feed consumption, feed:grain ratio, and meat yield equivalent to those of a maize+soybean-meal diet. Lee *et al.* (2005) also reported that guar bean meal can be included at 2.5 percent in the diet of broilers, without adversely affecting chicken growth to 6 weeks of age. Even for treated guar bean meal, the feeding threshold should remain as low as 5 percent to avoid problems (Lee *et al.*, 2005). Hassan *et al.* (2011) reported that inclusion of 5 percent guar bean germ in the diet of chicks gave significantly higher body weight gain, higher daily feed intake, and improved feed efficiency compared with the control diet, while chicks fed on 25 percent guar bean germ diets showed significantly decreased values for all these parameters. It has been observed that guar bean meal can be fed to chicks at levels up to 6 percent of the diet without negative effects on growth, feed intake and feed conversion ratio (Mohammad *et al.*, 2012). A partial replacement of soybean meal with guar bean korma did not affect body weight and carcass traits of commercial broiler chickens (Mishra *et al.*, 2013).

Layers. Gutiérrez *et al.* (2007) observed no significant differences when fed 2.5 or 5 percent guar bean germ or meal on hen-day egg production or feed consumption. Significant increase in egg weight, total egg mass per hen, and feed conversion ratio were observed in hens fed 2.5 percent guar bean meal, whereas they remained unchanged for diets containing either level of guar bean germ or 5 percent guar bean meal. Feeding either level of guar bean germ or meal did not affect shell quality, Haugh units (calculated as Haugh unit = $100 \times \log (H + 7.57 - 1.7W^{0.37})$; where H is albumin height (mm) and W is egg weight in g; Panda, 1996), or egg yolk colour. The results showed that both guar bean germ and meal can be fed to high-producing laying hens at up to 5 percent without adverse effects on laying hen performance. Hossein (2012) concluded that adding 5 percent guar bean meal to laying hens' diet has adverse effects on their productive performance but it seems that hens can tolerate guar bean meal in the diet up to 2.5 percent with no detrimental effects on egg production, egg mass and feed efficiency.

SUMMARY

Guar meal and guar *korma* are protein-rich by-products of the guar gum industry, and used in monogastric and ruminant diets. Autoclaving of guar meal improves its inclusion level. Raw guar meal can constitute up to 25 percent of cattle rations, whereas, heat-treated guar meal can be used as the sole protein component in cattle diet. A maximum of 5 percent of raw guar meal can be included in pig diets. Raw and heat-treated guar meal can be included up to 2.5 and 5 percent levels, respectively, in poultry diet.

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4.5 Velvet bean

COMMON NAMES

Bengal bean, buffalo bean, cabeca-de-frade, chiporro, cowage, cowhage, cowitch, fava-coceira, Florida velvet bean, itchy bean, kapikachhu, krame, lacuna bean, Lyon bean, Mauritius velvet bean, mucuna, Nescafé, pica-pica, pó de mico, velvet bean, Yokohama velvet bean (English); pois mascate, dolic, haricot de Floride, haricot de Maurice, pois velus, haricot pourpre, pois du Bengale (French); grano de terciopelo, fríjol terciopelo, picapica, chiporro, nescafe, mucuna, fogaraté, café incasa, café listo, fríjol abono (Spanish); feijão-da-flórida, po de mico, fava coceira (Portuguese); fluweelboon (Dutch); Juckbohne (German); pwa grate (Haitian creole); Kara benguk [Indonesian].

DISTRIBUTION

Velvet bean [*Mucuna pruriens* (L.) DC.] is native to areas in southern China, and eastern India, where it was at one time widely cultivated as a green vegetable crop (Duke, 1981). Now, it is widely distributed to other tropical areas of the world such as the West Indies, tropical America, the Pacific Islands, and the United States of America. It was introduced to the southern states of the United States of America in the late nineteenth century and from there, it was re-introduced to the tropics in the early part of the twentieth century (Eilittä and Carsky, 2003).

DESCRIPTION

Velvet bean is a herbaceous vine and generally tap-rooted. Leaves have three leaflets up to 15 cm long, densely hairy beneath and rather silvery, with the lateral leaflets asymmetrical. Flowers occur in showy, many-flowered pendent racemes up to 30 cm long, dark purple and creamy-coloured. Pods are up to 12 cm long, oblong, thick and curved, covered with stiff brownish or orange spicules or hairs, which produce irritation if the pods are handled; however, non-stinging cultivated varieties has been developed. The stems are slender and slightly pubescent. The seeds are variable in colour, ranging from glossy black to white or brownish with black mottling. Seeds are oblong ellipsoid 1.2 to 1.5 cm long, 1 cm broad and 0.5 cm thick (FAO, 2011; US Forest Service, 2011).

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*Photo 4.5.1 Seeds of Velvet bean [*Mucuna pruriens *(L.) DC.]*

In recent decades, there has been increased interest in the potential of *Mucuna* species as cover crop, fodder and green manure for tropical and subtropical regions. Historically, velvet bean has been used as a livestock feed. Prior to the beginning of the twentieth century, it has been reported to have been used as a fodder for cattle in Mauritius (Piper and Tracy, 1910). It was considered as promising feed in the United States, when it was identified by researchers at the Florida Agricultural Experimental Station in 1895 (Clute, 1896).

CLIMATIC CONDITIONS FOR CULTIVATION

Velvet bean can grow in very diverse environments. It prefers well-drained soil, but it able to grow well in sandy and acid soils. It prefers hot, climates with rainfall ranging between 1 000 and 2 500 mm, but also can grow in as little as 400 mm of annual rainfall. It does have some tolerance to drought, but it will not survive in waterlogged soils. The best temperature range to grow velvet bean is between 19 °C and 27 °C and it requires high light intensity to grow.

NUTRITIONAL VALUE

Velvet bean seeds are rich in protein (24–30 percent, DM basis; Table 4.5.1), starch (28 percent, DM basis) and gross energy (10–11 MJ/kg, DM basis) (Siddhuraju, Becker and Makkar, 2000; Pugalenthi, Vadivel and Siddhuraju, 2005). Bressani (2002) compared the nutritional quality of velvet bean with common beans (*Phaseolus vulgaris* L.) and concluded that the proximate composition, amino acid and micronutrient content, protein quality and digestibility of velvet beans are in general similar to those of common beans. Yields of velvet bean range from 10 to 35 tonne green material/ha per year, and from 0.25 to 3.3 tonne seed/ha per year depending on the cultivation conditions (Ecocrop, 2011).

ANTI-NUTRITIONAL FACTORS

Several anti-nutritional factors such as L-dopa (L-3,4-dihydroxyphenylalanine), total free phenolics, tannins, haemagglutinin, trypsin and chymotrypsin inhibitors, dimethyltryptamine, anti-vitamins, protease inhibitors, phytic acid, flatulence factors, saponins, and hydrogen cyanide are present in velvet beans (Vadivel and Janardhanan, 2000).

L-dopa

L-dopa is one of the two important non-protein amino acids (the other is dimethyltryptamine; a hallucinogenic substance) present in velvet beans. L-dopa is used for symptomatic relief of Parkinson's disease. The level of L-dopa in seeds varies from 1.6 to 7 percent (Cook *et al.,* 2005). Matenga *et al.* (2003) reported that ensiling decreased L-dopa content in the seeds by 10–47 percent. Ruminants are less susceptible to L-dopa, as it does not modify

Table 4.5.1 Chemical composition of velvet bean and its by-products (percent, DM basis)

Parameter	Seeds	Aerial part, fresh	Pods	Pod husk	Hay
Crude protein	18.2–37.0	10.2–25.9	21.0	4.3	14.8
Ether extract	0.7–4.7	1.3–4.7	2.6	0.7	2.6
Crude fibre	4.8–9.5	14.2–36.6	15.6	42.4	30.7
Ash	3.0–4.6	5.2–12.2	4.5	5.9	8.9
NDF	14.6–28.4	10.3–59.6			
ADF	6.0–9.1	7.1–45.6			
Lignin	0.2–1.8	10.0–14.9			
Calcium	0.10–0.30	0.63–1.42			
Phosphorus	0.29–0.51	0.12–0.31			

Notes: DM (as fed) is 88.5–94.7 for seeds, 15.0–45.4 percent for fresh aerial part, 90.3 percent for pods, 89.2 percent for pod husk, and 90.6 percent for hay.
ADF = acid detergent fibre; NDF = neutral detergent fibre.
Source: Feedipedia (2016).

the rumen fermentation pattern, and rumen microbes get adapted to L-dopa (Chikagwa-Malunga *et al.*, 2009b). L-dopa may also cause skin eruptions in monogastrics (Pugalenthi, Vadivel and Siddhuraju, 2005).

Alkaloids and others

A number of alkaloids, such as mucunain, prurienine and serotonin, are present in velvet bean seeds. Mucunain is produced by pod hairs. It causes severe itching to the skin, and the hairs coming in contact with the eyes can be very painful. It has been reported that haemorrhage and death can result from cattle eating the hairy pods (Miller, 2000).

In addition to the above, velvet bean seeds also contain other anti-nutritional factors such as trypsin and chymotrypsin inhibitors, which decrease protein digestibility, induce pancreatic hypertrophy and hyperplasia, increase trypsin secretion and, therefore, reduce nitrogen retention, growth and feed conversion. Phytate present in the seeds may reduce availability of minerals and protein. Oligosaccharides (mainly verbascose) cause flatulence. The amount of hydrogen cyanide found in velvet bean seeds is well below (5.8 mg/100g) the lethal dose (35 mg/100g). Lectins and saponins are also present in velvet bean seeds (Pugalenthi, Vadivel and Siddhuraju, 2005).

These anti-nutritional factors can be efficiently reduced by a wide range of treatments, such as boiling in water (1 hour), autoclaving (20 minutes), water-soaking (48 hours and then boiling for 30 minutes), or soaking the cracked seeds (24 hours in 4 percent calcium hydroxide solution) (Cook *et al.*, 2005; Pugalenthi, Vadivel and Siddhuraju, 2005).

DIGESTIBILITY

Various studies on ruminants showed no negative impacts on animal performance and health on consumption of Velvet bean grain or foliage. Ayala-Burgos *et al.* (2003) and Sandoval-Castro *et al.* (2003) studied the effect of anti-nutritional compounds present in velvet bean on degradation activity of rumen micro-organisms. Sandoval-Castro *et al.* (2003) found that *in vitro* dry matter digestibility of beans and husks were high at 97.9 and 79.0 percent, respectively. This study suggests that the anti-nutritional factors showed no detrimental effect on the *in vitro* fermentation. Also, in another *in vitro* study, Adesogan *et al.* (2004) found higher DM digestibility of velvet bean than soybean. These results suggest that velvet bean has potential to replace conventional energy sources (maize and sorghum) in ruminant diets. The husks have high digestibility and can also be incorporated into the diet.

VELVET BEAN SEED AND ITS BY-PRODUCTS AS ANIMAL FEED

Velvet bean seeds

Velvet bean seeds are a promising protein supplement for situations where cost or availability precludes the use of soybean in ruminant rations. Pods with their seeds can be ground into a rich protein meal and can be fed to all classes of livestock (Chikagwa-Malunga *et al.*, 2009c).

Sheep and goats. Many studies confirmed that supplementing velvet beans and pods in the diet of sheep and goats has no adverse effects (Castillo-Caamal, Castillo-Caamal and Ayala-Burgos, 2003; Castillo-Caamal *et al.*, 2003; Matenga *et al.*, 2003; Mendoza-Castillo, Castillo-Caamal and Ayala-Burgos, 2003; Pérez-Hernandez, Ayala-Burgos and Belmar-Casso, 2003).

Velvet bean forage

Velvet bean intended for forage can be harvested when the pods are still young, usually between 90–120 days after sowing (Wulijarni-Soetjipto and Maligalig, 1997). They also reported that at 5-week cutting intervals, and cutting at 30 cm height provides forage with good quality and high yield. Biomass yield and nutritive value can be enhanced by harvesting at about 120 days after planting (Chikagwa-Malunga *et al.*, 2009a). Velvet beans yield green fodder up to 20–35 tonne/ha resulting in 8.2–16.4 tonne DM/ha (Ecocrop, 2011).

Cattle. Armstrong *et al.* (2008) reported that, when cultivated in association with maize, velvet bean forage increased the protein content of the mixture, but did not increase the milk yield of dairy cattle. Juma *et al.* (2006) observed similar lactation performance with velvet bean and Gliricidia [*Gliricidia sepium* (Jacq.) Kunth ex Walp.] with a Napier grass (*Pennisetum purpureum* Schumach.) basal diet in cows. Velvet bean and gliricidia forages gave similar daily milk yield (5.2 and 5.5 kg/cow, respectively) when used to supplement a grass basal diet (Muinga, Saha and Mureithi, 2003), and these authors concluded that velvet bean forage at 2 kg DM/day can be used to supplement dairy cows fed a grass-based diet.

Velvet bean hay

Due to its long vines and dense matted growth of velvet bean, it is difficult to handle for hay making (FAO, 2011). Milk production increased by 13 percent in dairy cows fed Napier grass supplemented with velvet bean hay (Nyambati, Sollenberger and Kunkle, 2003). Murungweni, Mabuku and Manyawu (2004) also observed higher milk yields, protein, lactose and non-fat solids for cows fed velvet bean-hay based diets compared with those fed hyacinth bean-based diets.

Sheep and goats. Murungweni, Mabuku and Manyawu (2004) found that feeding velvet bean hay at 2.5 percent of BW, along with poor quality roughage (maize stover) had no adverse effects in young rams. However, velvet bean hay caused metabolic disorders (diarrhoea) if given in excess of 2.6 percent of BW. The addition of a small quantity of molasses may improve consumption (Matenga *et al.*, 2003) and reduce dustiness (Pérez-Hernandez, Ayala-Burgos and Belmar-Casso, 2003).

Pigs

The use of velvet bean seeds in pig diets is limited, mainly because of deficiency in sulphur-containing amino acids, and the presence of numerous anti-nutritional and toxic factors (Pugalenthi, Vadivel and Siddhuraju, 2005). Sridhar and Bhat (2007) observed that feeding raw seeds can result in deleterious effects on pig performance as well as their blood constituents. Emenalom *et al.* (2004) observed that incorporating 15 percent of raw velvet beans in pig feeding caused 50 percent mortality in young animals.

It is most desirable to process velvet bean seeds in order to use them safely in pig feeds. Lizama *et al.* (2003) reported that inclusion of boiled seeds at 25 percent could satisfactory replace maize in a diet of pigs (40 kg BW). A more extensive process, consisting of cracking the seeds, soaking them in water for 48 hours and boiling for 1 hour allowed the use of up to 40 percent seeds in the diets of 15–35 kg pigs. This treatment also allowed full replacement of soybean meal while maintaining growth rate (341–351 g/day) and feed conversion ratio (2.53–2.58) (Emenalom *et al.*, 2004).

Poultry

The high protein and energy values of velvet bean seeds make it attractive to use them in poultry diets; however, the presence of anti-nutritional factors limits their practical interest, unless appropriate technical treatments are applied (Carew and Gernat, 2006).

Broilers, quails and guinea fowls. Various studies reported that raw velvet bean seeds should not be included in broiler diets, as it markedly reduced broiler performance (Emiola, Ologhobo and Gous, 2007; Tuleun and Igba, 2008). Iyayi, Kluth and Rodehutscord (2006) observed that 5 percent inclusion of raw velvet beans can induce a 25 percent drop in broiler performance. High levels (20 percent of diet) may cause significant mortality in guinea fowl (Dahouda *et al.,* 2009). Velvet beans appear to be more detrimental to growth than to feed intake, although results differ among groups (Trejo *et al.,* 2004; Emiola, Ologhobo and Gous, 2007; Tuleun and Igba, 2008).

Various treatments that have been tested for reducing the levels of anti-nutritional factors include soaking (with or without additives in water), boiling, autoclaving, dry roasting and combinations of these techniques (Vadivel *et al.,* 2011). Processed seeds (dry roasting or soaking + boiling) can be included at up to 10 percent of the diet, but even processed seeds should be used carefully and probably avoided for starter animals. Dry roasting has been found to be an efficient way to limit the negative effects of velvet beans in broilers and Japanese quails (Emiola, Ologhobo and Gous, 2007; Ukachukwu and Obioha, 2007; Tuleun, Igyem and Adenkola, 2009). However other authors compared various treatments and found roasting less efficient than boiling for broilers and Guinea fowls (Emenalom *et al.,* 2005; Dahouda *et al.,* 2009).

Soaking alone (in water with or without additives) is not efficient (Tuleun and Dashe, 2010; Vadivel *et al.,* 2011), therefore, it should be combined with a heat treatment such as boiling or autoclaving. Carew and Gernat (2006) reported that heat treatments can help to reduce the negative effects of velvet beans. The duration of heat treatments can have an effect on their efficiency of utilization: boiling velvet bean seeds for 20 minutes resulted in lower growth rates than boiling for 40 or 60 minutes (Tuleun and Igba, 2008). In the opinion of several authors, the optimal treatment consisted of soaking in water or sodium bicarbonate, followed by boiling (60 to 90 minutes) and drying. This procedure was found to eliminate anti-nutritional factors efficiently (Vadivel *et al.,* 2011) and broiler performance was maintained at up to 10–20 percent inclusion of velvet beans in the diet (Akinmutimi and Okwu, 2006; Emenalom *et al.,* 2006; Farougou *et al.,* 2006; Ukachukwu and Obioha, 2007; Ani, 2008).

Layers and quails. The feeding of raw velvet bean seeds to layers can result in a marked reduction in performance. Daily egg production dropped from 78.5 to 65.5 percent with 12.5 percent raw seeds in the diet, and from 84 to 38 percent with 20 percent inclusion (Tuleun, Carew and Ajiji, 2008). Seed treatments reduced the negative effects of velvet bean seeds, but did not enable the same performance as control diets, even with lower levels of velvet bean seeds: in laying hens, the best treatment (toasting) allowed 74 percent hen-day egg production versus 84 percent from the control diet with 20 percent velvet bean seeds, while boiled seeds yielded 59 percent hen-day egg production (Tuleun, Carew and Ajiji, 2008). In laying Japanese quails, 15 percent toasted seeds caused a significant reduction in performance, but the lower feed cost per egg produced, and feed cost per bird, justified using velvet bean seeds (Tuleun and Dashe, 2010). Nevertheless, even processed velvet bean seeds are not recommended for feeding in commercial egg production, though they are economically profitable.

SUMMARY

Velvet bean seeds are a promising protein supplement for ruminants. Seeds contain two important non-protein amino acids: L-dopa and dimethyltryptamine, which are anti-nutrients. Velvet bean forage can be supplemented at 2 kg dry matter/head/day in dairy cows. Maximum inclusion level for velvet bean hay was recommended at up to 2.5 percent of body weight in sheep and goats. The use of velvet bean seeds in diets of pig and poultry is limited, due to presence of anti-nutritional factors. The processing of seeds such as cracking, soaking in water and boiling of seeds allows replacing soybean meal in the diets of pig. Processed seeds (soaking, boiling, drying) can be used up to 20 percent in broiler diets, but are not recommended for layer diets.

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4.6 African yam bean

COMMON NAMES

African yam bean, yam-pea (English); pois tubéreux africain, haricot igname, pomme de terre du Mossi (French); kutreku, kulege, akitereku, apetreku (Ghana); girigiri, kutonoso, roya, efik, nsama, ibibio (Nigeria); cinkhoma, nkhoma (Malawi); okpo dudu (Ibo); bitei (Obudu); sesonge, gundosollo, sumpelegu, tschangilu (Togo); Yoruba: sese, sheshe (Yoruba); giliabande, pempo, or mpempo (Congo).

DISTRIBUTION

African yam bean [*Sphenostylis stenocarpa* (Hochst. ex A. Rich.) Harms] originated in Ethiopia. Both wild and cultivated types are now cultivated in tropical west and central Africa, and southern and eastern Africa, particularly in Cameroon, Cote d'Ivoire, Ghana, Nigeria and Togo (Potter, 1992). It is cultivated in Nigeria mainly for seed. It is also cultivated for tubers in Côte d'Ivoire, Ghana, Togo, Cameroon, Gabon, Democratic Republic of the Congo, Ethiopia, and parts of East Africa, notably Malawi and Zimbabwe.

DESCRIPTION

African yam bean is a vigorously climbing herbaceous vine whose height can reach 1.5–3 m or more. The main vine/stem produces many branches which also twine strongly on available supports. The vegetative growing stage is characterized by the profuse production of trifoliate leaves. The slightly woody pods contain 20–30 seeds, are up to 30 cm long and mature within 170 days. The plant produces underground tubers that are used as food in some parts of Africa, and serve as organs of perennation in the wild (Potter, 1992).

It flowers profusely in 100 to 150 days, producing brightly-coloured flowers, which may be pink, purple or greenish white. From 4 to 10 flowers are arranged in racemes on long peduncles, usually on the primary and secondary branches. The large and attractive flowers blend pink with purple; the standard petals twist slightly backwards on themselves at anthesis. The flowers seem to exhibit self-pollination; up to 6 pods/peduncle may result after fertilization. The pods are usually linear, housing about 20 seeds. The linear and long unicarpel pods turn brown when mature (Duke, 1981). There are varieties with different seed colours (Oshodi *et al.*, 1995) and sizes (Adewale *et al.*, 2010) with mono-coloured or mosaic

*Photo 4.6.1 Seeds of African yam bean [*Sphenostylis stenocarpa* (Hochst. ex A. Rich.) Harms]*

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*Photo 4.6.1 Plants of African yam bean [*Sphenostylis stenocarpa *(Hochst. ex A. Rich.) Harms] with pods*

types. Mono-coloured seeds are white, grey, cream, light or dark brown, purple, or black.

CLIMATIC CONDITIONS FOR CULTIVATION

African yam bean grows on a wide range of soils including acid and highly leached sandy soils at altitudes from sea level to 1 950 masl (Amoatey *et al.,* 2000). It thrives on deep, loose sandy and loamy soils with good organic content and good drainage. It grows better in regions where annual rainfall ranges between 800 and 1 400 mm, and where temperatures are between 19 and 27 °C (Ecoport, 2009).

NUTRITIONAL VALUE

According to Fasoyiro *et al.* (2006), African yam bean is a good source of protein, fibre and carbohydrate. The seeds are rich in protein (22–25 percent, DM basis) with relatively low fibre content (less than 10 percent, DM basis; Table 4.6.1). The protein is particularly rich in lysine (up to 9 percent of protein) and methionine (1–2 percent). The tubers contain 11 to 19 percent protein, 63 to 73 percent carbohydrate and 3 to 6 percent fibre, on DM basis. The tuber protein is also of high quality (cysteine 1.8, isoleucine 4.5, leucine 7.7, lysine 7.6, methionine 1.7, phenylalanine 4.5, threonine 4.3, and valine 5.5 percent).

The protein in the tuber of African yam bean is more than twice the protein in sweet potato [*Ipomoea batatas* (L.) Lam.] or Irish potato (*Solanum tuberosum* L.) (NRC, 1979) and higher than in cassava (*Manihot esculenta* Crantz) (Amoatey *et al.,* 2000). Moreover, the amino acid values in African yam bean seeds are higher than in pigeon pea, cowpea or bambara groundnut (Uguru and Madukaife, 2001). The content of crude protein in African yam bean seeds is lower than that in soybean, but the amino acid composition indicates that the levels of most of the essential amino acids especially lysine, methionine, histidine, and iso-leucine in African yam bean are higher than in other legumes, including soybean (NRC, 2007). The African yam bean is rich in minerals such as potassium, phosphorus, magnesium, calcium, iron and zinc, but low in sodium and copper (Edem, Amugo and Eka, 1990).

PRODUCTION OF SEEDS AND TUBERS

Seed yield is very poor in Nigeria, about 300–500 kg/ha (Ezueh, 1984) although much higher estimates of yield (2 000–3 000 kg/ha) have been reported for fertile soils. The average seed yield per plant is between 100 and 200 g and the tuber yield per plant is 500 g (NRC, 1979). The African yam

Table 4.6.1 Chemical composition of African yam bean and its by-products (percent, DM basis)

Parameter	Seeds	Hulls	Foliage, fresh
Crude protein	21.6–25.9	11.4	23.5
Ether extract	1.1–4.2	2.6	2.2
Crude fibre	6.0–9.9		
Ash	3.2–5.0	2.6	
NDF			46.8
ADF			20.1
Lignin			8.3
Calcium	0.06	0.30	
Phosphorus	0.33	0.20	

Notes: DM (as fed) is 90.2–92.5 percent for seeds, 87.5 percent for hulls, and 52.5 percent for fresh forage.
ADF = acid detergent fibre; NDF = neutral detergent fibre.
Source: Feedipedia (2016).

bean has very high ability to fix nitrogen; therefore, it is an important crop that merits significant consideration for land reclamation.

ANTI-NUTRITIONAL FACTORS

African yam bean seeds contain tannins, trypsin inhibitors, hydrogen cyanide, saponins and phytic acid (Akinmutimi, Amaechi and Unogu, 2006). In addition, it also contains alpha-galactosides and lectin (Oboh *et al.,* 1998). Betsche *et al.* (2005) reported alpha-amylase inhibitor (6–13 Units/g), saponin (2–4 mg/kg), trypsin inhibitor (0.7–3.0 TIU/mg), total and soluble oxalate (21–35 and 3–6 mg/100 g, respectively), tannin (0.9–20 mg/g), phytic acid (4.5–7.3 mg/g) and beta-galactosides (2.3–3.4 g/100 g).

Various processing methods (soaking, blanching, dehulling, heating, and soaking with potash) have been employed to reduce anti-nutritional factors (Aminigo and Metzger, 2005). Long time cooking gives the highest digestibility value in African yam bean. Long cooking with moist heat treatment is a way to rid African yam bean from anti-nutritional factors (Fasoyiro *et al.*, 2006).

Dehulling of seeds significantly improved the digestibility of African yam bean protein compared with whole seed (Abbey and Berezi, 1988). Roasting the bean at 160 ºC for 30 minutes and pre-soaking treatment in alkaline water for 24 hours, followed by autoclaving was optimally effective and did not harm the protein quality of African yam bean (Agunbiade and Longe, 1996). Fermentation can also substantially improve the nutritional quality of African yam bean (Betsche *et al.*, 2005; Jeff-Agboola, 2007) and reduce losses (due to thermal influences) of most food factors.

Aminigo and Metzger (2005) reported that protein content was slightly increased by soaking and blanching, while ash and fat contents were reduced. They also observed that the levels of tannins in marbled genotype seeds were reduced by blanching for 40 minutes (reduced by 19.2 percent), soaking for 12 hours (reduced by 16.0 percent), dehulling (reduced by 72.0 percent), and dehulling and blanching (reduced by 88.8 percent). Generally, a combination of dehulling and wet-processing reduced firmness of the beans more than soaking or blanching of the whole beans.

AFRICAN YAM BEAN SEED AND ITS BY-PRODUCTS AS ANIMAL FEED

Little information is available on feeding of African yam bean and its by-products to animals.

African yam bean seeds

Rabbit. Anya *et al.* (2011) recommended the inclusion of African yam bean seeds up to 20 percent, as a protein source in cassava-peel-meal-based diets for weaned rabbits, with no adverse effect on performance.

Poultry. African yam bean seeds were found to have a higher metabolizable energy value than soybean meal. Heat treatment (autoclaving or cooking) results in a significant increase in metabolizable energy (Nwokolo and Oji, 1985). Raji *et al.* (2014) observed that African yam bean can be used up to 20 percent in the diet of broiler finisher, as it did not affect weight of carcass cuts, internal organs or viscera. It was reported that a 50 percent protein replacement of soybean meal with cooked African yam bean was equally good as feeding soybean meal as the protein source in the diet of broiler chicks. Hence, aqueous heating was a better processing method for African yam bean compared with dehulling. It was also better to dehull the seeds prior to aqueous heating to facilitate adequate elimination of the anti-nutritional factors (Emiola, 2011).

African yam bean hull

The hulls contain 11.4 percent protein and 2.6 percent fat (DM basis). The hull is rich in cell wall polysaccharides, with a cellulose content of 35.4 percent. The crude protein of hulls is almost double that in braod bean (*Vicia faba* L.) (Agunbiade and Longe, 1996) and more than twice that in Bambara groundnut (Mahala and Mohammed, 2010).

Rat and rabbit. Trials of African yam bean hull as rat feed (Agunbiade and Longe, 1996) showed increased weight and higher feed conversion efficiency compared with cellulose-free and pure cellulose meal. This implies that African yam bean hull could be a good source of dietary fibre. A low quantity of African yam bean in the meal of weaner rabbit could substantially substitute for soybean (Akinmutimi *et al.,* 2006). The leaves and stovers, the grains and the hull of African yam bean have been used to substitute for the commonly used livestock feeds (Agunbiade and Longe, 1996; Akinmutimi *et al.,* 2006). Since the tuber of African yam bean does not form a part of the meal of West Africans, its incorporation in animal feeds should be explored.

Goats

Ajayi (2011) observed that the silage made from mixtures of napier grass

(*Pennisetum purpureum* Schumach.) and African yam bean plants enhanced protein digestibility, nitrogen absorption and retention.

SUMMARY

African yam bean seeds and tubers are good source of protein and minerals. The seed protein is rich in lysine and methionine. The anti-nutritional factors present in seeds are tannins, trypsin inhibitors, hydrogen cyanide, saponins, and phytic acid. Various processing methods such as cooking with moist heat treatment, dehulling, roasting and pre-soaking in water alkali solution help reducing anti-nutritional factors from the seeds. African yam bean seeds can be included up to 20 percent in the diets of broiler and rabbit. More research is required to efficiently exploit the potential for feeding of African yam bean seeds and by-products in livestock and monogastric animals.

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Chapter 5
Bambara bean

COMMON NAMES

Bambara bean, bambara groundnut, Congo earth pea, Congo goober, Congo groundnut, earth pea, ground bean, hog-peanut, kaffir pea, Madagascar groundnut, njugo bean, stone groundnut (English);jugo beans (South Africa); ntoyo ciBemba (Republic of Zambia); Gurjiya or Kwaruru (Hausa, Nigeria); Okpa (Ibo, Nigeria); Epa-Roro (Yoruba, Nigeria); Nyimo beans (Zimbabwe); pois bambara, pois de terre, voandzou (French); bambarra, guandsú, guisante de tierra, maní de bambarra (Spanish), jinguba de cagambe (Portuguese); gongongu, gorosgoros, biriji daɓɓi, biriji damuɗi, ngalaa-wu/ji, ngalgalaa-wu/ji (Fulfulde); Bambara-Erdnuss (German); Kacang bogor (Indonesian); mnjugu-mawe (Swahili).

DISTRIBUTION

Bambara bean [*Vigna subterranea* (L.) Verdc.] originated in West Africa, its name probably derived from the Bambara tribe, who currently live mainly in Central Mali (Nwanna *et al.*, 2005). There has been some debate regarding the exact area of origin; nevertheless, Begemann (1988) has indicated that bambara bean's centre of origin should be located between north-eastern Nigeria and northern Cameroon because of the occurrence of wild forms in this area. It has been cultivated in tropical Africa for centuries (Yamaguchi, 1983). Bambara bean is the third most important legume in terms of consumption and socio-economic impact in semi-arid Africa behind groundnut (*Arachis hypogaea* L.) and cowpea [*Vigna unguiculata* (L.) Walp.]. It is found in the wild from central Nigeria eastwards to southern Sudan, and is now cultivated throughout tropical Africa, and to a lesser extent in tropical parts of the Americas, Asia and Australia (Brink, Ramolemana and Sibuga, 2006).

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*Photo 5.1.1 Seeds of bambara bean [*Vigna subterranea *(L.) Verdc.]*

DESCRIPTION

Bambara is a herbaceous, annual plant, with creeping stems at ground level (Bamshaiye, Adegbola and Bamishaiye, 2011). This legume is a small plant that grows to a height of 30–35 cm, with compound leaves of three leaflets. The plant generally looks like bunched leaves arising from branched stems which form a crown on the soil surface. After fertilization, pale yellow flowers are borne on the freely branching stems; these stems then grow downwards into the soil, taking the developing seed with it (known as geocarpy). The seeds form pods encasing seeds just below the ground in a similar fashion to *Arachis* L. Bambara pods are round, wrinkled, and average 1.3 cm long. Each pod contains 1 or 2 seeds that are round, smooth, and very hard when dried.

CLIMATIC CONDITIONS FOR CULTIVATION

Bambara can be grown on a range of soils, especially light loams and sandy loams, but may be successfully grown on heavier soils than groundnuts. It does better than most other bean crops in poor soils and grows best with moderate rainfall and sunshine. Under less favourable growing conditions, such as limited water supply and infertile soil, it yields better than other legumes, such as groundnut (NRC, 1979). The crop is the least demanding for mineral elements and thrives in soils considered too marginal for groundnut. It can grow in more humid conditions (annual rainfall >2 000 mm), and in every type of soil provided it is well drained and not too calcareous. Bambara requires moderate rainfall from sowing until flowering. A minimum annual rainfall of 500 to 600 mm is required. The plant tolerates heavy rainfall, except at maturity. It is tolerant to drought, to pests and diseases, particularly in hot conditions. In many traditional cropping systems it is intercropped with other root and tuber crops (Brink, Ramolemana and Sibuga, 2006). Average temperatures between 20 and 28°C are most suitable for the crop.

NUTRITIONAL VALUE

According to Mazahib *et al.* (2013), high carbohydrate (56 percent) and relatively high protein (18 percent; Table 5.1) content as well as sufficient quantities of oil (6.5 percent) make the bambara bean a complete food. Baudoin and Mergeai (2001) reported that the ripe seeds contain on average 10 percent water, 15–20 percent protein, 4–9 percent fat, 50–65 percent carbohydrate, and 3–5 percent fibre (DM basis). The essential amino acid profile of the seeds is comparable with that of soybean (Omoikhoje, 2008), and better than groundnuts (Bamshaiye, Adegbola and Bamishaiye, 2011). The fatty acid content is predominantly linoleic, palmitic and linolenic acids (Minka and Bruneteau, 2000).

Yield of bambara seeds

Average yields of dry seeds usually range between 300 and 800 kg/ha in traditional farming, and may exceed 3 000 kg/ha in intensive farming (Baudoin and Mergeai, 2001). The highest recorded seed yield under field conditions is 4 000 kg/ha. Average yields are 300–800 kg/ha, but yields of less than 100 kg/ha are not uncommon (Brink, Ramolemana and Sibuga, 2006).

Table 5.1 Chemical composition of bambara bean and its by-products (percent, DM basis)

Parameter	Seeds	Seeds, dehulled	Pods	Shells	Offal	Hay	Straw
Crude protein	16.7–23.4	15.7–24.9	18.2	6.7	18.2	14.5	7.7
Ether extract	4.6–6.4	3.2–7.5	5.5	2.6	3.7	1.8	1.1
Crude fibre	3.4–17.0	2.0–8.8	14.2		13.0	30.2	22.7
Ash	3.8–5.1	3.1–5.7	5.4	3.9	3.6	9.5	5.4
NDF	24.2	7.8		47.6			
ADF	14.0–18.0	3.6		29.8			
Lignin	3.2	0.3		10.0			
Calcium	0.14	0.01–0.08					0.88
Phosphorus	0.26	0.20–0.84					0.13

Notes: DM (as fed) is 83.0–89.7 percent for seeds, 85.7–97.7 percent for dehulled seeds, 96.6 percent for pods, 91.8 percent for shells, 90.3 percent for offal, 90.2 percent for hay, and 94.3 percent for straw.
ADF = acid detergent fibre; NDF = neutral detergent fibre.
Source: Feedipedia (2016).

ANTI-NUTRITIONAL FACTORS

Despite the nutritional benefits of bambara bean, there are nutritional constraints, such as presence of anti-nutritional factors. Bambara seeds contain anti-nutritional factors such as trypsin inhibitors, phytates and tannins. They have higher anti-tryptic activity than soybean, and the level of activity depends on the landrace (Tibe, Amarteifio and Njogu, 2007). Heat treatments (boiling, roasting) are usually effective in destroying trypsin inhibitors. Phytates are found in high concentrations in bambara seeds and are known to reduce cation availability (Ca in particular) (Nwanna *et al.*, 2005). Cooking and other forms of processing (soaking, milling, dehulling, germination or fermentation) reduce the concentration of anti-nutritional factors. However, processing does not always increase the feeding value (Nwanna *et al.*, 2005; Oloyede *et al.*, 2007).

BAMBARA BEAN AND ITS BY-PRODUCTS AS ANIMAL FEED

Ruminants

Bambara seeds. Bambara has long been used as an animal feed (Linnemann, 1991). Nwanna *et al.* (2005) reported that bambara seeds had a higher feeding value than groundnut cake. Belewu *et al.* (2008) reported that due to the overall nutritional qualities of bambara seeds, their inclusion as an alternative, cheap source of protein and energy in livestock diet by economically weak farmers (mostly in developing countries) should be encouraged.

Bambara pods, shells, and offal/waste. Bambara pods, shells and offal are the by-products of processing the seeds into flour for human consumption. Bambara pods have been used to feed goats in Zambia during the dry season as they contain adequate levels of carbohydrate and protein (Aregheore, 2001). The leafy shoots are also used as fodder (Brink, Ramolemana and Sibuga, 2006). The leaves are suitable for animal grazing because they are rich in nitrogen and phosphorus (Rassel, 1960).

The offal is produced after splitting the seeds in a mill to remove the shells, winnowing to remove loosened testa and converting the cotyledons into fine flour by milling several times followed by sieving. In Nigeria, large amounts of offal are discarded as waste (Onyimonyi and Okeke, 2007). The bambara offal is available throughout the year and is cheap, It has no industrial or other uses in Nigeria. The offal contains 21.2 percent protein (DM basis), 5.3 percent fibre (DM basis) and 12.44 MJ/ kg gross energy (Amaefule and Iroanya, 2004).

Pigs

In weaner pig diets, inclusion of bambara seeds at up to 10 percent level was found economical for producing affordable and cheaper pork (Onyimonyi and Okeke, 2007).

Poultry

Bambara seeds have been successfully used to feed chicks (Oluyemi, Fetuga and Endeley, 1976). However, there is a big gap in the knowledge of the nutrient content of bambara seed, digestibility of its nutrients, and its effect on growing broiler chickens and performance of laying hens.

Broilers. Ologhobo (1992) reported that feed intake of broilers fed 12.5 percent bambara seeds was not significantly different while, at 25 percent level, it was significantly lower than the control group (maize + soybean-meal-based diet). Nji, Niess and Pfeffer (2004) reported that between 40 and 60 percent bambara could be included in the grower diet of broilers. Feeding broilers and adult cockerels with raw bambara seeds gave lower feed intake, live weight gain and feed use efficiency compared with soybean meal, as those parameters are negatively correlated with trypsin inhibitors (Akanji, Ologhobo and Emiola, 2007; Oloyede *et al.,* 2007). Teguia and Beynen (2005) reported that the replacement of meat meal in the starter diet of broiler chickens by meals of bambara seeds reduced growth rate. During the finishing period however, the groups of broiler birds fed either bambara seeds or a 1:1 mixture of bambara seeds and large-grained cowpea meal had growth rates comparable to those of the controls, but the control birds consumed significantly more feed than did the groups fed bambara grain meal.

Boiling or roasting was effective in removing the anti-nutritional factors, and it was possible to include treated seeds up to 30 percent in broiler diets (Bello, Doma and Ousseini, 2005). However, the heat-processed seeds compared unfavourably with soybean meal (lower protein quality and lower metabolizable energy) (Nji, Niess and Pfeffer, 2003; Oloyede *et al.,* 2007).

Layers. Inclusion of 451 g bambara seeds/kg in layer feed had no significant adverse effect on egg production. Eggs from hens fed bambara seeds had lower mass and stronger shells than the control group. Egg yolk colour did not differ. The yolk fraction of the control group was significantly higher than that of the test group, while the reverse was found for the albumen fraction. The yolk and albumen indices did not differ significantly (Nji, Niess and Pfeffer, 2004).

Bambara offal/waste

Amaefule and Osuagwu (2005) conducted an experiment with different levels of raw bambara offal (0, 5, 10, 15, 20, and 25 percent), and found that it is a valuable feedstuff for poultry when used at 5 percent level. However it can lower performance at even 10 percent of the ration, and enzyme supplementation (Roxazyme G) could not compensate the performance loss (Ani, Omeje and Ugwuowo, 2012). The recommended dietary inclusion rates are: 5 percent raw offal for pullet chicks (Amaefule and Osuagwu, 2005); up to 45 percent heat treated offal for broilers (Asaniyan and Akinduro, 2008); 20 percent raw offal for broilers, if supplemented with lysine and methionine (Ukpabi, Amaefule and Amaefule, 2008).

There have been attempts to use mixtures of bambara offal with cassava root meal as maize replacer in poultry rations. In most experiments, animal performances were lower when maize was replaced, however, feed costs were reduced and bambara offal could be considered a potential maize replacer. In layer hens, mixtures of cassava root meal and bambara offal in variable proportions (1:2; 1:1; 2:1) were used to completely replace maize. However, all mixtures had depressive effects on layer performance (Anyanwu *et al.,* 2008).

The development of the offal as an alternative energy and protein source could solve the problem of high feed cost for small-scale farmers and also provide an avenue for a better disposal of the waste (offal), which could otherwise constitute an environmental problem.

Bambara nut sievate

Bambara by-products, such as bambara sievate, which is a result of processing bambara into flour for human use, has undergone extensive research and it was suggested that it can be used in poultry diets (Ugwu and Onyimonyi, 2008; Ekenyem and Odo, 2011). The levels of protein, fibre and fat are reported as 15.7, 6.7 and 4.7 percent (DM basis), respectively, in bambara nut sievate. Ekenyem and Odo (2011) conducted a study to replace soybean meal with bambara nut sievate (0, 5, 10 and 15 percent) and found that 5 percent inclusion is optimal for carcass and organ characteristics of finisher broilers.

SUMMARY

Bambara bean is an alternative cheap source of protein and energy in livestock diets, mainly in African countries. Bambara seeds can be included up to 10 percent in the diet of pigs. Heat processed seeds can be included up to 45 percent in broiler diet. Bambara by-products such as offal and sievate are also valuable sources of protein and energy. The raw bambara offal can be included up to 5 and 20 percent levels in layer and broiler diets, respectively. Bambara nut sievate can be included up to 5 percent in broiler diets.

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Chapter 6

Pea

COMMON NAMES

Feed pea, field pea, garden pea, mange-tout, pea, petit-pois, protein pea (English); pois, pois protéagineux (French); guisante, chícharo, arveja (Spanish); ervilha (Portuguese); erwt (Dutch); ercis katiang, ercis (Indonesian); pisello (Italian); tsitsaro (Tagalog); bezelye (Turkish).

DISTRIBUTION

The origin of pea (*Pisum sativum* L.) is not very well known. Archaeological evidence found in the Fertile Crescent (the area surrounding modern day Israel, Jordan, Iraq, Syrian Arab Republic, Lebanon, Palestine, Turkey, the Islamic Republic of Iran, and the land in and around the Tigris and Euphrates rivers), indicates that people have been cultivating pea since 8 000 BC. The pea was first cultivated in western Asia, and from there it was spread to Europe, China and India (Beentje, 2010). Currently, it is grown in temperate regions, at high elevations, or during cool seasons in warm regions throughout the world (Elzebroek and Wind, 2008).

DESCRIPTION

The pea is a cool season annual vine that is smooth and has a bluish-green waxy appearance. Vines can be up to 270 cm long, however modern cultivars have shorter vines (about 60 cm long). The stem is hollow, and the taller cultivars cannot climb without support (Elzebroek and Wind, 2008). Leaves are alternate, pinnately compound, and consist of two large leaflike stipules, one to several pairs of oval leaflets, and terminal tendrils. Many modern cultivars have a semi-leafless or *afila* leaf type in which the leaflets are converted into additional tendrils.

Inflorescences occur in the leaf axils, and consist of racemes with one to four flowers. Flowers have five green fused sepals and five white, purple or pink petals of different sizes. The ovary contains up to 15 ovules, and the fruit is a closed pod, 2.5 to 10 cm long that often has a rough inner membrane. Ripe seeds are round, smooth or wrinkled, and can be green, yellow, beige, brown, red-

*Photo 6.1.1 Split peas (*Pisum sativum* L.)*

orange, blue-red, dark violet to almost black, or spotted. Peas can be broadly classified as garden pea and field pea (Black, Bewleyand Halmer, 2006). Garden peas (fresh peas, green peas, vining peas) are harvested while still immature, and eaten cooked as a vegetable. They are marketed fresh, canned, or frozen. Garden peas are usually of the white-flower *hortense* types. Field peas (dried peas, combining peas) are harvested ripe. Dried peas are used whole, or split, either made into flour for human food or fed to livestock. Field peas are usually from the coloured flower *arvense* type.

CLIMATIC CONDITIONS FOR CULTIVATION

Peas grow better in relatively cool climates with average temperatures between 7 and 24°C, and in areas with 800–1 000 mm annual rainfall, mostly distributed during the early stages of growth (Messiaen *et al.,* 2006). Peas are adapted to many soil types, but grow best on fertile, light-textured, well-drained soils (Elzebroek and Wind, 2008). Peas are sensitive to soil salinity and extreme acidity. The ideal soil pH range for pea production is 5.5 to 7.0 (Hartmann *et al.,* 1988). Field peas can be grown as a winter crop in warm and temperate areas because pea seedlings have considerable frost resistance. Where winters are too cold, peas can be grown as a spring crop. They only require 60 days to reach the bloom stage and 100 days to mature and dry.

PRODUCTION OF PEA SEED AND ITS CROP RESIDUES

Major pea producing countries are China, India, Canada, Russian Federation, France and the United States of America (FAO, 2012). Pea crops can produce about 1.7 tonne/ha of seeds and 2–3 tonne/ha of straw (Prolea, 2008).

NUTRITIONAL VALUE

Peas are considered a highly valuable protein source for animal nutrition due to their high protein content (22–24 percent, DM basis), which is intermediate between cereals and oil seed meals (Table 6.1). The amino acid profile of peas is well-balanced in lysine, but deficient in tryptophan and sulphur-containing amino acids (notably methionine) for species where these are essential amino acids (Vander Pol *et al.,* 2008). Peas are high in starch (48–54 percent, DM basis), and relatively low in fibre (less than 8 percent, DM basis). Many processes such as mechanical treatments (grinding and decortication), dry or wet heat treatments (cooking and autoclaving) and their combinations (flaking, extrusion, pelleting) have been used to improve the nutritive value of peas.

ANTI-NUTRITIONAL FACTORS

Trypsin inhibitors are the main anti-nutritional factor in peas, their levels vary with genotype. For example, trypsin inhibiting activity of 33 European spring pea varieties ranged from 1.69 to 7.56 trypsin inhibiting units (TIU), while the level in winter peas was 7.34–11.24 TIU (Leterme, Beckers and Thewis, 1998). Smooth peas contain more trypsin inhibitors than wrinkled peas (Perrot, 1995). Similarly, protein peas contain low levels of anti-tryptic

Table 6.1 Chemical composition of pea and its by-products (percent, DM basis)

Parameter	Seeds	Aerial part, fresh	Straw	Pods, silage	By-products, fresh	By-products, dried	By-products, ensiled
Crude protein	19.0–28.5	17.7	8.2	5.7–23.7	17.8	18.6	12.0
Ether extract	0.7–2.2	3.1	2.1	0.5–3.6	2.1	2.0	3.2
Crude fibre	3.7–8.5	22.9	36.3	12.2–56.4	22.6	17.7	24.3
Ash	2.7–4.9	9.1	9.8	3.3–11.4	13.3	15.2	18.7
NDF	9.1–22.0	31.1	54.9	16.6–58.1	43.1	43.0	53.7
ADF	5.6–8.8	23.1	38.7	9.3–45.1	26.8		40.5
Lignin	0.1–1.1	4.8	7.2	0.4–12.9	4.7	8.0	9.3
Calcium	0.03–0.29	1.86	2.37	0.30–1.66		1.27	
Phosphorus	0.32–0.60	0.39	0.11	0.05–0.30		1.24	

Notes: DM (as fed) is 82.0–90.7 percent for seeds, 15.6 percent for fresh aerial part, 88.8 percent for straw, 27.5–95.1 percent for pods, 26.5 for fresh crop by-products, 90.4 percent for dehydrated crop by-products, and 28.2 percent for ensiled crop by-products.
ADF = acid detergent fibre; NDF = neutral detergent fibre.
Source: Feedipedia (2016).

activity (2–6 TIU/mg) (GNIS, 2011). Myer and Brendemuhl (2001) reported that grains with dark seed coats contain more tannins. Tannin content is much lower in white flowered peas than in coloured flowered ones (Canbolat, Tamer and Acikgoz, 2007; Prolea, 2008). Another important antinutritional factor is lectin, which represents about 2.5 percent of pea protein (Perrot, 1995).

Improving the nutritive value of peas by decreasing trypsin inhibitors and tannins is the goal of many breeding programmes. Modern cultivars of “protein peas” are tannin-free and have low concentrations of trypsin inhibitors, which make them particularly suitable for animal feeding, even in the unprocessed form, for monogastrics (Mihailovic *et al.*, 2005).

PEA SEED AND ITS BY-PRODUCTS AS ANIMAL FEED

Pea seeds

Pea seeds contain approximately half the protein (25.6 vs 46.3 percent) of soybean meal, with lower rumen undegradable protein content (20 vs 34.6 percent) (Schroeder, 2002). Pea seeds contain a high level of starch (54 percent), but starch degradation rate is low (from 4 to 6 percent/hour), which is much lower than that of cereals, e.g. barley (21 to 34 percent/hour) (Schroeder, 2002).

Dairy cattle. Peas can be included up to 40–50 percent (DM basis) in concentrates fed to pre-weaned and weaned dairy calves. It can partly replace maize grain, barley and/or soybean meal (Schroeder, 2002). Peas can be the sole protein source for dairy heifers (Anderson *et al.*, 2002).

Petit, Rioux and Ouellet (1997) observed non-significant differences in DMI, milk yield and milk composition when feeding raw and extruded peas as 20 percent in the diet of dairy cows. Khorasani *et al.* (2001) reported that addition of peas in place of soybean meal at levels of 33, 67 and 100 percent of the concentrate did not influence DMI (21.6 kg/day) and milk yield (30 kg/day) in lactating dairy cattle. At higher levels of substitution, pea seeds should be supplemented with better quality protein sources, especially with higher concentrations of sulphur-containing amino acids. Anderson *et al.* (2002) reported that peas can be included at up to 25 percent level in concentrates for lactating cows. Vander Pol *et al.* (2008) demonstrated that field peas could be safely fed to high-producing dairy cows at a 15 percent inclusion rate, replacing both soybean meal and maize grain together. At this inclusion rate, no adverse effects on milk yield or milk composition were observed. However, Vander Pol *et al.* (2009) observed that peas should be coarsely ground for dairy cow diets to avoid depression in total tract digestibility of nutrients.

Beef cattle. Peas can be used as an ingredient in creep feed to increase calf weight gain, without impairing rumen fermentation and digestion (Gelvin *et al.,* 2004). Anderson *et al.* (2002) recommended an optimum inclusion rate of between 33 and 67 percent in creep feed. However, it should not comprise more than 25 percent in the diet of growing steers and heifers. Gilbery *et al.* (2007) and Lardy *et al.* (2009) demonstrated that field peas can be included up to 36 percent (diet DM basis) successfully in the ration of finishing beef cattle, without negatively affecting growth and carcass characteristics. However, Jenkins *et al.* (2011) recommended inclusion of 30 percent peas in the diet of steers, without affecting steer performance and carcass characteristics.

Sheep and goats. Loe *et al.* (2004) recommended that field pea is a suitable replacement for maize in lamb finishing diets and is at least equal in energy density to maize. Lardy, Bauer and Loe (2002) recommended inclusion of 45 percent in a feedlot diet by replacing all soybean meal and part of the maize. Lanza *et al.* (2003) reported that the replacement of soybean meal with peas did not significantly affect growth and slaughter parameters, and preserved meat quality. The use of pea seeds increases the proportions of total n-3 fatty acids, and meat from lambs fed peas showed a more favourable n-6:n-3 ratio in the intramuscular fatty acid composition (Scerra *et al.,* 2011). Antunović *et al.* (2013) recommended the addition of 15 percent pea (replacing maize) in alfafa (*Medicago sativa* L.) hay-based diet of lactating dairy goats, without affecting milk yield and composition.

Pigs. Due to large variation in nutrient composition and anti-nutritional factors in peas, use of raw seeds is limited in pig diets. However, processing methods such as extrusion can have positive effects on protein and amino acid digestibility (O'Doherty and Keady, 2001; Stein and Bohlke, 2007). Starter diets can contain up to 10 percent ground field peas and processing (extrusion, toasting, steam pelleting) the peas could increase the maximum recommended level up to 20 percent (Myer and Froseth, 1993). Above this level, growth performances are generally reduced. This effect is mainly explained by a low palatability of the diet, an imbalance in secondary limiting amino acids (methionine, tryptophan) and a low digestibility or availability of amino acids (Friesen, Kiarie and Nyachoti, 2006). For growing-finishing pigs, ground raw peas could be included as the only source of supplemental protein in diet, provided that the amino acid balance is optimal (methionine or methionine + tryptophan) (Vieira *et al.*, 2003). It has been suggested that a mixture of peas and rapeseed (*Brassica napus* L.) meal was a better supplement for growing-finishing pigs than peas alone, since rapeseed meal is rich in sulphur-containing amino acids while peas are a superior source of lysine (Castell and Cliplef, 1993).

Poultry. Earlier studies recommended maximum levels for layer diets of 25 percent (Pérez-Maldonado, Mannion and Farrell, 1999) and 30 percent for broilers (Farrell, Pérez-Maldonado and Mannion, 1999). It is also recommended that, if the diet is balanced with synthetic amino acids, peas can be included at 20 percent (Nalle, Ravindran and Ravindran, 2011) to 35 percent (Diaz *et al.*, 2006) in broiler diets.

Commercial feed enzymes can be added to increase protein digestibility in diets containing high levels of field peas (Cowieson, Acamovic and Bedford, 2003). Johnson, Deep and Classen (2014) observed a positive impact in terms of improved performance and feed conversion efficiency in broilers on phytase supplementation in pea-based diets. For laying hens, similar inclusion levels are suggested by Pérez-Maldonado, Mannion and Farrell (1999).

Pea chips

Pea chips (by-product) are derived from milled peas during air classification into pea starch fractions. It contains about 29.8 percent protein (DM basis) and 2.2 percent fat (DM basis). Igbasan and Guenter (1996) reported that pea chips at 300 g/kg inclusion level with methionine supplementation were unable to sustain broiler performance equal to birds fed a conventional maize-soybean diet. This study suggested that pea chips should not be fed to broiler chicks in excess of 150 g/kg (DM basis).

The authors found no information regarding feeding of pea plant residue to animals.

SUMMARY

Peas are rich in protein and starch, while low in fibre. Anti-nutritional factors present in peas are trypsin inhibitors, tannins, and lectins. Peas can be included up to 50 percent in the diet of dairy calves, and it can serve as a sole protein source for dairy heifers. Peas can be included up to 25 percent in dairy cattle, and 30 percent in steer diets. Sheep and goat diets may contain up to 45 and 15 percent of peas, respectively. Extrusion of pea improves its digestibility. Maximum recommended level for extruded seeds in pig starter diet is 20 percent, as against 10 percent for raw seeds. Ground raw peas could be the only source of protein supplement in growing-finishing pigs, provided that the amino acid balance is optimal. If the diet is balanced with synthetic amino acids, peas can be included up to 30 percent in broiler and layer diets.

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Chapter 7
Chickpea

COMMON NAMES

Bengal gram, Egyptian bean, gram pea (English); garbanzo (Spanish); pois chiche (French); grão-de-bico, ervilha-de-bengala (Portuguese); kikkererwt (Dutch); Kichererbse (German); kacang arab (Indonesian); cece (Italian); nohut (Turkish).

DISTRIBUTION

Chickpea (*Cicer arietinum* L.) is thought to have originated in South-East Anatolia and neighbouring Syrian Arab Republic and The Islamic Republic of Iran, where the earliest remains date back to around 7 000 BC (Feedipedia, 2016). It was introduced to the Mediterranean Basin, Africa and the Indian subcontinent before 2 000 BC. Chickpea grows from sea level up to an altitude of 2 500 masl in areas where temperatures ranges from 15 to 29 °C (van der Maesen, 1989). The chickpea, cultivated for its edible seeds, is a major legume in the Mediterranean Basin, Asia and Australia.

DESCRIPTION

The chickpea plant is quick-growing, branched, and reaches a height between 20 and 60 cm, even up to 1 m. It has a deep taproot, down to 2 m, and many lateral secondary roots exploring the upper layers (15–30 cm) of the soil. The stems are hairy, simple or branched, straight or bent. Leaves are 5 cm long with 10 to 20 sessile, ovate to elliptical leaflets. Chickpea flowers are white, pink to purplish or blue, typically papillonaceous and solitary. The pod is pubescent, inflated and oblong, with 2 or 3 seeds. The seeds are variable in size (5 to 10 mm in diameter), shape (spherical to angular) and colour (creamy-white to black) (Bejiga and van der Maesen, 2006; Ecoport, 2013).

Chickpea is not a labour-intensive crop, and its production needs low external inputs compared with cereals. Chickpea is an important crop in mixed crop-livestock production systems. It is cultivated as a food-feed crop, where the pods provide food for humans and fodder for livestock. In mixed crop-livestock systems, fodder shortage is commonly a serious constraint to obtaining greater benefit from livestock (Rangnekar, 2006).

*Photo 7.1.1 Plants of chickpea (*Cicer arietinum *L.) with flowers*

There are two main types of chickpea (*kabuli* and *desi*


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Photo 7.1.2 Seeds of chickpea

types), distinguished by seed size, shape and colour. *Desi* types produce relatively small seeds with an angular shape. The common seed colours include various shades and combinations of brown, yellow, green and black. *Kabuli* types have large, rounded, seeds, characterized by white or cream coloured seeds, or a beige-coloured seed with ram's head shape, thin seed coat, smooth seed surface, white flowers, and is called *kabuli*. *Kabuli* chickpea seeds are grown in temperate regions, whereas the *desi* type is grown in the semi-arid tropics (Naghavi and Jahansouz, 2005; Iqbal *et al.,* 2006).

CLIMATIC CONDITIONS FOR CULTIVATION

Chickpea is grown as a winter crop in the tropics, and as a summer or spring crop in temperate environments. It is adapted to deep black soils in the cool semi-arid areas of the tropics and sub-tropics, as well as temperate areas. Chickpea is a cool-season grain legume that withstands hot temperatures during fruiting and ripening (Ecoport, 2013) and notably is used as a source of protein (Bejiga and van der Maesen, 2006). The plant is well adapted to tropical climates with moderate temperatures and is successfully cultivated under irrigation in the cool season of many tropical countries (Bejiga and van der Maesen, 2006). It can grow with annual rainfall ranging from 500 to 1 800 mm (Bejiga and van der Maesen, 2006). It is tolerant of drought but does not withstand the humid and hot low-land tropics. Rainstorms during flowering, which may occur during the monsoon season, may harm the crop that is then used mainly for fodder (van der Maesen, 1989). Early summer heat or frost during flowering may also hamper crop yield (Ecoport, 2013).

PRODUCTION OF CHICKPEA

Chickpea is the fourth-largest pulse crop in the world, with a total production of 11.6 million tonne from an area of 12.3 million ha and productivity of 0.94 tonne per ha (FAOSTAT, 2012). Major producing countries for chickpea are India, Australia, Pakistan, Turkey, Myanmar, Ethiopia, The Islamic Republic of Iran, United States of America, and Canada (FAOSTAT, 2013; ICRISAT, 2013).

CHICKPEA AND ITS BY-PRODUCTS AS ANIMAL FEED

Chickpea seeds

Chickpea seeds provide a high quality and cheap source of protein (19–25 percent, DM basis; Table 7.1), for developing countries. It can be eaten raw, roasted or boiled. It can also be processed into flour or dehulled grain (*dal*) and also play a key role in alleviating protein-energy malnutrition (Manjunatha, 2007). *Desi* type chickpea contains less starch (about 35 percent, DM basis) and more crude fibre (about 10 percent, DM basis) than *kabuli* types (about 50 percent starch and

Table 7.1 Chemical composition of chickpea and its by-products (percent, DM basis)

Parameter	Seeds (*desi*)	Seeds (*kabuli*)	Bran (*chuni*)	Straw	Pod husk
Crude protein	18.2–26.5	18.8–25.7	12.5–18.5	2.8–8.8	3.5–10.5
Ether extract	3.3–7.8	5.1–8.0	2.8–4.2	0.5–1.6	0.9–3.0
Crude fibre	8.6–12.9	3.1–5.1	22.3–31.1	31.4–50.6	48.4
NDF	14.1–29.5	8.0–17.3	43.0	46.0–78.0	56.7–76.0
ADF	7.6–17.6	3.6–6.1	35.3	33.0–59.6	46.9–65.2
Ash	2.9–4.0	3.0–13.9	5.1–7.0	3.8–13.3	3.8–7.3
Lignin	0.2–1.3	0.0–0.5		8.5–15.8	3.3–6.1
Calcium	0.12–0.26	0.11–0.18	0.67–1.56	0.34–1.36	
Phosphorus	0.19–0.47	0.33–0.50	0.27–0.32	0.05–0.44	

Notes: DM (as fed) is 87.6–91.0 percent for *desi* seeds, 87.6–91.0 percent for *kabuli* seeds, 84.4–91.0 percent for brans, percent for straw, and 86.6–88.0 percent for pod husks.
ADF = acid detergent fibre; NDF = neutral detergent fibre.
Source: Feedipedia (2016).

4 percent crude fibre, DM basis). The fat content ranges from 4 to 7 percent (DM basis) in chickpea seeds. Chickpeas are particularly rich in lysine (6–7 percent of the protein) but sulphur-containing amino acids and threonine may be deficient for monogastric species. It is a good source of minerals (calcium, phosphorus, magnesium, iron, and potassium) and vitamins (thiamine and niacin) (Wood and Grusak, 2007, Marioli Nobile *et al.*, 2013). Therefore, it has become an important source of minerals and vitamins in the cereal-based daily diet of millions of people in developing countries (Jukanti *et al.*, 2012).

Digestibility. Organic matter digestibility of chickpeas in sheep was between 84 percent (Hadjipanayiotou, Economides and Koumas, 1985) and 92 percent (Bampidis and Christodoulou, 2011), while energy and protein digestibility were both about 79 percent (Hadjipanayiotou, Economides and Koumas, 1985). In rams, potential DM and NDF *in sacco* degradability were 45 percent and 39 percent, respectively (Bruno-Soares *et al.*, 2000). The effective rumen protein degradability of chickpea is between 59 percent (ewes) and 75 percent (non-lactating Holstein cows) (Bampidis and Christodoulou, 2011).

Chickpea crop residue (straw/ haulm)

Chickpea straw is the main by-product produced after chickpea grain threshing, and is usually equal to or more than the seed yield by weight. Chickpea straw can be used as a ruminant feed (Bampidis and Christodoulou, 2011) and it contains higher nutritive value than cereal straws (44–46 percent total digestible nutrients and 4.5–6.5 percent protein, DM basis) and is more palatable than wheat straw. It is suggested that animals should be allowed to acclimatize to the taste before offering large quantities (Lardy and Anderson, 2009; EI-Bordeny and Ebtehag, 2010; Kafilzadeh and Maleki, 2012). Compared with other straws, chickpea straw has a relatively high nutritive value (e.g. ME = 7.7 MJ/kg DM for chickpea straw vs 5.6 MJ/kg DM for wheat) (López *et al.*, 2004; López *et al.*, 2005; Bampidis and Christodoulou, 2011), but lower than that of other legume straws, such as purple vetch (*Vicia* *benghalensis* L.), common vetch (*Vicia sativa* L.), winter vetch (*Vicia villosa* Roth), broad bean (*Vicia faba* L.), lentil (*Lens culinaris* Medik.) or pea (*Pisum sativum* L.) (Bruno-Soares *et al.*, 2000; López *et al.*, 2005).

Dry matter digestibility and rumen degradability of chickpea straw were 10 to 42 percent higher than those of the cereal straws (Kafilzadeh and Maleki, 2012). The digestible energy and metabolizable energy content of chickpea straw were 8.3 and 7.7 MJ/Kg DM, respectively (Bampidis and Christodoulou, 2011), indicating that the chickpea straw can be used as alternative forage in ruminant diets.

Chickpea bran (*chuni*)

Chickpea bran is a by-product of chickpea processing. It is also called *chuni* in many Asian countries, including India. *Chuni* is the residual by-product, which contains broken pieces of endosperm including germ and a portion of husk. Chickpea *chuni* is a good source of protein (13–19 percent, DM basis).

Chickpea husk

Chickpea husk contained (percent, DM basis) 76.0 NDF, 65.2 ADF, 6.1 acid detergent lignin and 8.4 tannin (Sreerangaraju, Krishnamoorthy and Kailas, 2000). Authors have also observed that a part of the carbohydrate is bound to tannins, which is protected from rumen fermentation but digested in the small intestine. Chickpea husk contains a large rumen degradable DM fraction, above 94 percent (Ngwe *et al.*, 2012).

ANTI-NUTRITIONAL FACTORS

Chickpea contain a number of secondary compounds that can impair nutrient absorption from the gastro-intestinal tract (Bampidis and Christodoulou, 2011). Depending on the genotype, chickpea seeds contain variable amounts of trypsin and chymotrypsin inhibitors that may decrease the feeding value for pigs and poultry. Reported levels of inhibitors are in the 15–19 TIU/mg range, lower than that of raw soybean [*Glycine max* (L.) Merr.] (43–84 TIU/mg). Heat treatments, such as cooking or extrusion, reduce the amount of trypsin and chymotrypsin inhibitors (Bampidis and Christodoulou, 2011).

FEEDING OF SEED AND ITS BY-PRODUCTS

Cattle

Chickpea can be used as a high energy and protein feed in animal diets to support milk and, meat production (Bampidis and Christodoulou, 2011). Gilbery *et al.* (2007) observed greater overall DMI (7.59 vs 6.98 kg/day; $P \leq 0.07$) and final BW (332 vs 323 kg; $P \leq 0.04$) in growing cattle (254 kg BW) fed chickpeas than control (maize and canola-meal-based diet). Illg, Sommerfeldt and Boe (1987) observed that average daily gains were higher for heifers fed 25 and 50 percent chickpeas than those fed 0 and 75 percent in concentrates of total mixed ration. Increasing chickpea inclusion rate from 0 to 75 percent of concentrate DM resulted in a linear decrease in DMI and feed conversion efficiency (Illg, Sommerfeldt and Boe, 1987). Chickpeas can be used as a substitute for soybean meal and maize grain up to 50 percent (DM basis) of the concentrate, or 25 percent (DM basis) of the whole diet of lactating cows. The milk yield and fat contents increased with high inclusion rates of chickpeas, and it has been attributed to the relatively high fat content of chickpeas (Hadsell and Sommerfeldt, 1988).

Various studies also observed that replacing soybean meal and cereal grains by chickpea seeds in the diet of heifer, steer or lamb diets improved the apparent digestibility of crude protein and crude fat, with no adverse effect on the digestibilities of DM, fibre and energy (Illg, Sommerfeldt and Boe, 1987; Sommerfeldt and Lyon, 1988; Hadjipanayiotou, 2002). However, Gilbery *et al.* (2007) observed no improvement in digestibility when replacing mixtures of maize grain and rapeseed meal, field peas or lentils by chickpeas in steer diets.

Sheep and goats

Milk yield and milk composition were not affected by replacing soybean meal and cereal grains with chickpeas, up to 30 percent (DM basis) of the concentrates in the diets of lactating ewes (Christodoulou *et al.*, 2005; Bampidis and Christodoulou, 2011). In lambs and kids, the replacement of soybean meal and cereal grains with chickpeas did not affect body weight gain, intake or feed conversion ratio up to 42 percent inclusion of chickpeas in the dietary DM (Hadjipanayiotou, 2002; Bampidis and Christodoulou, 2011). Similarly, partial or total replacement of soybean meal and cereal grains with chickpeas did not affect carcass weight, yield, or the physical and chemical characteristics of the *longissimus dorsi* muscle (Lanza *et al.*, 2003; Christodoulou *et al.*, 2005).

In 6–8-month old lambs and wethers, chickpea husks included at 10 to 20 percent of the diet (DM basis) replacing de-oiled rice bran, or rice straw, increased the digestibilities of DM, OM, NDF and ADF (Sreerangaraju, Krishnamoorthy and Kailas, 2000; Ngwe *et al.*, 2012). A reduction in the digestibility of crude protein when chickpea husk was included at 10 percent DM was reported by Ngwe *et al.* (2012).

Pigs

Studies showed that chickpeas can be fed raw, dehulled, cooked or extruded to pigs (Batterham *et al.*, 1993; Singh, Barneveld and Ru, 2005; Christodoulou *et al.*, 2006b). True ileal digestibility of all amino acids is similar to that of soybean (full-fat or soybean meal) (Rubio, 2005; Singh, Barneveld and Ru, 2005). The ileal digestibility of chickpea starch was high (85 percent) in Iberian pigs (Rubio *et al.*, 2005).

Results on the use of raw chickpeas for pigs are contradictory. Inclusion of up to 75 percent raw chickpeas (from low-fibre varieties or dehulled) replacing soybean meal was found to have no adverse effect on daily gain, feed intake and feed efficiency in growing pigs. Furthermore, pigs tolerated the trypsin and chymotrypsin inhibitors of the chickpeas and showed no sign of organ toxicity (Batterham *et al.*, 1993). In another study, raw chickpeas fed to growing and finishing pigs at 30 percent of the dietary DM resulted in a similar body weight gain, feed intake and feed conversion ratio as soybean meal during the whole rearing period (growing and finishing) (Mustafa *et al.,* 2000). Chickpeas included at 10–20 percent (Pennisi *et al.,* 1994), 26 percent (Visitpanich, Batterham and Norton, 1985), and in one study 75 percent (Batterham *et al.,* 1993) of the diet DM had no effect on carcass yield, percentage of lean meat and overall meat quality. However, Mustafa *et al.* (2000) reported lower crude protein digestibility and weight gain in growing pigs fed 30 percent raw chickpeas. Christodoulou *et al.* (2006b) observed that even 10 percent inclusion of raw chickpeas in the diet of finishing pig reduced weight gain and feed conversion ratio compared with the soybean meal controlled diet.

Extruded chickpeas included at up to 30 percent, in the diets of growing and finishing pigs, fully replaced the soybean meal with positive effects on body weight gain and feed conversion ratio (Christodoulou *et al.,* 2006b), and with no effect on meat quality (Christodoulou *et al.,* 2006c). The positive effect of extrusion may be due to the improved utilization of starch, fat and protein of extruded chickpeas by the pigs (Bampidis and Christodoulou, 2011).

Poultry

The digestibility and biological value of chickpea nutrients are high for poultry (Brenes *et al.,* 2008; Nalle, 2009). However, due to the presence of anti-nutritional factors, raw chickpeas have been reported to increase pancreas weight in growth birds, which may indicate some toxicity (Farrell, Pérez-Maldonado and Mannion, 1999; Viveros *et al.,* 2001).

Broilers. Brenes *et al.* (2008) observed decreased growth in growing chickens when raw chickpeas were introduced at 10 percent level. It has also been observed that the inclusion of raw chickpeas led to decreased growth performance and an increased feed conversion ratio when used at rates above 15–20 percent in growing chicken diets (Viveros *et al.,* 2001; Christodoulou *et al.,* 2006a). Katogianni *et al.* (2008) also observed reduced growth rate in broilers with 50 and 75 percent replacement of soybean expeller by chickpea.

The positive effect of thermal treatments such as pelleting or autoclaving has been reported by several authors (Farrell, Pérez-Maldonado and Mannion, 1999; Viveros *et al.,* 2001; Christodoulou *et al.,* 2006a;). Extrusion allowed inclusion of up to 20 percent chickpeas in diets for young broilers, whereas raw chickpeas reduced performance (Brenes *et al.,* 2008). In turkeys, inclusion of 20 percent extruded chickpeas did not reduce performance, and extreme inclusion rates of up to 80 percent resulted in a reduction of only 8 percent in growth (Christodoulou *et al.,* 2006b). The recommendation is to limit chickpeas to 5–10 percent in starter diets and 10–15 percent in grower and finisher diets (DM basis). Higher levels up to 20 percent could be used with heat-processed chickpeas.

Layers. Inclusion rates of chickpeas as high as 25 to 40 percent in layer diets were shown to maintain egg production (Pérez-Maldonado, Mannion and Farrell, 1999; Garsen *et al.,* 2007). Robinson and Singh (2001) observed that dehulling chickpeas, or applying thermal treatments such as pelleting did not change the laying rate but improved layer body weight. Garsen *et al.* (2007) observed that when used as a substitute for maize grain, chickpeas may decrease egg yolk colour, which has to be considered in feed formulation (Garsen *et al.,* 2007).

SUMMARY

Chickpea straw has higher nutritive value than cereal straws. It is palatable and can be used as a ruminant feed. Chickpea bran (*chuni*) is a good source of protein (13–19 percent, DM basis) for ruminants. Chickpeas can be used as a substitute for soybean meal and maize grain up to 50 percent of the concentrate in large and small ruminant diets. Extruded chickpeas can be included up to 30 percent in the diets of growing and finishing pigs. The recommendation is to limit raw chickpeas to 5–10 percent in starter diets, and up to 10–15 percent in grower and finisher pig diets. Heat processed chickpeas can be included up to 20 percent in broiler and layer diets.

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Chapter 8
Cowpea

COMMON NAMES
Asparagus bean, black-eyed pea, catjang, catjang cowpea, Chinese long bean, clay pea, cream pea, crowder pea, pea bean, purple-hull pea, southern pea, sow pea, yard-long bean [subsp. sequipedalis] (English) dolique asperge, dolique mongette, haricot asperge, haricot indigène, niébé, pois à vaches (French); feijão-espargo, feijão-fradinho (Portuguese); costeño, frijol de costa, judía catjang, judía espárrago, rabiza (Spanish); adua, ayi, too, tipielega, yo, tuya, saau (Ghana); wake, ezo, nyebbe, ngalo, azzo, dijok, alev, arebe, lubia, mongo, ewa, akedi, akoti (Nigeria); kunde (Swahili); Kedesche, sona, kadje, tombing, isanje (Togo); imbumba, indumba, isihlumaya (Zulu); kacang bol, kacang merah, kacang toonggak, kacang béngkok (Indonesian).

DISTRIBUTION
Cowpea [*Vigna unguiculata* (L.) Walp.] has been domesticated and cultivated in Africa for centuries. It is now grown worldwide, especially in the tropics, between latitudes 40°N to 30°S and below an altitude of 2 000 masl (Ecocrop, 2009). Cowpea is grown in over two-thirds of the developing world as a companion or relay crop with major cereals. The largest producers are Nigeria, Niger, Brazil, Haiti, India, Myanmar, Sri Lanka, Australia, and the United States of America (FAOSTAT, 2013).

DESCRIPTION
Cowpea is often called "black-eyed pea" due to its black- or brown-ringed hilum. Cowpea is called the "hungry-season crop", because it is the first crop to be harvested before the cereal crops (Gomez, 2004). Its fresh or dried seeds, pods and leaves are commonly used as human food. Varieties may be short and bushy, prostrate, or tall and vine-like. Canopy heights can be 60 to 90 cm, depending on the genotype. The upright stems are hollow and hairless, roughly 1 cm wide. The stems of twining varieties are thinner. The leaves are 10 cm long and 8 cm wide. Leaves are trifoliate, egg-shaped, and hairless. The two lateral leaves are asymmetrical, and the terminal leaf is symmetrical. The plant also has extra floral nectaries, small pores on its leaves and stems of leaves that release nectar and attract beneficial insects. The branchless inflorescence produces stemmed flowers, 2.5 cm long, along the main axis. The flowers

*Photo 8.1.1 Seeds of cowpea [*Vigna unguiculata *(L.) Walp.]*

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*Photo 8.1.2 Plants of cowpea [*Vigna unguiculata *(L.) Walp.] cultivated for fodder*

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*Photo 8.1.3 Different pod types of cowpea [*Vigna unguiculata *(L.) Walp.].*

can be purple or white. The lowermost whorl of leaves under the flower is bell-shaped. The lobes of the flower are fused, and the lateral petals are shorter than the upper petal. The seeds are born in 8–15 cm long, slender, round, two-valved pods growing from the leaf axils. There are roughly 6–13 seeds per pod growing within spongy tissue. The kidney-shaped seeds are white with a black mark around the scar that marks the point of attachment to the seed stalk.

CLIMATIC CONDITIONS FOR CULTIVATION

Cowpea is a warm-season crop that can be produced in semi-arid regions and dry savannas. Cowpea grows in savannah vegetation at temperatures ranging from 25 to 35 °C and in areas where annual rainfall ranges from 750 to 1 100 mm (Madamba *et al.*, 2006). Cowpea is tolerant of shading and can be combined with tall cereal plants such as sorghum and maize (FAO, 2013). It is better adapted to sandy soils and droughty conditions than soybean [*Glycine max* (L.) Merr.] (TJAI, 2010). Cowpea grows on a wide range of soils provided they are well drained (Madamba *et al.*, 2006). It is recommended to avoid moisture laden soil or any type of soil that tends to retain too much moisture for the growth of this plant.

ANTI-NUTRITIONAL FACTORS

Cowpeas contain anti-nutritional factors such as lectins, trypsin inhibitors and tannins (Makinde *et al.*, 1997). Anti-nutritional factors can be eliminated with appropriate processing methods. Most anti-nutritional factors are heat-labile (Emiola and Ologhobo, 2006) and so heat treatment could be the appropriate method to denature anti-nutritional factors. Oven heating, micro-waving, boiling, autoclaving and infrared irradiation are some of the heat treatment methods that can be used to reduce the anti-nutritional factors in cowpeas (dBede, 2007). Ravhuhali *et al.* (2011) reported that some cultivars had high

Table 8.1 Chemical composition of cowpea and its by-products (percent, DM basis)

Parameter	Seeds	Seeds, heat treated	Aerial part, fresh	Aerial part, dried	Hay	Haulm	Pod husk
Crude protein	25.2	26.1	18.1	17.1	14.8	13.7	12.7
Ether extract	1.6	1.7	2.8		1.7	2.2	0.7
Crude fibre	5.6	4.1	24.1		32.6	29.9	31.8
NDF	16.6	21.3	38.6	43.2	49.0	49.0	54.2
ADF	6.5		27.1	32.8	37.2	35.4	41.1
Ash	4.1	4.8	11.3	15.8	13.7	11.0	7.9
Lignin	0.8		4.6	8.4	8.0	8.5	
Calcium	0.11	0.09	1.25		1.31	1.14	
Phosphorus	0.42	0.27	0.24		0.39	0.26	

Notes: DM (as fed) is 89.9 percent for seeds, 87.9 percent for heat treated seeds, 20.9 percent for fresh aerial part, 92.5 percent for dried aerial part, 91.2 percent for hay, 95.0 percent for haulm, and 51.6 percent for pod husk.
ADF = acid detergent fibre; NDF = neutral detergent fibre.
Source: Feedipedia (2016)

amounts of condensed tannins (0.11 percent, DM basis), but these did not exert negative effects on intake and digestibility.

COWPEA AND ITS BY-PRODUCTS AS ANIMAL FEED

Ruminants

Cowpea seeds. Cowpea seeds contain, on DM basis, about 24 percent protein, 53 percent carbohydrates and 2 percent fat (FAO, 2012; Table 8.1). The protein and *in vitro* dry matter digestibility (DMD) of cowpeas indicated that they could efficiently replace maize or cottonseed meal in livestock diets. Though not as efficient as soybean as a protein source, cowpea was capable of accumulating useful levels of protein and digestible DM under the variable growing conditions of the study (Rao and Northup, 2009).

Paduano *et al.* (1995) reported that supplementing cowpeas to sheep fed poor quality roughages resulted in improved DMI and organic matter (OM) digestibility. Singh *et al.* (2006) reported that replacing 100 percent of groundnut (*Arachis hypogaea* L.) cake with cowpea seeds in the diet of growing lamb had a positive effect on roughage intake and growth performance. Sarwar *et al.* (1995) reported that cowpeas used as a source of urease for buffalo male calves fed ureatreated straw resulted in increased body weight gain and DMD.

Cowpea seed waste. Cowpea seed waste and cowpea hulls (which result from the dehulling of the seeds for food) have been used to replace conventional feedstuffs in some developing countries (Ikechukwu, 2000). Olubunmi, Oyedele and Odeyinka (2005) observed that cowpea seed waste successfully replaced groundnut cake, maize bran or wheat offal in goat diets.

Cowpea forage. Cowpea provides high quality forage, rich in protein (14–24 percent, DM basis). Leaves and shoots usually contain more than 20 percent protein (DM basis), depending on the stage of maturity and seasonal climatic variation (Mullen, 1999). Organic matter digestibility of cowpea forage has been reported to be higher than 60 percent in ruminants (Cook *et al.,* 2005; Anele *et al.,* 2011a).

In some African countries, several varieties of cowpea have been grown together for both food and feed. It is widely intercropped with maize, sorghum and millet (Cook *et al.,* 2005). Dual-purpose varieties, although lower in protein than forage-type varieties, require little or no input, and provide sufficient biomass in marginal lands, without additional fertilizer, to provide a livestock feed supplement during the dry season (Anele *et al.,* 2011a). Maize-cowpea intercrops have considerable potential as forage, and also these intercrops have a higher DMD than maize or cowpea grown alone.

Farmers may harvest up to 0.4 tonne/ha of cowpea leaves in a few cuts with no noticeable reduction in seed yield. A potential yield of 4 tonne/ha of hay can be achieved with good management from a pure stand of cowpea. However, the world average yield of cowpea fodder is 0.5 tonne/ha (air-dried leafy stems) as reported by Madamba *et al.* (2006). Mehdi *et al.* (2009) reported that the optimum forage quality occurs at the milky stage. Mullen (1999) reported that cowpea forage is suitable for growing, fattening and lactating animals, including dairy cows.

Cowpea pasture. Holzknecht, Poppi and Hales (2000) reported that cowpea can be grazed by steers with no adverse effect on live-weight gain during late summer to early autumn in Australia. However, in India, cowpea did not re-grow adequately to provide late autumn grazing (Singh *et al.,* 2010). In the south-eastern United States of America, cowpea was incorporated in a subtropical grass pasture for grazing cows and calves, but did not persist in July and August (Vendramini, Arthington and Adesogan, 2012).

Cowpea haulms. Cowpea haulms have low protein content (14 percent DM, basis) and high fibre content (33 percent, DM basis). The protein content of cowpea haulm differs widely between leaves (22 percent, DM basis) and stems (8 percent, DM basis) (Singh *et al.,* 2010). Due to seasonal differences in the quality of haulms, care must be taken when handling to minimize loss of leaves (Anele *et al.,* 2012). Dry matter digestibility of cowpea haulm is between 65 and 70 percent (Savadogo *et al.,* 2000; Karachi and Lefofe, 2004), and differs greatly between leaves (60–75 percent) and stems (50–60 percent). Because of this difference, the proportion of leaves and stems in the haulm affects its nutritional value (Singh *et al.,* 2010).

Anele *et al.* (2010) observed that cowpea haulm can be used for sheep as a supplement to poor quality basal diets. Anele *et al.* (2011b) also observed that cowpea haulms can provide adequate protein and energy to sustain ruminant production during an extended dry season.

Savadogo, Zemmelink and Nianogo (2000) reported that the intake of cowpea haulms by sheep can reach 86 g OM/kg $BW^{0.75}$/day. However, selective consumption of leaves resulted in higher intakes of protein and digestible OM than expected from the offered haulms. Rams ate up to 60 g OM/kg $BW^{0.75}$/d of cowpea haulms as a supplement to sorghum stover. Although supplementation decreased total DMI, this was compensated for by an increase in stover digestibility (Savadogo *et al.,* 2000). In sheep fed 200–400 g/day of cowpea haulms as a supplement to a basal diet of sorghum stover, the resulting average live-weight gain (80 g/day) was twice that obtained with sorghum fodder alone (Singh *et al.,* 2003). In male Ethiopian Highland sheep, supplementation of maize stover with cowpea haulms (150 or 300 g DM/day) improved DM and protein intake, OM digestibility, average daily gain, final live weight, carcass cold weight and dressing percentage (Koralagama *et al.,* 2008). Anele *et al.* (2010) reported higher DMI when cowpea haulms were used as a supplement for West African dwarf sheep fed a basal diet of napier grass (*Pennisetum purpureum* Schumach.). The authors suggested that cowpea haulms can be utilized as a supplement for livestock production and its inclusion in the diet of sheep had no deleterious effects while improving the haematological and serum biochemical variables.

Cowpea hay. If cowpea is specifically grown for hay, cutting should be done when 25 percent of the pods are coloured (Van Rij, 1999). Well-cured cowpea haulms are a useful feed and can make excellent hay, provided that the leaves are well preserved (too much exposure to the sun makes them fall off) and that the stems are adequately wilted (Cook *et al.,* 2005; FAO, 2013). In Australia, the ideal time to cut a cowpea crop for hay is at peak flowering, which occurs 70–90 days after sowing (Cameron, 2003).

Singh *et al.* (2010) reported that lambs (Local × Corridale) fed a diet based on organically produced cowpea hay and barley grain had similar DMI and nutrient digestibility as that from a conventional diet produced with inorganic fertilizers. Feeding cowpea hay (30 percent diet; native grass-hay-based diet) in crossbred growing steers improved LWG by nearly 250 g/day (Varvikko, Khalili and Crosse, 1992). Umunna, Osuji and Nsahlai (1997) also observed that feeding cowpea hay at 1 percent of body weight in cereal-legume cropping systems, led to LWG of 280 to 373 g/day in steers. In calves fed teff straw [*Eragrostis tef* (Zuccagni) Trotter)] + cowpea hay supplemented at up to 1.5 percent BW was found as efficient as hyacinth bean hay [*Lablab purpureus* (L.) Sweet] in improving DMI and teff straw degradability (Abule *et al.,* 1995).

In Zimbabwe, cowpea hay was used as a supplement at 30 percent of the diet to improve ME intake and microbial protein supply when the lambs consumed low-quality forages such as maize stover (Chakeredza, ter Meulen and Ndlovu, 2002).

Cowpea silage. Cook *et al.* (2005) reported that excellent silage can be made by harvesting a mixed crop of cowpea and forage sorghum, millet or maize. Cowpea haulms (vines) can be used to make silage through the addition of water and 5 percent molasses. This ensiling process enhanced feed value but was not sufficient to fulfil the requirements of goats (Solaiman, 2007). Intercropping of maize and cowpea at a seed ratio of 70:30 increased fodder production and produced silage of high digestibility (higher than maize silage alone supplemented with urea) when harvested at 35 percent DM (Azim *et al.,* 2000).

Pigs

Cowpea seeds. Makinde *et al.* (1997) observed that feeding raw cowpeas gave lower growth performance in weaner pigs, which may be due to antigenic factors causing damage to the intestinal mucosa. However, the introduction of creep feeding before weaning had some ameliorative effects. Physical treatment such as dry fractionation or heating of cowpea beans may alleviate adverse effects in weaner pigs due to antinutritional factors (Makinde *et al.,* 1996). Soaked and crushed cowpea beans ensiled with lactic acid bacteria strains from sow milk were a valuable feed for weanling pigs (Martens and Heinritz, 2012).

Cowpea forage. Cowpea forage can be a valuable source of protein (13 to 25 percent, DM basis) for pigs, though its level of fibre and NDF-bound N (24 to 40 percent N) may limit protein availability (Heinritz *et al.,* 2012). Sarria *et al.* (2010) observed that pigs fed a diet with 30 percent of the CP from cowpea leaf meal had greater development of the large intestine and less development of the small intestine, compared with pigs fed the control diet (maize and soybean). It is concluded that the cowpea leaf meal was well accepted by the pigs, increasing consumption by 8 percent without affecting the apparent digestibility of DM and gross energy. However, the digestibility of CP was decreased in a curvilinear way with increasing cowpea leaf meal in the diet up to 30 percent. Using cowpea silage in a mixture with maize grain (40:60) increased *in vitro* digestibility to 73 percent (Heinritz *et al.,* 2012).

Poultry

Broilers. Trompiz *et al.* (2002) observed that dried and ground cowpeas included at 16 percent in starter broiler diets had no negative effects. Chakam, Teguia and Tchoumboue (2010) also observed that cooked and sun-dried cowpea seeds included at up to 20 percent in the diet did not have deleterious effects on LWG, feed conversion ratio, feed cost/kg live-weight, and carcass quality. Dehulling, combined dehulling and roasting, or the addition of enzymes (beta-glucanase at a level of 0.25 g/kg) increased feed intake, body weight gain and protein intake when processed cowpeas were included at 15 percent in chicken diets (Belal *et al.*, 2011).

Broilers finished with cowpea had a higher carcass yield than broilers fed black common bean (*Phaseolus vulgaris* L.) (Defang *et al.,* 2008). Sun-dried cowpeas successfully replaced 75 percent of soybean meal in broiler diets (Lon-

Wo and Cino, 2000). The general conclusion is that inclusion of processed cowpeas is feasible up to 15–20 percent in broiler diets, but deleterious at higher levels. However, Eljack, Fadlalla and Ibrahim (2010) reported that the inclusion of 30 percent cowpeas (replacing groundnut meal and sorghum) improved weight gain, feed conversion ratio, dressing percentage and carcass quality. Kur *et al.* (2013) observed that inclusion of treated cowpea seeds at 15 percent (DM basis) in broiler diets resulted in similar performance as from the control diet (0 percent cowpea).

Layers. Hlungwani (2011) reported that layer hens fed a cowpea diet had lower egg production during the first eight weeks, but then improved.

No additional information was found reporting on feeding of cowpea and its by-products in the diets of layers.

Cowpea hulls. Cowpea hulls are an inexpensive potential feedstuff and have been assessed as a replacer of conventional feedstuffs in poultry diets. Though increasing levels of cowpea hulls decreased overall performance, it was possible to include up to 25 percent cowpea hulls in diets of growing geese (Ningsanond *et al.*, 1992). For starter and finisher broilers, cowpea hulls were used to replace maize offal and maize grain (Ikechukwu, 2000). Chicken fed on raw cowpea hulls had a lower performance than those fed on conventional diets, but inclusion of cowpea hulls up to 15 percent in starter and finisher diets was more cost effective than conventional diets (Ikechukwu, 2000). There have been attempts to reduce fibre in cowpea hulls by different physico-chemical treatments such as soaking plus boiling or soaking for 3 days. It was shown that soaking for 3 days reduced fibre and increased carbohydrate contents, which may be due to fermentation during soaking (Adebiyi *et al.*, 2010).

SUMMARY

Cowpea forage has high protein contents (14–24 percent, DM basis). Cowpea hay can be recommended up to 30 percent in the diet of large and small ruminants. Raw cowpea seeds and by-products (seed waste, hulls) can be successfully used in the diets of small and large ruminants, however, they cannot be recommended for use in pigs and poultry diets. Heat treatment could be an appropriate method to denature the anti-nutritional factors present in cowpea seeds. Heat treated seeds can be included up to 20 percent in broiler diets. Cowpea hulls (which results from dehulling of seeds for food) are low-cost potential feedstuffs for poultry diets, and can be included up to 15 percent in starter and finisher diets.

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Chapter 9
Pigeon pea

COMMON NAMES
Cajan pea, no-eye pea, no-eyed pea, tropical green pea (English); pois d'Angole, pois cajan, pois-congo, ambrevade (French); guandú, gandul, guandul, frijol de palo, quinchoncho (Spanish); guandu, andu, anduzeiro, guandeiro, feijão boer (Portuguese); Straucherbse (German); pwa kongo (Haitian creole); gude, kacang gude (Indonesian); caiano (Italian); umukunde (Kinyarwanda).

DISTRIBUTION
The origin of pigeon pea [*Cajanus cajan* (L.) Huth] has been the matter of some debate; some authors indicate that the species originated from north-eastern Africa and others assure that it is native to India. However, pigeon pea has most probably originated from India where the closest wild relative [*Cajanus cajanifolius* (Haines) Maesen] is also found (Fuller and Harvey, 2006; Ecocrop, 2016). In any case, its cultivation dates back at least 3 000 years (Mallikarjuna, Saxena and Jadhav, 2011). It is now a pan-tropical and sub-tropical species, particularly suited for rainfed agriculture in semi-arid areas. It can be found in both hemispheres from 30 °N to 30 °S and from sea level to an altitude of 2 000 masl (Ecocrop, 2016).

DESCRIPTION
Pigeon pea is an erect, short-lived perennial leguminous, warm-season crop. It is a shrub generally about 1–2 m in height, but can go up to 2–5 m high. Pigeon pea quickly develops a deep (2 m depth) poisonous taproot. The stems are woody at the base, angular, branching. The leaves are alternate, trifoliate. The leaflets are oblong, lanceolate, 5–10 cm long × 2–4 cm wide. Leaves and stems are pubescent. The flowers (5 to 10) are grouped in racemes at the apices or axils of the branches. The flowers are papillonaceous and generally yellow in colour. They can also be striated with purple streaks. The corolla is about 2–2.5 cm. The pigeon pea fruit is a flat, straight, pubescent, 5–9 cm long x 12–13 mm wide pod. It contains 2–9 seeds. The pigeon pea seeds are brown, red


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*Photo 9.1.1 Seeds of pigeon pea [*Cajanus cajan *(L.) Huth]* or black in colour, small and sometimes hard coated (Bekele-Tessema, 2007; FAO, 2016a).

CLIMATIC CONDITIONS FOR CULTIVATION

Pigeon pea is adapted to a wide range of soil types. It grows best in well-drained soils and does not survive waterlogged conditions. It does better where annual rainfall is more than 625 mm but it is highly tolerant of dry periods and, in places where the soil is deep and well-structured, pigeon pea still grows with as low as 250 to 375 mm rainfall. It can be grown in a pH range of 4.5–8.4 (Cook *et al.,* 2005). It grows better in places where temperatures range from 20 to 40 °C (FAO, 2016a). Pigeon pea is drought resistant and can survive under very dry conditions because of its deep root system. It has been found to grow throughout a six month dry season (Cook *et al.,* 2005); however, flowering is delayed and seed yield decreases with long periods of drought (Mullen, Holland and Heuke, 2003). It is less adapted to humid, wet conditions.

PRODUCTION OF PIGEON PEA SEEDS

Global production of pigeon pea seeds was 4.85 million tonne in 2014. Most important producers of pigeon pea seeds were India (65 percent of world production), Myanmar, Malawi, Kenya and Tanzania. Asia accounted for the bulk of production with 79.1 percent, followed by Africa (17.6 percent) and the Americas (2.5 percent) (FAO, 2016b).

ANTI-NUTRITIONAL FACTORS

Pigeon pea seeds contain various anti-nutritional factors including haemagglutinins, trypsin and chymotrypsin inhibitors, cyanoglucosides, alkaloids and tannins (Onwuka, 2006). These anti-nutritional factors can have deleterious effects on animals. Cheva-Isarakul (1992) reported that the trypsin inhibitor activity (TIA) in pigeon pea seeds was 3 times that found in the leaves (19.5 vs 7.0 mg TIA/g DM). Feeding of pigeon pea produced worse effects on pig performance and feed use efficiency compared with pigs fed chickpeas. This suggests the presence of other anti-nutritional factors in pigeon pea (Batterham *et al.,* 1990). However, heat treatments such as cooking or extrusion reduced the amount of trypsin and chymotrypsin inhibitors and increased pigeon pea digestibility (Batterham *et al.,* 1990; Batterham *et al.,* 1993; Onwuka, 2006).

PIGEON PEA AND ITS BY-PRODUCTS AS ANIMAL FEED

Cattle

Pigeon pea seeds. Pigeon pea seeds and its by-products such as split and shrivelled seeds are used as livestock feed (Phatak *et al.,* 1993). Pigeon pea is typically used as a protein source, due to its high concentration of protein in both seeds (23.0 percent, DM basis) and leaves (19.0 percent, DM basis; Table 9.1). However, a high proportion of protein is bound to fibre (20–26

Table 9.1 Chemical composition of pigeon pea and its by-products (percent, DM basis)

Parameter	Seeds	Aerial part, fresh	Hay	Leaves, dry	Pods	Pod husk
Crude protein	23.2	10.1–26.7	14.5	19.3	20.3	6.7
Ether extract	2.5	2.4–6.1	1.9	5.5	1.7	0.3
Crude fibre	9.1	21.3–45.1	32.5	24.1	35.2	38.0
NDF	15.5	37.2–62.9	78.6			
ADF	10.5	15.7–38.7	60.2			
Ash	5.3	4.0–8.8	4.6	8.8	3.3	5.0
Lignin		7.3–21.4	17.1			
Calcium	0.38	0.46–1.08		1.24		0.97
Phosphorus	0.32	0.10–0.26		0.25		0.18

Notes: DM (as fed) is 89.5 percent for seeds, 24.4–49.7 percent for fresh aerial part, 90.3 percent for hay, 90.0 percent for dry leaves, 87.3 percent for pod, and 93.0 percent for pod husk.
ADF = acid detergent fibre; NDF = neutral detergent fibre.
Source: Feedipedia (2016).

percent N fixed in ADF; Pires *et al.*, 2006; Veloso *et al.*, 2006; Foster *et al.*, 2011), suggesting not all protein being available for digestion. Nutritive value of pigeon pea may also be limited by low sulphur concentration (0.06 percent, DM basis) that is below ruminant requirements.

Corriher *et al.* (2007) observed that total replacement of whole cotton seeds, maize gluten feed or maize+soybean [*Glycine max* (L.) Merr.] meal by pigeon pea seeds had no effect on the average daily gain of yearling beef heifers fed on a maize silage-based diet. Corriher *et al.* (2010) also observed that pigeon pea seeds can be incorporated at a rate of 20 percent (DM basis) in a maize silage-based diet without any detrimental effect on DMI (22.5 kg DM/day) and milk production (42 kg/day) in early lactation Holstein cows.

Pigeon pea forage. Pigeon pea is a good protein source and provides excellent forage for livestock (Phatak *et al.*, 1993). Pigeon pea foliage (leaves and pods) is valuable and palatable fodder. The foliage and young pods are palatable to livestock and provide good quality forage. Pigeon pea can be grown in association with cereals such as maize, sorghum or millet (Cook *et al.*, 2005; Bekele-Tessema, 2007). However, it is not recommended for growing in associations with other legumes for fodder production (Cook *et al.*, 2005). Rao and Northup (2012) reported an average daily weight gain of about 1.0 kg/day on yearling cattle, intensively grazing pigeon pea forage in late-summer.

Generally, the yields of pigeon pea forage range from 20 to 40 tonne DM/ha. Pigeon pea ranks alongside the highest biomass producers, such as switchgrass (*Panicum virgatum* L.) (Sloan *et al.*, 2009), and could be expected to yield up to 40 tonne DM/ha under optimal conditions (ILRI, 2013).

Pigeon pea hay. da Silva *et al.* (2009) observed that DM or OM digestibility of pigeon pea hay ranges from 50 to 60 percent. Foster *et al.* (2009a) also observed that *in vivo* DM or OM digestibility of pigeon pea hay was found to be close to that of cowpea [*Vigna unguiculata* (L.) Walp.] hay (55–56 percent). However, Foster *et al.* (2009b) observed that pigeon pea haylage seems clearly less digestible than the other warm-season legumes, such as groundnut (*Arachis hypogaea* L.) and cowpea. Pigeon pea, as fresh, hay or haylage, including the leaves, is characterized by low *in situ* ruminal DM, NDF and N disappearance kinetics when compared with other warm-season legumes or poor quality forage hays, with much lower potentially degradable fractions and much greater undegradable fractions (Carvalho *et al.,* 2006; Pires *et al.,* 2006; Veloso *et al.,* 2006; Foster *et al.,* 2011). This clearly limits its potential use for high producing animals such as dairy cows.

Sheep and goats

Pigeon pea seeds. On a rice-straw-based diet containing 50 percent of concentrate, total and isonitrogenous replacement of ingredients (maize, bran, meals) by ground pigeon pea seeds had no effect on DMI, *in vivo* DMD and average daily gain (Cheva-Isarakul, 1992). Dry matter intake levels ranged from 2.9 to 3.6 percent BW at an incorporation rate of pigeon pea seeds of from 17 to 57 percent in a rice-straw-based diet (Cheva-Isarakul, 1992). This suggests that pigeon pea seeds can be used to replace soybean meal in concentrate rations for ruminants or directly supplemented to low quality roughages. Raw or processed pigeon pea seed meal included up to 30 percent in diets of West African Dwarf goats improved feed intake (Ahamefule, Ibeawuchi and Ibe, 2006).

Pigeon pea forage. Omokanye *et al.* (2001) observed that chopping of pigen pea enhanced intake by around 60 percent in sheep. As the study period progressed, the consumption of fresh and chopped materials remained moderately consistent, while those of dried and unchopped materials in turn increased gradually. Voluntary DMI of sheep can be 2.5 percent of BW (58 g/kg $BW^{0.75}$) on a pigeon pea-leaf-based diet (Cheva-Isarakul, 1992) and 3.5 percent of BW (65 g/kg $BW^{0.75}$) on a pigeon pea-hay-based diet (da Silva *et al.,* 2009). When incorporated at a rate of 50 percent of DM in a bahia grass (*Paspalum notatum* Flüggé) hay- or haylage-based diet, pigeon pea, as hay or haylage, had a clear detrimental effect on DMI when compared with other warm-season legumes, such as groundnut or cowpea (Foster *et al.,* 2009a; Foster *et al.,* 2009b).

Pigs

Pigeon pea seeds. Mekbungwan, Thongwittaya and Yamauchi (2004) reported that the digestibilities of crude protein (49.8 percent), crude fat (23.6 percent), and crude fibre (43.2 percent) in pigeon pea were much lower than those of soybean (80.6, 23.6 and 52.4 percent, respectively). The digestible energy of pigeon pea seeds was also lower than that of soybean meal and only half the protein could be digested. Raw pigeon pea seeds can be added up to 20 percent in the diets of growing pigs (Mekbungwan *et al.,* 1999); while Mekbungwan and Yamauchi (2004) recommended that raw pigeon pea seeds could be incorporated up to 40 percent in a growing (13 kg) pig diet.

Addition of pigeon pea seeds to the diet linearly depressed growth rate, feed intake ($P < 0.05$) and feed use efficiency of growing pigs (20 kg) when included at levels varying from 25 to 75 percent. Mean growth responses and feed use efficiency of pigs fed on pigeon pea were inferior to those of pigs fed on soybean or chickpea (*Cicer arietinum* L.) (Batterham *et al.,* 1990). Piglets fed on pigeon pea seeds had lower weight gain and lower feed intake, and feed cost was higher with pigeon pea than with the control (Etuk *et al.,* 2005). Fuji *et al.* (1995) reported that feeding pigeon pea at 6–12 percent in concentrate diet (DM basis) increased meat mass, and had no signs of illness in growing pigs (20–60 kg). Amaefule *et al.* (2016) reported that growing pigs could be fed up to 30 percent raw pigeon pea seeds in the diet to ensure better performance and reduce total feed cost and feed cost per kg live weight gain, improving the gross margin.

Pigeon pea forage. Pigeon pea forage could be fed at up to 24 percent to creola pigs without health problems. However, pigs had increased ileal and rectal flow of both DM and water, which indicates lower digestibility of diets containing pigeon pea forage (Diaz and Ly, 2007). Growth performances were decreased at levels as low as 6 percent in creole pigs diets, back thickness increased as pigeon pea forage increased, and economic performance decreased with increasing pigeon pea forage (Estupiñán, 2013; Estupiñán *et al.,* 2013).

Poultry

Broilers. Hassan, Yassin and Gibril (2013) observed that broilers can perform well up to a 12 percent incorporation rate of pigeon pea seeds as a substitute for sesame cake. However, incorporation rates above 20 percent decreased performance (Etuk and Udedibie, 2003; Amaefule, Ukpanah and Ibok, 2011; Ani and Okeke, 2011). In some cases, feed intake, and weight gain decreased at low incorporation rates of from 5 to 10 percent (Babiker, Khadiga and Elawad, 2006; Saeed, Khadiga and Abdel, 2007; Oso *et al.,* 2012). The effect seems to be higher in starters than in finisher broilers (Ani and Okeke, 2011; Igene *et al.,* 2012). In some cases, growth performances were maintained with 10 to 20 percent raw pigeon pea (de Oliveira *et al.,* 2000; Iorgyer *et al.,* 2009).

Many groups tried to improve performance with technical treatments such as thermal treatments (roasting or cooking), soaking, fermentation or dehulling (Onu and Okongwu, 2006; Abdelati, Mohammed and Ahmed, 2009). In most cases the growth performance of broilers is improved, with no clear advantage to one particular processing except that fermented pigeon pea did not produce good animal performance (Oso *et al.,* 2012). Optimization of thermal treatments showed that over-processing (autoclaving at 120 °C for 30 min.) led to decreased performance (Pezzato *et al.,* 1995). Toasted pigeon pea could support growth up to 27 percent in finisher diets, while performance was reduced (although non-significantly) in younger birds (Ani and Okeke, 2011).

In summary, the general recommendation in broilers would be to limit incorporation to 10 percent raw pigeon pea in young animals. With processed (toasted) pigeon pea and in older animals, higher incorporation rates, up to 20 percent, could be used.

Layers. The supplementation of raw pigeon pea at a 30 percent level in layer diets reduced hen-day egg production (Agwunobi, 2000; Amaefule *et al.*, 2007) although in some experiments production was maintained with 20 percent pigeon pea in the diet. Treatments such as toasting or boiling can improve performance (Amaefule, Ironkwe and Obioha, 2006; Amaefule *et al.*, 2007). Pigeon pea can be used in diets of pullets (Amaefule and Nwagbara, 2004; Amaefule, Ojewola and Ironkwe, 2006). The overall recommendation is to use pigeon pea in layers diet with care, to avoid a decrease in feed use efficiency. It should be safe to use 10 percent raw pigeon pea in diets, with special attention to methionine content in the diet. Higher rates (20 percent) can be tested, especially if a technical treatment (toasting or boiling) can be applied to pigeon pea.

SUMMARY

Pigeon pea seeds and its by-products are used as livestock feed. Pigeon pea seeds are good source of protein and can be incorporated up to 20 percent (DM basis) in the diet of lactating cows. Raw or processed seeds can be included up to 30 percent in goat diets. Pigeon pea provides excellent forage for livestock. Raw pigeon pea seeds can be included up to 20 percent in growing pig diets. Raw pigeon pea seeds can be included up to 10 percent, whereas processed (toasted) seeds can be included up to 20 percent in broiler and layer diets.

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Chapter 10
Lentil

COMMON NAMES

Lentil, red dahl (English); lenteja (Spanish); lentilha (Portuguese); lentille (French); Linse, Erve (German); lenticchia (Italian); mdengu (Swahili); Linze (Dutch); Mercimek (Turkish).

DISTRIBUTION

Lentil (*Lens culinaris* Medik.) may have been one of the first agricultural crops grown, more than 8 500 years ago. The plant was given the scientific name *Lens culinaris* in 1787 by Medikus, a German botanist and physician (Hanelt, 2001). Lentils were domesticated in the so-called Fertile Crescent (within the boundaries of what is Iraq today) and from there spread to other regions (Ron, 2015). The genus *Lens* includes both cultivated and wild forms distributed in West Asia and North Africa. However, wild forms are confined to the Mediterranean region (Dikshit *et al.,* 2015).

DESCRIPTION

Lentil is a bushy, annual legume, and grown mainly for its edible seeds, which are cooked and eaten (Ford *et al.*, 2007). The plant can reach 60–75 cm high. The lentil plant is slender and erect or sub-erect and has branching, hairy stems. The leaves of the plant are arranged alternately and are made up of 4–7 individual oval leaflets. The plant produces small blue, purple, white or pink flowers arranged on racemes with 1–4 flowers. The fruits are small, laterally compressed pods that contain two or three lens-shaped, grey, green, brownish, pale red or black seeds, the size of which depend on cultivar type and ranges from 2 to 9 mm × 2 to 3 mm (Ecocrop, 2012). The most recent classification identified seven taxa groups under four species, namely *Lens culinaris* subsp. *culinaris*, *L. culinaris* subsp. *orientalis* (Boiss.) Ponert, *L. culinaris* subsp. *tomentosus* (Ladiz.) M.E. Ferguson *et al.*, *L. culinaris* subsp. *odemensis* (Ladiz.) M.E. Ferguson *et al.*, *L. ervoides* (Brign.) Grande, *L. lamottei* Czefr., and *L. nigricans* (M. Bieb.) Godr. (Ferguson *et al.*, 2000; Kole *et al.*, 2011).

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*Photo 10.1.1 Seeds of lentil (*Lens culinaris *Medik.)*

PRODUCTION OF SEEDS

Lentils rank fifth among the most important pulses in the

*Photo 10.1.2 Plants of lentil (*Lens culinaris *Medik.)*

world and are extremely important in the diets of many people in the Middle East and India (FAOSTAT, 2012). The major lentil growing countries of the world are Canada, India, Turkey, Australia, United States of America, Nepal, China, and Ethiopia. Out of the total increased volume of global production in recent years, most is coming mainly from Canada and India (FAOSTAT, 2014). The total lentil cultivated area in the world is estimated around 4.34 million hectare with annual production of 4.95 million tonne (FAOSTAT, 2014). Most of the production (56 percent) is consumed locally and rest (44 percent) is supplied to the global market (Kumar *et al.,* 2013).

CLIMATIC CONDITIONS FOR CULTIVATION

Lentils are adapted for cultivation in cool climates and are tolerant of some light frost. It can grow on a wide variety of soils, ranging from sandy to clay loams, but grows optimally in a sandy, well-draining soil with a pH of 4.5 to 8.2. A soil pH of close to 7 is ideal. Lentils grow under a wide range of temperatures (6–27 °C); an optimum temperature for growth being 24 °C. Lentils do well in places with annual rainfall below 750 mm and a marked dry period before harvest. Lentils are generally rainfed but do well under irrigation. Though it can stand a wide rainfall distribution (300 to 2400 mm), lentils cannot bear waterlogging and should be sown at the end of the rainy season in warmer areas, where they can grow on residual moisture (Bejiga, 2006; Ford *et al.,* 2007).

ANTI-NUTRITIONAL FACTORS

Lentil seeds contain anti-nutritional factors such as protease inhibitors, lectins, phytic acid, saponins and tannins, though in moderate amounts (Blair, 2007). Heat treatment of seeds helps in reducing these anti-nutritional factors (Castell and Cliplef, 1990). Microwave cooking also helps in improving nutritional quality, and reducing anti-nutritional factors (Hefnawy, 2011).

LENTIL SEEDS AND ITS BY-PRODUCTS AS ANIMAL FEED

Cattle

Lentil seeds. Lentil seeds are a good source of protein (27 percent, DM basis) and starch (48 percent, DM basis) and thus considered as a nutrient-dense and versatile feed (Table 10.1). However, lentils are low in sulphur amino acids and

Table 10.1 Chemical composition of lentil and its by-products (percent, DM basis)

Parameter	Seeds	Screening	Bran	Pod husk	Straw
Crude protein	24.6–30.0	22.7–25.9	15.0–26.4	12.6	5.8–8.6
Ether extract	0.5–5.0	1.7–2.6	0.6–1.4	0.8	0.8–2.2
Crude fibre	2.9–7.7	5.3–19.4	8.4–32.2	29.0	29.9–41.8
NDF	8.1–27.4	20.9	48.6–53.0		42.8–71.0
ADF	3.3–6.3	10.9	35.9–48.6		27.1–51.3
Ash	2.7–6.8	3.8–10.7	2.8–9.8	3.5	6.0–11.2
Lignin	1.2–2.0		7.4		5.9–13.3
Calcium	0.06–0.23	0.20	0.51–0.82		1.50–3.01
Phosphorus	0.31–0.66	0.47	0.22–0.56		0.11–0.19

Notes: DM (as fed) is 87.1–91.0 percent for seeds, 87.9–90.4 percent for screenings, 87.6–91.1 percent for bran, 88.0 percent for pod husk, and 90.4–93.8 percent for straw.
ADF = acid detergent fibre; NDF = neutral detergent fibre.
Source: Feedipedia (2016).

tryptophan (Wang and Daun, 2006) and should therefore be supplemented with other protein sources when they are intended for feeding to monogastrics (Castell and Cliplef, 1990).

Lardy and Anderson (2009) suggested that lentil seeds are very palatable and the growth rate of the calves fed lentil containing diet was equal to those fed diets containing field pea (*Pisum sativum* L.) or chickpea (*Cicer arietinum* L.) . Organic matter digestibility and DMI were similar in beef cattle receiving diets containing either lentils, chickpeas or field peas, replacing maize and canola (*Brassica napus* L.) as the grain component in the diet (Gilbery *et al.*, 2007).

Lentil screenings. Lentil screenings are the by-product of cleaning lentil seeds. They may consist of whole and broken lentils, cereal grains, weed seeds, chaff and dust (Stanford *et al.*, 1999). Stanford *et al.* (1999) found that lentil screenings have a poor OM digestibility (55 percent) despite a fairly low NDF content (29 percent, DM basis) and a high CP (23 percent, DM basis). However, good quality lentil screenings can be a useful protein- and energy-rich feed because of the competitive price (Lardy and Anderson, 2009).

Lentil bran (hulls, *chuni*)

Lentil bran (called *chuni* in India) or lentil hulls are the outer envelopes of lentils resulting from dehulling operations. Its fibre content (22 percent, DM basis) is higher than those of the seeds and screenings. However, its composition can vary extensively as it depends on the proportions of envelopes and kernel fragments in the bran.

The *in vitro* DMD of lentil hulls (51 percent) was found to be lower than that of broad bean (*Vicia faba* L.) hulls (57 percent), but was higher than that of pea hulls (48 percent) (Mekasha *et al.*, 2002; Mekasha *et al.*, 2003). Yalçin, Cetinkaya and Sehu (1992) also observed that *in sacco* degradability of DM was lower for poor-quality lentil bran than for lentil screenings (30 vs 49 percent). Gendley *et al.* (2009) reported that the rumen fermentation was improved when bulls were fed a diet of 50 percent lentil bran and 50 percent wheat bran, compared either of these two alone in the diet.

Lentil straw

Lentil straw is the crop residue of lentil seed harvesting from the threshing process. It is rich in fibre (ADF >30 percent, DM basis) and low in protein (<10 percent, DM basis) though of a better quality than straws of small grain cereals such as wheat straw (Lardy and Anderson, 2009). Several studies have demonstrated that lentil straw has a lower NDF content, higher rumen degradability and a higher whole tract digestibility than cereal straws (López *et al.,* 2005; Singh *et al.,* 2011). *In vivo* OM digestibility values are between 47 and 55 percent (Dutta, Sharma and Naulia, 2004). Higher values, between 54 and 57 percent by *in vitro* methods, have been recorded (Denek and Deniz, 2004). In addition to different methods used for analysis, such differences may also be due to the variable leaf:stem ratio, which depends on the harvesting method. For instance, using *in vitro* gas production, a stem-rich lentil straw was found to have an ME of 6.7 MJ/kg DM vs 8.3 MJ/kg DM for a leaf-rich lentil straw (López *et al.,* 2005). Dutta, Sharma and Naulia (2004) observed that the nutritive value of lentil straw appeared to be no different from urea-treated wheat straw (4 percent, w/w). However, a positive synergistic effect was evident by feeding a mixture of lentil straw and urea-treated wheat straw on performance of lactating buffaloes.

Sheep and goats

Haddad and Husein (2001) observed that the palatability, nutrient digestibility and weight gain in Awassi ewe labs fed lentil straw were comparable to those fed alfalfa (*Medicago sativa* L.) hay, and higher than those fed bitter vetch [*Vicia ervilia* (L.) Willd.] straw or wheat straw. A DMI of 70 g/kg for lentil straw in sheep has been reported by Abreu and Bruno Soares (1998). Dutta, Sharma and Naulia (2004) also observed that the nutritive value of lentil straw appeared to be no different from urea-treated (4 percent, w/w) wheat straw. However, a positive synergistic effect was evident on performance of goats by feeding a mixture of lentil straw and the urea-treated wheat straw.

Pigs

Surplus and cull lentils are valuable feed for pigs as the levels of antinutritional factors are relatively low (Blair, 2007). However, due to low sulphur amino acid content in lentils, diet should be balanced with another protein source (Blair, 2007) or with synthetic amino acids. Lentil seeds could be included in growing-finishing pig diets at up to 40 percent without decreasing animal performance. However, this high an inclusion rate had deleterious effects on meat quality, and therefore a lower rate (10 percent) was recommended (Castell and Cliplef, 1988). Castell and Cliplef (1990) reported that supplementing the lentil-based diet with methionine (1 g/kg dietary level) resulted in better meat quality even at 40 percent lentil inclusion rate. In starter pigs, replacement of soybeans [*Glycine max* (L.) Merr.] with lentils may be cost-effective but the inclusion rate should not exceed 22.5 percent in the diet, because higher levels decreased animal performance and feed conversion efficiency (Landero, Beltranena and Zijlstra, 2012).

Poultry

Though the nutritional value of lentils in poultry is lower than that of mung bean [*Vigna radiata* (L.) R. Wilczek] or chickpea (Wiryawan *et al.*, 1995), lentils are occasionally used in poultry diet (Blair, 2008), with supplementation of sulphur amino acids (Wiryawan, 1997).

Broilers. Farhoomand (2006) included raw or processed (heated followed by boiling) lentils in broiler diets at a concentration of 10, 20 and 30 percent. Growth was best with 10 percent and lowest with 30 percent levels. Processing did not confer any advantages. The authors suggested that lentil seeds could be used in broiler diets up to 20 percent but not as the sole source of protein. For broilers, lentils should be used in carefully formulated diets, with consideration given to the amino acid levels.

Layers. Kiliçalp and Benli (1994) reported that the use of lentils in layers diets led to decreased egg production even at low inclusion rates (5 percent). Lentils might be used in layer diets because of low-price opportunities, but it is essential to balance the amino acid content of the diet.

SUMMARY

Lentil seeds are a good source of protein and energy, but low in sulphur amino acids. Lentil seeds and by-products (screenings and bran) can be incorporated in ruminant feeding. Lentil straw can also be used in large and small ruminant diets. Inclusion rate of lentil seeds should not exceed 10 percent in growing-finishing pig diets. Lentil seeds can be included up to 20 percent in broilers ration, but are not recommended in layer rations. Amino acid supplementation is recommended, when lentil seeds are used in pig and poultry diets.

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Chapter 11
Common vetch

COMMON NAMES

Common vetch, garden vetch, tare, the vesce (English); vesce commune, vesce cultivée (French); veza, alverja común (Spanish); ervilhaca (Portuguese); voederwikke (Dutch); Futterwicke, Saatwicke (German); veccia comune (Italian).

DISTRIBUTION

The common vetch (*Vicia sativa* L.) is native to Southern Europe (Frame, 2005). It is now cultivated throughout the Mediterranean, West and Central Asia, China, Eastern Asia, India and the United States of America.

DESCRIPTION

The common vetch is a scrambling annual herb growing up to 2 m tall. Its stem is four-angled and sometimes hairy and can be branched, unbranched, climbing or decumbent (trailing along the ground). It has a slender highly branched taproot that can go down to 1 to 1.5 m deep. Its stems are thin, angled, procumbent and branched, reaching up to 2 m. The leaves are composed of 3–8 pairs of opposite leaflets and a terminal 2–3 branched tendril that assists the climbing habit. The leaflets are elliptic or oblong, 1.5–3.5 cm long, 5–15 mm wide. Stems and leaves are mainly glabrous. The flowers, borne in leaf axils, are blue to purple, sometimes white, mostly paired, sometimes single. Pods are cylindrical, 3.5–8 cm long and erect; with 4–12 round but flattened, black to brownish seeds (UC SAREP, 2006; FAO, 2010).

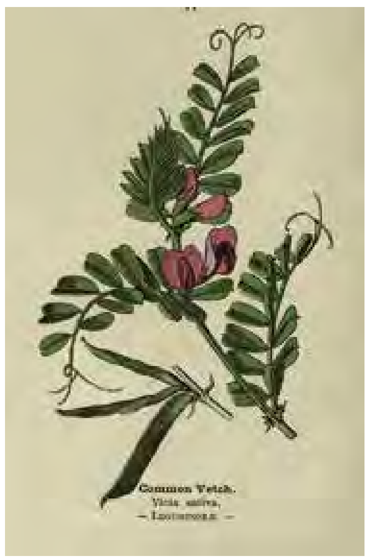

*Photo 11.1.1 Coloured line drawing of common vetch (*Vicia sativa* L.) showing pods and flowers*

CLIMATIC CONDITIONS FOR CULTIVATION

The common vetch is moderately tolerant of cold and can grow in areas with mild winters (UC SAREP, 2006). It grows on a wide range of soils. It does well on loams, sandy loams, or gravelly soils, as well as on fine-textured clay soils as long as there is good drainage. It can tolerate soil pH of 5.5–8.2, but optimum pH is 6.5. Although common vetch tolerates short periods of saturated soils, it does not tolerate extended waterlogging. It is found in areas with annual rainfall ranging from 310 to 1 630 mm. It does not tolerate drought during the early stages of establishment, and it is advisable to plant it in autumn (UC SAREP, 2006; FAO, 2010).

Table 11.1 Chemical composition of common vetch and its by-products (percent, DM basis)

Parameter	Seeds	Aerial fresh	Hay	Straw
Crude protein	14.7–35.8	12.5–35.9	16.9–22.5	6.0–8.3
Ether extract	0.9–3.0	1.2–3.1	0.7–2.4	1.2–1.5
Crude fibre	4.2–5.7	21.3–35.1	20.4–28.5	34.4–41.5
Ash	2.4–7.5	4.8–12.0	9.0–12.3	8.7–12.3
NDF	13.6–21.7	13.1–46.6	27.1–47.8	56.0–64.7
ADF	3.8–9.6	24.3–33.7	20.6–35.2	39.0–45.8
Lignin	0.9	6.1	4.4–8.5	7.4–10.4
Calcium	0.04–1.38	0.49–1.51	1.11–1.79	1.30–2.12
Phosphorus	0.37–0.60	0.26–0.61	0.09–0.70	0.07–0.22

Notes: DM (as fed) is 75.0–91.0 percent for seeds, 16.2–25.8 percent for aerial fresh, 84.8–92.8 percent for hay, and 90.1–92.0 percent for straw.
ADF = acid detergent fibre; NDF = neutral detergent fibre.
Source: Feedipedia (2016).

ANTI-NUTRITIONAL FACTORS

Common vetch seeds contain anti-nutritional factors such as cyanogenic amino acids, and cyanogenic glycosides that are toxic to monogastric animals. Therefore, its use in pigs and poultry is restricted (Tate and Enneking, 2006). The mature seed contains the neurotoxin gamma-glutamyl-beta-cyanoalanine, which affects the conversion of methionine to cysteine, and has indirect effects on glutathione metabolism (Collins *et al.*, 2002). The toxins damage the nervous system, with signs such as convulsion and leg paralysis. However, several varieties of common vetch have low levels of this toxin. For example, cyanoalanine concentrations of 9–12 g/kg and ~13 g/kg have been reported in cultivars Blanchefleur and Languedoc, respectively, while common vetch cv. Morava is reported to contain cyanoalanine levels of less than 7 g/kg (Collins *et al.*, 2002). Thus, it would make possible to include seed of low cyanogenic content genotypes in pig and poultry diets (Tate and Enneking, 2006). Post-harvest detoxification treatments such as mild acid hydrolysis have proved to be effective, but are costly (Enneking, 1995).

Generally, common vetch forage does not contain anti-nutritional factors when it is grazed or cut frequently enough to prevent flowering and seed-heading. However, some cases of poisoning of ruminants consuming common vetch forage have been reported. The symptoms of poisoning include severe dermatitis, skin oedema, conjunctivitis, corneal ulcers and diarrhoea. Occasional death of animals has also been reported (Suter, 2002; Mayland *et al.*, 2007).

FEEDING OF SEEDS AND ITS BY-PRODUCTS

Ruminants

Common vetch seeds. Valentine and Bartsch (1996) observed reduction in milk yield, fat and protein on supplementation with a barley+common vetch grain mixture (1:1; 8 kg/day, fresh basis) in dairy cows, but there was no reduction in feed intake or liveweight gain. The milk can become bitter if dairy cows are fed 2 kg/day of common vetch seed, and the taste of vicine and convicine passes into the milk, which renders it unsuitable for both direct consumption and cheese production. Common vetch-related deterioration of milk quality can be easily monitored by taste analysis and may be transitory in nature. The milk obtained from animals unaccustomed to feeding on diets containing common vetch grain should be tested for the presence of vicine as well as beta-cyanoalanine and gamma-glutamyl-beta-cyanoalanine and their metabolites. A maximum feeding rate of 3 kg/head/day is recommended by Enneking (1995).

Gül *et al.* (2005a) observed that the supplementation of common vetch seeds to diets of Awassi lambs at 0, 15 and 25 percent rates showed no statistical differences in fattening performance, wholesale cuts of carcasses, meat colour parameters and pH values, but there was improvement in feed conversion efficiency.

Common vetch forage. Common vetch provides palatable forage (fresh, hay or silage) for livestock. Common vetch may be sown in pure stands or mixed with a cereal companion that helps it to climb and thus precludes rotting during winter. Biomass yields in pure stands or in mixed pastures range from 1 to 6 tonne DM/ha in the Mediterranean basin (FAO, 2010) and up to 8 tonne DM/ha in the United States of America (Sattell *et al.,* 1998). Common vetch is tolerant of short cutting before flowering and to high cutting at flowering (Sattell *et al.,* 1998). Fresh common vetch at early flowering has a protein content of about 24 percent (DM basis), and OM digestibility in sheep is 74 percent. Nutritive value decreases with maturity but digestibility remains relatively high (69 percent) at the mature seed stage (Sattell *et al.,* 1998).

Common vetch hay. Common vetch hay is a valuable forage with an OM digestibility of 69 percent and a CP content close to 20 percent (DM basis; Table 11.1). Haj Ayed *et al.* (2001) observed that common vetch hay shows a progressive decrease in digestibility and degradability as its vegetative structures mature, unlike winter vetch (*Vicia villosa* Roth), which benefits from a compensatory effect produced by increasing grain proportions as the plant ages. The nutritive value at flowering was higher for common vetch hay than for winter vetch hay, but the opposite was observed at maturity. Voluntary DMI was not affected by the species or harvest stages (Haj Ayed *et al.,* 2001). Haj Ayed *et al.* (2001) observed that *in sacco* N degradability is quite high at flowering (78 percent effective degradability) and decreases with maturity (65 percent at seed filling). At seed filling, the high rumen bypass protein and low ratio of "structural carbohydrates:non-fibre carbohydrates" suggests that common vetch forage should be harvested at this stage (Caballero *et al.,* 2001).

Berhane and Eik (2006a) observed that common vetch hay supplementation (0, 0.5, 1.0 and 1.5 percent BW) lineary increased milk yield by up to 50 percent, but decreased percent fat and total solids in milk of both Begait and Abergelle goats. Berhane and Eik (2006b) also observed that kid weight at birth, at 90 days and 270 days also increased significantly with this level of supplementation.

Common vetch silage. Field wilting or silage additives are required to prevent poor silage production due to low concentrations of water-soluble carbohydrates and the high buffering capacity of common vetch (Kaiser, Dear and Morris, 2007).

Common vetch straw. Common vetch straw has a nutritive value higher than that of cereal straws (barley, oat or wheat), with an OM digestibility of 53 percent and a CP content >6 percent (DM basis). The energy value of common vetch straw is close to that of ammonia-treated cereal straws and the N value is intermediate between that of untreated and ammonia-treated cereal straws (Tisserand and Alibes, 1989).

Pigs

Common vetch seeds are a potential alternative protein source for pigs due to their high protein and lysine content. However, their use in pig feeding has been limited by the detrimental effects of their toxins on feed intake and growth performance. Enneking (1995) observed that maximum safe levels for common vetch seeds could be up to 20 percent for growing pigs and 10 percent for piglets. The author has also noted that the contents of cyanoalanine and cynogenic glycosides differ amongst individual cultivars and hence the safe feeding of common vetch seeds depends on the cultivar used.

In Australia, low-cyanoalanine varieties have been marketed as suitable for pigs up to 35 percent of the diet, though even a 10 percent inclusion rate was considered to be encouraging enough to lead to an increased planting of this species (Enneking, 1995). The Morava cultivar, which contains very low levels of cyanoalanine (less than 7 g/kg) was tested successfully in the early 2000s. It was possible to include it in the diet up to 22.5 percent for growing pigs (41 to 65 kg BW), without affecting growth performance, and at less than 15 percent for finishing pigs. Higher rates caused significant decreases in feed intake and growth. The total tract apparent digestibility of energy was 14.3 MJ/kg (Seabra *et al.*, 2001; Collins *et al.*, 2002; Collins *et al.*, 2005a; Collins *et al.*, 2005b). In Poland, a low-vicianine common vetch cultivar was used in pig finishing diets at 15–18 percent. It partly replaced soybean meal in the first stage of finishing (from 40 to 70 kg BW) and completely in the finishing stage. Weight gains of about 800 g/d and a feed conversion ratio of 3.08 were observed (Potkanski *et al.*, 1999)

Poultry

Common vetch seed has been used as an alternative source of protein in poultry diets (Darre *et al.*, 1999). Raw seeds are detrimental for poultry species (Saki *et al.*, 2008) due to presence of anti-nutritional factors that interfere with efficient utilization of common vetch, such as beta-cyanoalanine, vicine, concivine and tannins (Abdullah *et al.,* 2010). The incorporation of untreated common vetch seeds at higher than 15 percent in broiler diets and 20 percent in layer diets decreased their performance (Gül *et al.,* 2005b).

Broilers. Devi *et al.* (1997) reported that replacing 25 or 50 percent of the dietary protein by proteins from common vetch seeds resulted in a significant reduction in weight gain and feed intake in young chicks. This negative effect increased with increase in the seed protein level in the diet. Darre *et al.* (1999) reported that growth rate and feed utilization in young broilers were not affected while supplementing 10 percent cooked and raw seeds, from a low beta-cyanoalanine variety. Cooked and raw seeds had deleterious effects on body weight gain when used at 20 percent or more in broiler diets, and a maximum of 10 percent was recommended by Saki *et al.* (2008). About 60 percent unprocessed common vetch seeds in the diet were detrimental to broilers, and caused 100 percent mortality (Farran *et al.,* 2001).

Farran *et al.* (2001) observed that soaking the seeds in acetic acid at room temperature resulted in no detrimental effects on broiler performance at a 60 percent inclusion rate, though processing did not prevent metabolic disorders from occurring. Sadeghi, Tabeidian and Toghyani (2011) observed that unprocessed common vetch seeds can be used up to 10 percent in grower diets of broiler chickens. The processing of seed (soaking the seeds in water (1:1, w/v) at room temperature for 10 hours, or cooking at 95 °C for 90 minutes, again washing, cooking at 95 °C for 93 minutes, and finally sun drying) could improve the nutritional value of seeds because the productive performance of birds fed 20 percent of processed seeds was similar to that of control birds.

Layers. A number of studies have highlighted the detrimental effect of unprocessed common vetch seeds on layer health and performance (Gül *et al.,* 2005b; Kaya 2011). Hens given diets containing 10 percent common vetch ate less feed and produced fewer eggs. The reduction in feed intake was high compared with the drop in egg production, but the specific gravity of eggs increased. Hens fed on diets with 5 percent common vetch seeds had a significant increase in the yolk index. Other indicators of egg quality, as well as serum calcium and inorganic phosphorus levels, were similar between groups. Processing can help to increase the inclusion rate of common vetch seeds in layers diets. Autoclaved common vetch seeds could be included up to 25 percent in diets of layers (Farran *et al.,* 1995). Gül *et al.* (2005b) showed that raw common vetch seeds fed at 22 percent level are detrimental to laying performance and egg quality. Kaya (2011) reported that soaked (in water for 72 hours) and boiled (100 °C for 30 minutes) common vetch seeds may safely be used up to the 25 percent level in rations for laying hens.

SUMMARY

Common vetch provides palatable forage, having about 24 percent protein (DM basis). Forage at mature seed stage also has 69 percent organic matter digestibility. Common vetch straw contains more than 6 percent protein (DM basis), with 53 percent digestibility. Common vetch hay is valuable forage for small and large ruminants. Feeding of common vetch seeds can be recommended up to 3 kg/day in dairy cattle. Maximum safe levels for common vetch seeds could be up to 20 percent for growing pigs and 10 percent for piglets. Raw and processed (soaking and cooking) seeds can be included up to 10 and 20 percent, respectively in broilers diet. Processed seeds may safely be used up to 25 percent level in laying hens.

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Chapter 12

Lupins

LATIN AND RESPECTIVE COMMON NAMES

Lupinus albus: white lupin; *Lupinus angustifolius*: Australian sweet lupin, blue lupin or narrow-leaved lupin; *Lupinus luteus*: yellow lupin; *Lupinus mutabilis*: Andean lupin, chocho, pearl lupin, tarwi (English); lupin blanc (French); weisse lupine (German); lupino bianco (Italian); altramuz blanco, chocho, chorcho,entremozo, lupino blanco (Spanish); tremoceiro, tremoceiro branco, tremoceiro da Beira, tremoço (Portuguese).

DISTRIBUTION

It has long been known that lupins (different species of the genus *Lupinus* L.) were domesticated independently as pulse crops in both the Mediterranean and the Andes (Gladstones, Atkins and Hamblin, 1998). Lupins are currently grown as forage and pulse in the Russian Federation, Poland, Germany, the Mediterranean, and as a cash crop in Australia, where it is exported to the European seed markets. Both winter-hardy and non-hardy types are available. White lupin (*Lupinus albus* L.) is thought to have originated in southeastern Europe and western Asia (Jansen, 2006). The wild type [*Lupinus albus* subsp. *graecus* (Boiss. and Spruner) Franco and P. Silva] is found in southeastern Europe and western Asia. The modern cultivars of blue lupin (*Lupinus angustifolius* L.) is an established feed resource for the intensive animal industries of Australia, Japan, Korea and several other countries in Asia and Europe (Petterson, 2000).

DESCRIPTION

There are over 300 species of the genus *Lupinus*, but many have high levels of alkaloids (bitter tasting compounds) that make the seed unpalatable and sometimes toxic. Historically, lupin alkaloids have been removed from the seed by soaking. But plant breeders in the 1920s in Germany produced the first selections of alkaloid-free or "sweet" lupin, which can be directly consumed by humans or livestock (Gladstones, Atkins and Hamblin, 1998). Cultivated species of lupin used in animal feeding worldwide are white lupin, blue lupin and yellow

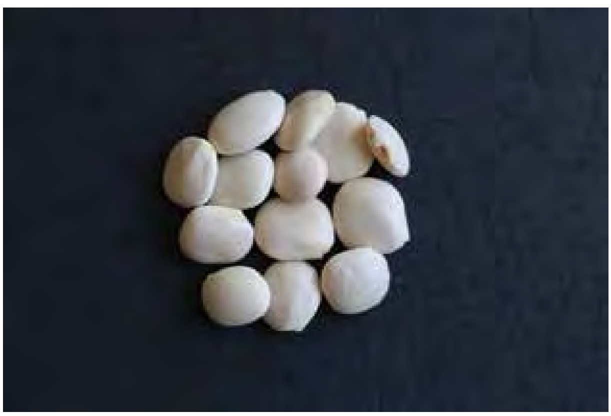

*Photo 12.1.1 Seeds of Andean lupin (*Lupinus mutabilis *Sweet)*

lupin (*Lupinus luteus* L.), which all originated from the Mediterranean area (Kim, Pluske and Mullan, 2007). There is also increasing interest in using the Andean lupin (*Lupinus mutabilis* Sweet) in diets for pigs because of its high protein (43 percent, DM basis) and oil (18 percent, DM basis) contents compared with other lupin species (Kim, Pluske and Mullan, 2007).

White lupin has flowers that are white to violet-blue. The seed is flat, has a whitish seed coat and typically weighs about 350 mg (Petterson, 2000). Blue lupin has flowers that are normally blue and hence its common name. In the 1960s, the leucospermus gene for white-flowered and white-seeded sweet, low-alkaloid, types was successfully introduced (Gladstones, Atkins and Hamblin, 1998). At present about 12 varieties of blue lupin are available for use. To minimize confusion and to differentiate these varieties from others, it is often also referred to as Australian sweet lupin. Yellow lupin has golden yellow flowers. A typical seed weight is about 120 mg, and it is more ellipsoid in shape than seed of blue lupin (Petterson, 2000).

Lupins are annual upright plants with coarse stems and medium-sized finger like leaves. In thin stands they branch quite freely. White lupin is a non-native, annual legume, reaching heights up to 120 cm. It has a strong taproot penetrating over 0.6 m into the soil (Brebaum and Boland, 1995). Leaves are alternate and compound with 5–9 leaflets, nearly smooth above and hairy beneath. Individual plants produce several orders of inflorescences and branches, resulting in clusters of long, oblong pods, each cluster having 3–7 pods, and each pod containing 3–7 seeds.

CLIMATIC CONDITIONS FOR CULTIVATION

Lupin is a cool-season crop, and is relatively tolerant to spring frosts. Early planting is ideal due to the plants' cold tolerance. Lupin can tolerate temperatures of -9 °C. Minimum soil temperatures at planting should be 7–10 °C. Flowering is a critical stage in lupin production. Early planting is a method to avoid these higher temperatures at flowering (GGI, 2003). The flowering process is affected by high temperatures, which cause blasting of flowers and a subsequent yield reduction. In areas that normally experience high temperatures in early summer, such as many parts of southern Minnesota and Wisconsin, the risk to the crop is high. Lupin is adapted to well-drained, coarsely textured, and neutral-to-acidic soils. Iron chlorosis and disease problems often result from plantings on poorly drained, high pH soils. Reports from Minnesota, New York and parts of New England indicate that many lupin production problems are due to planting on soils too heavy, too wet, or too high in pH (USDA, 2014).

PRODUCTION OF LUPIN SEEDS

The major producers of white lupin seed are Australia, Europe, South Africa, the Russian Fderation, Australia and the United States of America. The world producer and exporter of lupin seed is Australia, whose production represents

Table 12.1 Chemical composition of lupins and their by-products (percent, DM basis)

Parameter	Seeds, white	Seeds, blue	Seeds, yellow	Aerial fresh, white	Straw, white	Straw, yellow
Crude protein	35.8	29.8–37.7	34.4–48.4	18.3–27.9	5.9	6.7
Ether extract	9.4	4.7–7.2	4.6–6.3	2.6–3.6		
Crude fibre	10.6	13.1–20.0	13.5–20.2	17.1–28.1	55.3	49.9
Ash	3.3	2.9–4.3	3.6–6.5	6.3–13.9	4.1	4.7
NDF	17.6	20.3–30.6	21.6–28.6	31.1	82.4	88.6
ADF	14.6	17.9–24.5	18.4–24.6	25.6	63.8	58.3
Lignin	0.7	0.3–3.5	1.4–4.9	4.1	12.6	9.9
Calcium	0.20	0.22–0.42	0.29	1.26–1.28	0.43	0.66
Phosphorus	0.36	0.29–0.47	0.92	0.25–0.27	0.10	0.12

Notes: DM (as fed) is 91.4 percent for white seed, 87.7–92.4 percent for blue seed, 85.5–91.5 percent for yellow seed, 11.1–92.0 percent for white aerial fresh, 90.3 percent for white straw, and 90.5 percent for yellow straw.
ADF = acid detergent fibre; NDF = neutral detergent fibre.
Source: Feedipedia (2016); Kim, Pluske and Mullan (2007).

80–85 percent of global production, of which 90–95 percent is exported (White, Staines and Staines, 2007). Approximately 40 percent of the exported lupin seed is used as feed for dairy and meat-type cattle, 40 percent as feed for pigs and the rest is equally distributed for the nutrition of sheep, goats and poultry (White, Staines and Staines, 2007).

NUTRITIONAL VALUE

Among legume seeds, lupin seeds are one of the richest (Kohajdova, Karovičova and Schmidt, 2011). Chemical composition of lupin is influenced by species. Lupins are a good source of nutrients, not only proteins but also lipids, dietary fibre, minerals, and vitamins (Martinez-Villaluenga *et al.*, 2009). Sweet white lupin is high in CP (32–38 percent, DM basis) and total digestible nutrients (75–80 percent), low in oil (10 percent, DM basis), and does not contain trypsin inhibitors. Their high protein content makes them a valuable resource for feeding to monogastric and ruminants because they are cost competitive against a wide range of other protein sources. Furthermore, their low levels of starch and high levels of fermentable carbohydrate make them a highly desirable ruminant feed due to the low risk of acidosis. The comparatively high levels of soluble and insoluble non-starch polysaccharides can influence the utilization of other nutrients in lupins and hence they must be used strategically if livestock production responses are to be optimized. In addition, because of comparatively low levels of the sulphur amino acids, methionine and cysteine, in lupin seeds, supplementation with other proteins or synthetic amino acids are required, particularly in monogastric diets (USDA, 2014).

Although lupins are relatively high in protein (Table 12.1), the biological value of the protein is limited due to relatively low levels of methionine and lysine. However, low levels of these amino acids are of little or no consequence to ruminants where the protein is mostly rumenant fermented. In pig and poultry diets these shortfalls can be made up from other proteins or synthetic amino acids. Lupin is among eight potential vegetable sources of protein for use in feed and food that replace proteins of animal origin in the diets (Dijkstra, Linnemann and van Boekel, 2003).

ANTI-NUTRITIONAL FACTORS

Anti-nutritional factors in lupin seeds include non-starch polysaccharides, oligosaccharides, trypsin inhibitors, chymotrypsin inhibitors, tannins, saponins, phytin and alkaloids. Levels of these anti-nutritional factors in seeds of recent cultivars of lupin are similar to the levels found in soybean [*Glycine max* (L.) Merr.] meal, and can be considered low enough for use in pig diets without problems, except oligosaccharides and alkaloids (Kim, Pluske and Mullan, 2007).

More than 170 alkaloids of the quinolizidine group have been identified in different *Lupinus* species (Wink, 1988; 1993b), which act as part of a defence strategy against herbivores and micro-organisms (Wink, 1983; 1992). The main structural types of quinolizidine alkaloids belong to the groups lupinine, sparteine/lupanine/multi-florine, α-pyridone, matrine, Ormosia, piperidine and dipiperidine alkaloids (Kinghorn and Balandrin, 1984; Wink, 1993a). Sparteine and lupanine are the most widely distributed quinolizidine alkaloids in the genus *Lupinus* (Wink, Meissner and Witte, 1995). The presence of quinolizidine alkaloids and some anti-nutritional factors results in characteristically bitter taste, rendering the crop unacceptable for food/feed (Martini *et al.,* 2008; Erbas, 2010).

Chemical treatment of lupin grain is the most common processing method suggested to reduce alkaloid content of the crop (Arslan and Seker, 2002). The bitter varieties of lupins contain a toxic alkaloid and should not be fed to animals unless the alkaloid is removed by soaking in water (Feedipedia, 2016). Since most alkaloids in white lupin are water-soluble, the alkaloid levels can be decreased by soaking them in running water, brine, or scalding water (Erbas, Certel and Uslu, 2004). The sweet (alkaloid-free) genotypes, which can be distinguished by taste and smaller growth, are palatable to livestock. Sweet lupins are largely free of anti-nutritional factors such as trypsin inhibitors, lectins and saponins. White lupin seeds are generally classified as sweet or bitter depending on the alkaloid content, which ranges from 0.01 to 4 percent (Bhardwaj and Hamama, 2012). To overcome the anti-nutritional properties of lupins, plant breeding programmes have selected cultivars with almost zero alkaloid content, and current lupin cultivars are largely alkaloid free (Nalle, Ravindran and Ravindran, 2011).

When animals graze lupin stubble, a disease called lupinosis can develop. Lupinosis is a liver disease mainly caused by the consumption of lupin stalks colonised by the fungus *Diaporthe toxica.* Symptoms are loss of appetite and jaundice. Lupinosis has been a problem in sheep grazing in Australia and in Europe (Crowley and CAS burn, 2013).

FEEDING OF SEEDS AND ITS BY-PRODUCTS

Ruminants

Lupin seeds. Allan and Booth (2004) reported the apparent CP and OM digestibilities of lupin grain as 91 and 50 percent, respectively. Higher digestibilities (percent) of CP (80.8), ether extracts (57), crude fibre (45.5), NDF (60.2) and ADF (57.8) were found for lupin compared with extracted soybean meal (Pisarikova *et al.*, 2008). Similarly, Tadele, Mekasha and Tegegne (2014) reported CP digestibility as 81, 87 and 89 percent, respectively, for roasted coarsely ground, roasted soaked, and roasted soaked coarsely ground lupin grains in washera sheep fed natural grass hay as a basal diet.

Supplementation of ruminant diets with lupins has been shown to have many positive effects in terms of growth and reproductive efficiency, comparable with supplements of cereal grain (van Barneveld, 1999). Marley *et al.* (2008) observed no significant differences in the milk yield or milk composition from dairy cows fed concentrate diets containing either yellow lupins or soybean meal during 5 and 12 weeks of lactation, indicating that yellow lupins could be used as an alternative to soybean in dairy diets. Yilkal, Mekasha and Tegegne (2014) observed that supplementation of 30 percent (DM basis) roasted (at 145 °C for 12 min), soaked (in running water for 5 days) and coarsely ground lupin grain showed better nutrient utilization, response in live weight gains and carcass parameters in washera sheep. Tefera *et al.* (2015) also observed that supplementation with roasted white lupin grains significantly improved total DMI, nutrient digestibility, average daily gain, feed conversion efficiency, and carcass quality in sheep.

Lupin forages. White lupin is a valuable multipurpose crop which has the ability to maintain soil fertility and serve as a source of feed (Yeheyis *et al.*, 2010). The crop is an excellent protein and energy source for ruminants. It can be fed as whole plant silage, and even as hay. Azo *et al.* (2012) studied the use of white lupin in organic production and lupin+cereal mixtures. They found that bi-cropping lupin with cereals was successful and gave good forage yields. The combination of Dieta white lupin and spring wheat or spring triticale was most successful in yield and protein content. Also, harvest dates are as crucial as seeding rates for lupin+cereal forage because time of harvest determines the stage of maturity and therefore forage quality. Harvesting between 116–130 days is recommended by Azo *et al.* (2012). McKenzie and Spaner (1999) also suggested that white lupin can be used as an alternative legume in oat-legume green chop mixtures on mineral soils in Newfoundland, Canada.

Bhardwaj, Starner and Van Santen (2010) studied the potential to use white lupin as a forage crop in the Mid-Atlantic region of the United States of America. From preliminary evaluation they found that white lupin forage has an average of 18.7 percent protein (DM basis), and has potential as a forage crop in this region and compared quite well with alfalfa. Sweet cultivars of lupin are used for feeding livestock. These can be used as fresh fodder, dry fodder, whole plant silage or hay (Jansen, 2006). Introduction of fodder lupin varieties with alkaloid content of less than 0.01 percent minimizes the anti-nutritional effect of alkaloids on palatability, consumption and feed utilization.

Pigs

The major constraint of whole lupin seeds as a source of protein in pig diets is the low concentrations of lysine, methionine+cysteine, threonine, valine and tryptophan when compared with other protein sources such as soybean meal, canola meal, fish meal or meat and bone meals (Fernandez and Batterham, 1995; Wasilewko *et al.,* 1999). Blue lupins are currently utilized as a valuable protein source in pig diets.

In general, simple replacement of other protein sources, such as soybean meal, by lupin seeds without adjustment for apparent ileal-digestible essential amino acids showed an inferior response, mostly caused by the low lysine and methionine+cysteine contents in lupins (McNiven and Castell, 1995). However, if the lupin seed diets fed to pigs were formulated based on equal amounts of apparent ileal digestible amino acids, performance response of pigs fed lupin seed based diets were comparable or superior to the pigs fed soybean-meal-based diets (Fernandez and Batterham, 1995; Gdala *et al.,* 1996; Bugnacka and Falkowski, 2001; Roth-Maier, Bohmer and Roth, 2004).

Research suggests that low alkaloid cultivars of blue or yellow lupins could completely replace soybean meal in pig diets without adversely affecting growth (Gdala *et al.,* 1996; Mullan, van Barneveld and Cowling, 1997; Kim, Pluske and Mullan, 2007), while white lupin was not suitable for inclusion in diets (Gdala *et al.,* 1996; King *et al.,* 2000). Feeding white lupin to pigs was associated with reduced feed intake, owing to extended retention time in the stomach, and reduced growth rate, feed conversion efficiency and nitrogen retention (Gdala *et al.,* 1996; King *et al.,* 2000). van Nevel *et al.* (2000) also observed that inclusion of 15 percent white lupin in growing pig diets significantly decreased feed intake and daily gain. Kim *et al.* (2010) also observed that the Mandelup genotype of blue lupin can be used in grower/finisher diets up to 35 percent without compromising growth, carcass composition or meat quality of pigs.

Poultry

Broilers. Experimental work has shown that broiler chickens can tolerate up to 25 percent of low-alkaloid lupin-seed meal without adversely affecting growth, provided there are adequate supplements of lysine and methionine. However, in practice, inclusion of either blue *or* white lupin in broiler chicken diets should not exceed 10 percent. This is due to the incidence of wet-sticky droppings that may be promoted by high levels of lupin non-starch polysaccharides (Brenes *et al.,* 1993; Edwards and van Barneveld, 1998). Farrell, Pérez-Maldonado and Mannion (1999) recommended an optimum inclusion rate of up to 10 percent sweet lupin seed in broilers diet.

Roth-Maier and Paulick (2003) concluded that up to 20 percent yellow lupin seed can be included in broiler diets as replacement for soybean meal without impairing growth performance and feed-to-gain efficiency, when amino acid supplementation is adjusted. Rubio, Brenes and Centeno (2003) studied the effects of whole (not heat treated) or dehulled sweet (low in alkaloids) lupin seeds (40 and 32 percent, respectively) in broiler diets. Body weight was lower on feeding whole seed; however it was similar on feeding dehulled seeds. Smulikowska *et al.* (2014) recommended that inclusion of sweet lupins at a 15 percent level can be accepted in older broiler diets provided with adequate amino acid and fat supplementation.

Layers. Steenfeldt, González and Bach Knudsen (2003) reported that incorporation of blue lupin up to 20 percent in broiler diets did not reduce feed intake compared with a control; however, incorporation significantly depressed weight gain and feed conversion efficiency. They also reported that the use of an exogenous enzyme extract (lactase and galactanase) significantly improved digestibility and weight gain. Gebremedhn *et al.* (2014) reported that replacing processed (roasted at 145 °C for 12 minutes) lupin seeds (at 25, 50, 75 and 100 percent) for soybean meal (by weight; isocaloric and isonitrogenous) reduced cost of egg production and improved poultry egg productivity. Williams, Ali and Sipsas (2005) observed that by using commercially available pectinase (polygalacturonase), feed manufacturers should be able to use up to 20 percent whole lupins in layer diets. Inclusion of blue lupins in the diet of laying hens at a rate of 15 percent DM resulted in no adverse effects on egg production or hen health and could be used as part of a balanced ration with inclusion of enzymes (lactase and galactanase) to reduce reliance on soybean protein (Lee *et al.*, 2016).

SUMMARY

White (*Lupinus albus* L.), yellow (*Lupinus luteus* L.) and blue lupin (*Lupinus angustifolius* L.) are cultivated as crops. Currently, alkaloid-free variants of blue lupin are cultivated in Australia – the world's largest producer and exporter of lupin seeds. Lupin seeds are relatively high in protein (32–40 percent, DM basis). However, due to low levels of methionine and lysine, their inclusion in monogastric diets should be accompanied by supplementation with other proteins or synthetic amino acids. Processed (roasted, soaked) white lupin seeds can be used up to 30 percent in ruminant diet. Lupin forage can be used as fresh fodder, dry fodder, whole plant silage or hay for livestock feed. Blue lupin can be used up to 35 percent in the diet of pig. Inclusion of blue lupins at 15 percent level is recommended in poultry diet. Andean lupin (*Lupinus mutabilis* Sweet) is cultivated for human consumption in some regions of South America, but unfortunately there is almost no published information regarding its use as feed.

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Chapter 13
A synthesis

Pulse-based food is an important source of dietary protein and essential minerals, particularly for the vegetarian population in developing and developed countries. Pulses are of particular importance for food security – and more importantly nutrition security – particularly in regions where, for cultural reasons, the major sources of protein for humans are plants. Pulses are a relatively inexpensive source of protein when compared with most other protein sources. In addition to enhancing food and nutrition security directly, pulse crops also provide valuable by-products for animal feeding, which do not compete with human food, and thus indirectly contribute to food security. Pulse crops are becoming a cornerstone of sustainable agriculture due to their ability to enhance the nitrogen cycling of farming systems. In multiple cropping systems, besides enhancing soil fertility, pulses are able to improve yields and contribute to making a more rational use of nitrogen fertilizers while mitigating climate change (Calles, 2016). Several pulses are also resilient to adverse climate such as drought and heat, and grow in dryland regions of the world. This makes them important food crops that adapt easily to the rising temperatures, increasingly frequent droughts and other vagaries under the changing climate of the planet.

Pulses make a positive contribution to reducing greenhouse gas emissions (ICRISAT, 2016). It is also particularly remarkable that pulses have a very low water footprint compared with other protein sources, and can be grown in very poor soils where other crops cannot be cultivated (Nemecek *et al.*, 2008). Furthermore, pulses play an important role in climate change adaptation, since they have a broad genetic diversity from which climate-resilient varieties can be selected and/or bred. Thus, pulses are considered as smart food crops that can play a major role in addressing global food security and environmental challenges, as well as contribute to healthy diets.

This document outlines the various pulse crops and their by-products, their origin and regional distribution, description of plants along with their climatic conditions for cultivation, chemical composition, anti-nutritional factors, level and effect of their feeding in cattle, sheep, goats, pigs and poultry.

Globally, pulse production is estimated to have been about 76 million tonne in 2012 (FAOSTAT, 2013), which results in the availability of a large quantity of their by-products for use as animal feed. Pulses and their by-products are important for animal nutrition because they are excellent sources of amino acids, although content of some essential amino acid such as methionine is lower in pulses when compared with soybeans [*Glycine max* (L.) Merr.], fish meal and the FAO reference protein for 2–5-year-old children (Makkar *et al.*, 2014; Table 13.1). Carbohydrate levels are also high, which supply energy to

Table 13.1. Amino acids composition of commonly available pulses versus soybeans, fish meal and the FAO reference protein (g/16 g N)

Amino acids (% protein)	Common bean	Lima bean	Mung bean	Rice bean	Broad bean	African yam bean	Bambara bean	Pea
Alanine	3.0–5.3	0.5–5.6	3.1–3.7	3.9–6.0	3.4–4.5	3.9–4.6	4.4	4.0–5.1
Arginine	4.9–9.2	2.4–6.9	3.4–7.3	4.1–7.5	7.7–10.5	5.1–7.3	6.8	7.3–9.7
Aspartic acid	8.0–14.7	2.8–12.4	8.1–10.9	10.3–14.4	9.1–11.6	8.8–11.5	11.0	10.8–12.3
Cystine	1.0–1.2	1.0–1.1	0.7–1.2	0.1–1.5	1.0–1.5	2.0–2.6	1.5	1.2–1.7
Glutamic acid	9.7–18.8	6.3–16.9	10.8–15.6	13.2–20.0	13.0–18.2	11.8–16.4	16.9	15.4–18.7
Glycine	3.1–5.6	4.2–5.5	1.8–3.2	3.2–5.2	3.5–4.6	4.0–4.5	3.7	4.0–4.7
Histidine	2.1–3.4	2.1–3.2	2.4–2.9	2.2–3.8	2.2–3.0	4.0–5.3	3.1	2.3–2.7
Isoleucine	2.8–5.9	2.3–5.6	3.5–4.4	2.1–5.8	3.4–4.5	2.6–4.5	4.1	3.7–4.6
Leucine	5.5–10.0	5.8–9.0	5.9–8.2	4.2–9.5	6.3–7.8	7.0–7.8	7.6	6.5–7.5
Lysine	4.0–8.4	2.9–7.7	5.8–8.2	5.3–8.7	5.4–6.8	7.4–9.3	6.7	6.7–7.8
Methionine	0.3–1.7	1.3–1.7	0.7–1.9	0.5–1.5	0.6–1.0	1.2–1.4	1.3	0.8–1.2
Phenylalanine	3.6–7.1	2.8–6.7	3.1–6.7	4.7–7.7	3.5–4.5	4.6–5.8	5.5	4.4–5.0
Proline	2.1–5.1		4.6–5.5	1.1–5.4	2.9–4.7	4.1–4.8		3.7–4.5
Serine	4.4–7.2	1.6–7.2	2.9–4.5	2.7–5.4	3.6–5.4	5.0–6.4	4.7	4.3–5.1
Threonine	3.2–5.9	4.3–4.9	2.0–3.6	3.1–5.4	2.8–4.0	3.4–4.2	3.5	3.5–4.2
Tryptophan	1.1–1.7	1.0–1.1	0.9–1.8	0.8–1.1	0.7–1.0		1.2	0.8–1.0
Tyrosine	2.7–4.2	3.4–3.8	1.8–2.8	0.8–4.7	2.2–3.3	3.8–4.5	3.4	2.6–3.6
Valine	3.4–6.7	2.3–5.9	3.6–5.6	3.3–5.9	3.7–5.1	3.8–5.3	4.9	4.2–5.2

Amino acids (% protein)	Chickpea	Cowpea	Pigeon pea	Lentil	Lupins (blue)	Soybeans	Fish meal	*Reference protein
Alanine	3.2–4.3	3.4–5.1	3.6–6.3	2.4–4.3	3.1–3.7	3.8–4.6	5.7–6.4	
Arginine	7.1–12.3	5.0–8.7	3.2–6.8	3.9–8.8	9.5–12.3	6.6–7.9	4.2–6.6	
Aspartic acid	9.0–11.9	9.2–12.7	7.6–11.0	9.9–11.5	9.2–11.1	10.1–11.9	7.9–9.5	
Cystine	0.6–1.8	0.6–1.4	1.1–2.2	1.0–1.5	1.2–1.8	1.3–1.9	0.7–0.9	
Glutamic acid	12.7–20.2	14.1–18.7	15.9–24.7	14.7–16.3	20.8–25.0	16.9–18.7	11.8–15.0	
Glycine	3.1–4.3	3.1–4.8	3.6–4.0	3.8–4.4	3.9–4.4	4.0–4.5	4.3–7.7	
Histidine	2.1–3.1	2.4–4.1	2.2–3.8	1.3–3.8	2.4–2.9	2.3–3.1	1.6–3.5	1.9
Isoleucine	2.6–4.8	2.8–5.2	3.1–4.1	3.4–6.3	3.9–4.4	4.2–4.8	3.2–5.0	2.8
Leucine	5.9–7.8	5.8–11.3	5.5–8.6	6.8–10.9	6.2–7.8	7.1–7.9	5.5–8.1	6.6
Lysine	5.4–7.7	5.2–7.1	5.6–7.8	4.3–8.0	4.5–5.1	5.7–6.7	7.0–8.1	5.8
Methionine	0.7–1.6	0.9–1.6	0.3–1.5	0.7–1.1	0.5–0.8	1.2–1.7	2.3–3.5	2.5[a]
Phenylalanine	4.4–6.1	4.4–6.4	7.7–10.4	4.3–6.3	3.1–5.4	4.7–5.3	2.8–4.3	6.3[b]
Proline	3.7–4.5	3.8–5.7	3.5–5.4	2.6–4.0	3.7–4.6	4.5–5.6	3.2–4.3	
Serine	4.2–5.6	3.8–5.6	4.2–4.8	2.9–5.1	4.8–5.4	4.5–5.4	3.6–4.5	
Threonine	3.0–4.0	3.0–5.3	2.6–3.9	2.5–4.5	3.1–3.6	3.6–4.4	3.1–4.6	3.4
Tryptophan	0.7–1.2	0.9–1.3	0.3–0.9	0.5–1.2	0.8–1.0	1.2–1.4	0.8–1.2	1.1
Tyrosine	1.5–3.2	2.6–3.6	0.4–3.8	2.5–3.2	3.3–4.0	3.3–3.8	2.3–3.7	
Valine	2.8–4.9	3.4–5.5	2.9–5.7	4.0–5.4	3.4–4.3	4.4–5.2	3.9–5.7	3.5

Notes: * FAO reference protein for 2–5-year-old children (cited from Makkar *et al.*, 2014).
[a] Methionine plus cystine.
[b] Phenylalanine plus tyrosine.
Source: Feedipedia. 2016. Available at: http://www.feedipedia.org/

animals. Seeds are rich in protein (15–37 percent, DM basis) depending upon the crop species. The average fat and fibre contents (DM basis) ranges from 0.6 to 7.0 percent and 3 to 17 percent, respectively. Fresh aerial parts of most pulse crops contains about 10 to 36 percent protein (DM basis) and 1 to 5 percent fat (DM basis), depending upon the species. Pulse by-products such as straw (CP: 3–14 percent; DM basis) and hay (CP: 9–23 percent; DM basis) have higher levels of protein than cereal by-products (Table 13.2). Various processing by-products such as *korma* (50–55 percent; DM basis), meal (40–45 percent; DM basis) and *chuni* (19–23 percent; DM basis) also act as potential sources of protein for ruminant and monogastric animals. By-products of pulses in general have higher dry matter digestibility and metabolizable energy, and lower fibre contents than cereals. This is mainly due to their greater proportion of highly digestible cell contents. Thus, complementing animal feed with improved varieties of pulses and their by-products significantly improves animal nutrition, which in turn supports food security.

Pulses also contain various anti-nutritional factors such as trypsin and chymotrypsin inhibitors, lectins, saponins, tannins, oxalate, polyphenols, phytic acid, lathyrogens, anti-histamines and allergens (Table 13.3). The presence of anti-nutritional factors in pulses (mainly in raw seeds) affects their direct use in animals, particularly in monogastric animals. However, the effects of these factors disappear or decrease when pulses are properly processed. Among the processing methods that have been used are: germination, fermentation, peeling, soaking, cooking, treating with various chemicals, enzymes addition, roasting and frying. The heat treatment applied to remove anti-nutritious factors should be monitored carefully because it can lead to a decrease in essential amino acids and protein digestibility.

Nutritionally, pulses and their by-products fit very well into animal diets, although individual pulses have different applications for specific livestock groups. Pulses are a high quality source of protein and energy for all forms of livestock, combining with high levels of palatability and digestibility. Pulses have become an increasingly popular feed source in recent years with an estimated 10 to 20 percent of the diet comprising various pulses. Peas (*Pisum sativum* L.) are the most widely used pulse in the intensive livestock industries although lupins (*Lupinus* L. spp.) are widely recognized as a superior feed source for ruminants. In semi-intensive or extensive livestock systems typical of developing countries, pulse by-products such as korma, meal, *chuni* of mung bean [*Vigna radiata* (L.) R. Wilczek], mungo bean [*Vigna mungo* (L.) Hepper], moth bean [*Vigna aconitifolia* (Jacq.) Maréchal] and guar bean [*Cyamopsis tetragonoloba* (L.) Taub.] are more commonly used as animal feed supplements. Pulse crop residues such as straw, hay, pod, and husk also form the basal diet for ruminants, mainly in developing countries.

Maximum inclusion levels of pulses and their by-products in the diet vary between 5 and 50 percent, and usage varies with livestock species. Some of the major recommendations on the levels of incorporation of pulses and their by-products in the diets of cattle, sheep, goats, pig and poultry are given below:

- Raw common beans (*Phaseolus vulgaris* L.) can be incorporated up to 20 percent in the ration of cattle. Heat-treated seeds can replace up to 50 percent soybean meal protein in poultry diet. Straw has high DM digestibility (>68 percent) and high metabolizable energy (>7 MJ/kg DM), and can be fed to livestock.

- Raw seeds of lima bean (*Phaseolus lunatus* L.) are not recommended for use as livestock feed, as they may cause hydrogen cyanide (HCN) poisoning. However, soaking and cooking of raw seeds remove most of the HCN, and the treated seeds can be incorporated up to 10 percent in broiler diet. Lima bean silage can be fed to cattle up to 80 percent of the total forage DMI.

- By-products of mung bean such as mung bean *chuni* are a good source of protein (19 percent, DM basis), and can be included up to 50 percent in cattle diets. *Chuni* can be included up to 7.5 and 15 percent in nursery and finisher pig diets, respectively. Mung beans can be used up to 30 percent in layer poultry diets, provided that the diet is properly balanced with amino acids. Mung bean hulls are suitable for inclusion in the diets of ruminants. It is advisable to use a maximum 5 percent level of mung bean hulls in broiler diets. Fresh mung bean forage has a moderate (13 percent, DM basis) to high (21 percent, DM basis) protein content, and can be incorporated up to 100 percent in the ration of sheep, with no adverse effect.

- Mungo bean *chuni* is a potential feed resource and it is available in large quantities in India and other South Asian countries. It is reported that mungo bean *chuni* is the best in terms of available protein when compared with *chunies* of mung bean, chickpea (*Cicer arietinum* L.) or pigeon pea [*Cajanus cajan* (L.) Huth]. Mungo bean *chuni* can be included up to 40 percent of concentrates used for feeding cattle. The inclusion of mungo bean *chuni* up to 15 percent level is recommended for pig diets. Fresh mungo bean forage is rich in protein (18–19 percent, DM basis) and fibre content is reasonably low (25–27 percent, DM basis). Feeding mungo bean forage (50 or 100 percent of roughage) improves feed intake, fibre digestibility and milk production in lactating cows.

- Rice bean [*Vigna umbellata* (Thunb.) Ohwi & H. Ohashi] can replace 50 percent of concentrates used in the ration of calves and sheep. Raw rice bean should not be fed to poultry; however, roasted beans can be included up to 20 percent in the diet. Rice bean hay is generally used as a protein source (16 percent, DM basis) to supplement poor quality roughage-based diets in ruminants. Hay can be supplemented up to 15 percent of diet DM in goats.

Table 13.2 Protein (%, DM basis) and organic matter digestibility (%, ruminants) of commonly available pulses and pulse by-products versus cereals and cereal by-products

Pulses and their by-products			Cereals and their by-products		
Parameter	Protein	Digestibility	Parameter	Protein	Digestibility
			Species		
Common bean	22–27	92	Wheat (*Triticum aestivum* L.)	9–19	86–94
Lima bean	19–28	84	Barley (*Hordeum vulgare* L.)	8–16	41–86
Mung bean	19–29	92	Maize (*Zea mays* L.)	8–11	88
Mungo bean	21–27	92	Pearl millet [*Pennisetum glaucum* (L.) R. Br.]	8–17	88
Rice bean	18–25	60	Oat (*Avena sativa* L.)	8–15	68–82
Moth bean	27	92	Rice, polished (*Oryza sativa* L.)	8–13	92
Broad bean	25–34	87–96	Rough rice, paddy rice	6–12	72
Hyacinth bean	23–29	78	Rice, brown	7–14	89
Jack bean	20–37	91	Rye (*Secale cereale* L.)	8–13	89
Winged bean	39		Sorghum [*Sorghum bicolor* (L.) Moench]	8–14	79–91
Guar bean	28	92	Quinoa (*Chenopodium quinoa* Willd.)	14–17	
Velvet bean	18–37	92	Fonio [*Digitaria exilis* (Kippist) Stapf]	7–11	87
African yam bean	22–26		Triticale (×*Triticosecale*)	9–16	88
Bambara bean	17–23	91			
Pea	19–29	91–96			
Chickpea (desi type)	18–27	90			
Chickpea (kabuli type)	19–26	84–92			
Cowpea	18–30	92			
Pigeon pea	18–28	91			
Lentil	25–30	92			
Common vetch	15–36	90–92			
Lupin (yellow)	34–48	89			
Lupin (blue)	30–38	89			
Lupin (white)	34–45	90			
Seeds/grains (average)	15–48	78–96		6–19	41–94
			Bran/*chuni*		
Mung bean *chuni*	19		Wheat bran	14–21	66–81
Mungo bean *chuni*	21		Maize bran	9–18	75
Guar bean *chuni*	20		Pear millet bran	10–16	83
Chickpea *chuni*	12–18		Oat bran	17–22	86
Lentil bran	15–26		Rye bran	15–18	81
			Rice bran	4–18	46–94
			Rice bran, defatted	5–20	42–82
Bran/*chuni* (average)	12–26			4–22	42–94
			Fodder (fresh)		
Lima bean fodder	19	56	Wheat fodder	7–24	64–85
Mung bean fodder	13–21	73	Barley fodder	6–19	61–81
Mungo bean fodder	19	68	Maize fodder	3–13	56–69
Rice bean fodder	14–32	64	Pear millet fodder	7–17	68–75
Moth bean fodder	15	76	Oat fodder	6–26	54–74
Broad bean fodder	14–21	74–74	Rice fodder	3–19	66
Hyacinth bean fodder	12–24	67	Rye fodder	7–21	70–81
Jack bean fodder	15–25	60	Sorghum fodder	2–16	56–82
Guar bean fodder	16	73	Triticale fodder	5–28	68
Velvet bean fodder	10–26	68–70			
African yam bean fodder	23	64			

Pulses and their by-products			Cereals and their by-products		
Parameter	**Protein**	**Digestibility**	**Parameter**	**Protein**	**Digestibility**
			Species		
Pea fodder	18				
Cowpea fodder	13–24	71			
Pigeon pea fodder	10–27	65			
Common vetch fodder	12–36	60–80			
Lupin (white) fodder	18–28	72–82			
Fodder, fresh (average)	10–36	56–82		2–28	56–85
			Straw		
Common bean straw	5–11	48–60	Wheat straw	3–6	39–55
Mung bean straw	9–12	56–67	Barley straw	2–6	43–50
Mungo bean straw	9–17	62	Pear millet straw	3–7	38–53
Rice bean straw	14	39	Oat straw	2–6	39–58
Broad bean straw	5–11	37–55	Rice straw	2–7	46–56
Jack bean straw	27		Rye straw	2–7	48
Guar bean straw	7–11	59	Sorghum straw	2–8	41–70
Bambara bean straw	8		Fonio straw	5	
Pea straw	8		Triticale straw	2–4	50
Chickpea straw	4–9	43–61			
Lentil straw	6–9	47–55			
Common vetch straw	6–8	50–57			
Lupin (white) straw	6	46			
Lupin (yellow) straw	7	49			
Straw (average)	4–17	37–67		2–8	38–70
			Hay		
Rice bean hay	13–18	51	Wheat hay	2–10	42–65
Moth bean hay	9–17	62	Barley hay	4–13	54–68
Hyacinth bean hay	12–20	44–65	Pear millet hay	7–11	53–60
Velvet bean hay	15	61	Oat hay	5–15	53–81
Bambara bean hay	14		Rice hay	8	62
Cowpea hay	10–23	60	Sorghum hay	4–14	52–70
Pigeon pea hay	12–17	60			
Common vetch hay	17–22	64–73			
Hay (average)	9–23	44–73		2–15	42–70
			Pods/ husks		
Mungo bean pods	9	85	Pearl millet husks	5	59
Moth bean pods	10	88	Oat hulls	2–8	35
Velvet bean pods	21	89	Rice hulls	2–7	29
Pigeon pea pods	20	83			
Pods (average)	9–21	83–89		2–8	29–35
			Silage		
Mungo bean silage	14	77	Barley silage	7–12	64–71
Pea pod silage	6–24	72	Maize silage	5–12	
			Oat silage	7–12	57–71
			Sorghum silage	4–8	63–70
Silage (average)	6–24	72–77		4–12	57–71

Feedipedia. 2016. Animal feed resources information system. INRA/CIRAD/AFZ/FAO. Available at: http://www.feedipedia.org/

Table 13.3 Anti-nutritional factors present in different pulses and their by-products

Pulses	Anti-nutritional factors
Common beans (*Phaseolus vulgaris* L.)	Trypsin, chymotrypsin, and α-amylase enzyme inhibitors; phytic acid, lectin, saponins and flatulence factors.
Lima bean (*Phaseolus lunatus* L.)	Cyanogenic glucosides (linamarin and phaseolunatin) and linamarase, lectin and trypsin inhibitors; oxalate, saponins, phytic acid and tannins.
Mung bean [*Vigna radiata* (L.) R. Wilczek]	Trypsin inhibitors, chymotrypsin inhibitor, tannins and lectins.
Mungo bean [*Vigna mungo* (L.) Hepper]	Trypsin inhibitors and condensed tannins.
Rice bean [*Vigna umbellata* (Thunb.) Ohwi & H. Ohashi]	Phytic acid, polyphenol, tannins and trypsin inhibitors.
Moth bean [*Vigna aconitifolia* (Jacq.) Maréchal]	Phytic acid, saponin and trypsin inhibitors.
*Broad bean (*Vicia faba* L.)	Tannins and glycosides (vicin and convicin).
Hyacinth bean [*Lablab purpureus* (L.) Sweet]	Tannins, phytate and trypsin inhibitors.
Jack bean [*Canavalia ensiformis* (L.) DC.]	Concanavalin A, canavanine and canatoxin.
Winged bean [*Psophocarpus tetragonolobus* (L.) DC.]	Trypsin and chymotrypsin inhibitors; amylase inhibitors, phytohaemagglutinins, cyanogenic glycosides and saponins.
Guar bean [*Cyamopsis tetragonoloba* (L.) Taub.]	Trypsin inhibitors, saponin, haemagglutinins, hydrocyanic acid and polyphenols.
Velvet bean [*Mucuna pruriens* (L.) DC.]	L-dopa (L-3, 4-dihydroxyphenylalanine), total free phenolics, tannins, haemagglutinin, trypsin and chymotrypsin inhibitors, dimethyltryptamine, anti-vitamins, protease inhibitors, phytic acid, flatulence factors, saponins, and hydrogen cyanide and dimethyltryptamine. alkaloids such as mucunain, prurienine and serotonin.
African yam bean [*Sphenostylis stenocarpa* (Hochst. ex A. Rich.) Harms]	Tannins, trypsin inhibitors, hydrogen cyanide, saponins, phytic acid, alpha-galactosides, lectin, alpha-amylase inhibitors, oxalate, and beta-galactosides.
Bambara bean [*Vigna subterranea* (L.) Verdc.]	Trypsin inhibitors, phytates and tannins.
Pea (*Pisum sativum* L.)	Trypsin inhibitors, tannins and lectins.
Chickpea (*Cicer arietinum* L.)	Trypsin and chymotrypsin inhibitors.
Cowpea [*Vigna unguiculata* (L.) Walp.]	Lectins, trypsin inhibitors and tannins.
Pigeon pea [*Cajanus cajan* (L.) Huth]	Haemagglutinins, trypsin and chymotrypsin inhibitors, cyanoglucosides, alkaloids and tannins.
Lentil (*Lens culinaris* Medik.)	Protease inhibitors, lectins, phytic acid, saponins and tannins.
*Common vetch (*Vicia sativa* L.)	Cyanogenic amino acids, cyanogenic glycosides and neurotoxin (γ-glutamyl-β-cyanoalanine).
*Lupins (*Lupinus* L. spp.)	Non-starch polysaccharides, oligosaccharides, trypsin inhibitors, chymotrypsin inhibitors, tannins, saponins, phytin and alkaloids.

Note: All anti-nutritional factors, except for those species marked with an asterisk, can be inactivated by heat treatment. For those species marked with an asterisk, treatments are available to remove/inactivate them. Currently, improved varieties with zero/low anti-nutritional factors are also available for several of the pulse crops.

- Improved cultivars of broad bean (*Vicia faba* L.) with low tannins, glycosides and trypsin inhibitor contents are preferred for livestock feeding. Seeds are a valuable source of protein (25–33 percent, DM basis) and energy (18.7 MJ/kg DM), and can be used up to 30 percent in the ration of dairy cows. In sheep, broad beans can be included up to 60 percent of the diet. Although broad beans are a good source of protein, they are low in the sulphur-containing amino acids such as methionine and cysteine, which limit their inclusion in high-density diets of monogastrics. Zero-tannin broad beans can be included up to 30 percent in growing and finishing pig diets. The maximum inclusion level of broad bean should not be more than 10 percent in sow diet. Processed or glycosides-free genotypes of broad beans can be included up to 20 percent in broiler and layer poultry diets. Broad bean hulls can be used in the diets of ruminants. Good quality silage can be also made from broad bean plants.

- Hyacinth bean [*Lablab purpureus* (L.) Sweet] contains high protein (23–28 percent, DM basis) and low fibre (8–10 percent, DM basis); however, presence of anti-nutritional factors (tannins, phytate, and trypsin inhibitors) limits its use in monogastric diets. Raw and processed (boiling, toasting, steam pelleting) seeds can be included at up to 10 and 30 percent, respectively, in pig diets. A maximum 5 percent of unprocessed seeds is recommended for inclusion in poultry diets. Its fodder is one of the most palatable legumes for animals and a valuable source of protein (18 percent, DM basis). Good quality hay and silage can be prepared from hyacinth fodder.

- Jack bean [*Canavalia ensiformis* (L.) DC.] is a good source of protein, carbohydrate and minerals; however, the presence of various anti-nutritional factors (concanavalin A, canavanine, and canatoxin) limits its use in ruminant and monogastric diets. Processed seeds (alkali-treated, autoclaved or extruded) of jack bean can be included up to 15 percent in pig diets. Raw seeds are not recommended for poultry diets; however, toasted/boiled seeds can be incorporated up to 10 percent in broiler and layer diets. Fresh forage is not palatable; however, dried forage can be used in the diet of ruminant animals.

- Because of high protein (28 percent, DM basis) and organic matter digestibility (92 percent, in ruminant), guar bean seeds can efficiently replace other protein meals in the ration of livestock animals. Guar bean meal (40–45 percent, DM basis) and guar bean korma (50–55 percent, DM basis) are protein rich by-products of the guar bean gum industry, used in monogastric and ruminant diets. Autoclaving of guar bean meal improves its inclusion level. Raw guar bean meal can constitute up to 25 percent of cattle rations; whereas, heat treated guar bean meal can be used as the sole protein component of cattle diet. A maximum of 5 percent of raw guar bean meal can be included in pig diets. Raw and heat treated guar bean meal can be included up to 2.5 and 5 percent levels, respectively in poultry diet. Guar bean straw can be incorporated up to 70 percent in the maintenance ration of sheep.

- The use of velvet bean [*Mucuna pruriens* (L.) DC.] seeds in diets of pig and poultry is limited, due to the presence of anti-nutritional factors. The processing of seeds, such as by cracking, soaking in water and boiling, allows replacing soybean meal (by up to 40 percent) in the diets of pig. Processed seeds (soaking, boiling, drying) can be used up to 20 percent in broiler diets; but are not recommended for layer diets. Velvet bean forage can be supplemented at 2 kg DM/head/day in dairy cow rations. Maximum inclusion level for velvet bean hay was recommended as up to 2.5 percent of body weight in sheep and goat diets.

- African yam bean [*Sphenostylis stenocarpa* (Hochst. ex A. Rich.) Harms] seeds are rich in protein (22–25 percent, DM basis), with high levels of lysine (9 percent of protein) and methionine (2 percent of protein). The amino acid levels in African yam bean seeds are higher than in pigeon pea, cowpea [*Vigna unguiculata* (L.) Walp.] or Bambara bean [*Vigna subterranea* (L.) Verdc.]. Seeds can be included up to 20 percent in the diets of broilers.

- Bambara bean has long been used as an alternative, inexpensive source of protein and energy in livestock diets, mainly in African countries. Bambara bean seeds can be included up to 10 percent in the diet of pigs. Heat processed seeds can be included up to 45 percent in broiler diets. The raw Bambara bean waste (offal) can be included up to 5 and 20 percent levels in layer and broiler diets, respectively.

- Peas can be included at up to 50 percent in the diet of dairy calves, and it can serve as a sole protein source for dairy heifers. Peas can be included up to 25 percent in dairy cattle, and 30 percent in steer diets. Sheep and goat diets may contain up to 45 and 15 percent of peas, respectively. Maximum recommended level for extruded seeds in pig starter diet is 20 percent, as against 10 percent for raw seeds. If the diet is balanced with synthetic amino acids, peas can be included up to 30 percent in broiler and layer diets.

- Chickpeas, both *desi* and *kabuli* types, are also a good source of protein (18–26 percent, DM basis). Fibre content is lower in *kabuli* chickpea types (3–5 percent, DM basis) than in *desi* types (9–13 percent, DM basis). Chickpea can be used up to 50 percent of the concentrate in large and small ruminant diets. Extruded chickpeas can be included up to 30 percent in the diets of growing and finishing pigs. The recommendation is to limit raw chickpeas up to 5–10 percent in starter diets, and up to 10–15 percent in grower and finisher pig diets. Heat processed chickpeas can be included up to 20 percent in broiler and layer diets. Chickpea straw is palatable, with higher

DMD (10–42 percent higher) than cereal straws, indicating its potential as an alternative forage in ruminant diets. Chickpea bran (*chuni*) is a good source of protein (13–19 percent, DM basis) for ruminants.

- Raw cowpea seed and its by-products (seed waste, hulls) can be used in the diets of small and large ruminants; however, they cannot be recommended for use in pigs and poultry diets. Heat-treated seeds can be included up to 20 percent in broiler diets. Cowpea hulls (which results from dehulling of seeds for food) are low-cost feedstuffs for poultry, and can be included up to 15 percent in starter and finisher diets. Cowpea forage has high protein contents (14–24 percent, DM basis) and organic matter digestibility (>60 percent in ruminants). Cowpea hay can be added up to 30 percent in the diet of small and large ruminants.

- Pigeon pea seeds are a good source of protein (23 percent, DM basis) and can be incorporated up to 20 percent (DM basis) in the diet of lactating cows. Raw or processed seeds can be included up to 30 percent in goat diets. Raw pigeon pea seeds can be included up to 20 percent in growing pig diets. Raw pigeon pea seeds can be included up to 10 percent; whereas, processed (toasted) seeds can be included up to 20 percent in broiler and layer diets. Pigeon pea provides excellent forage for livestock. It is palatable and rich in protein (18 percent, DM basis).

- Lentil (*Lens culinaris* Medik.) seeds and by-products (screenings and bran) can be incorporated in ruminant feeding. Inclusion rate of lentil seeds should not exceed 10 percent in growing-finishing pig diets. The seeds can be included up to 20 percent in broiler rations, but are not recommended in layer rations. Amino acid (for example sulphur containing amino acids such as methionine and cysteine) supplementation is recommended when lentil seeds are used in pig and poultry diets. Lentil straw can also be used in diets for small and large ruminants.

- Feeding of common vetch (*Vicia faba* L.) seeds can be recommended up to 3 kg/day for dairy cattle. Maximum safe levels for common vetch seeds could be up to 20 percent for growing pigs and 10 percent for piglets. Raw and processed (soaking and cooking) seeds can be included up to 10 and 20 percent, respectively, in broiler diet. Processed seeds may safely be used up to a 25 percent level in laying hens. Common vetch provides palatable forage, having about 24 percent protein (DM basis). Common vetch straw contains about 6 percent protein (DM basis), and its organic matter disgestibility is 53 percent. Common vetch hay is a valuable forage for small and large ruminants.

- Processed (roasted, soaked) white lupin (*Lupinus albus* L.) seeds can be used up to 30 percent in ruminant diets. Blue lupin (*Lupinus angustifolius*

L.) can be used up to 35 percent in pig diets. Inclusion of blue lupins at a 15 percent level is recommended in poultry diets. Andean lupin (*Lupinus mutabilis* Sweet) is cultivated for human consumption in some regions of South America but there is almost no information regarding Andean lupin seed use for animal feed. Lupin forage can be used as fresh or dry fodder, whole plant silage or hay for livestock feed.

In addition to the above-mentioned, there are a number of underexploited and underutilized pulse crops of considerable nutritive value. Very little or no information about their chemical composition, anti-nutritional factors, levels in the diets and effect of their feeding are available. These include Scarlet runner bean (*Phaseolus coccineus* L.), Tepary bean (*Phaseolus acutifolius* A. Gray), Adzuki bean [*Vigna angularis* (Willd.) Ohwi & H. Ohashi], Moth bean [*Vigna aconitifolia* (Jacq.) Maréchal] and Winged bean [*Psophocarpus tetragonolobus* (L.) DC.]. Thus, there is a need to conduct further research on these pulses and their by-products as animal feed.

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Appendixes

Appendix A. Major international research centres working on various pulse crops

Research centres
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Patancheru 502 324, Telangana State, India
Indian Institute of Pulses Research (IIPR) Indian Council of Agricultural Research (ICAR) Kanpur – 208024, India
Indian Agricultural Research Institute (IARI) Hill Side Road, Pusa, New Delhi 110012
Centre for Legumes in Mediterranean Agriculture (CLIMA), The University of Western Australia 35 Stirling Highway, Crawley, Western Australia 6009 Mailbox M080, Australia
Department of Agriculture and Food, Western Australia (DAFWA) 3 Baron-Hay Court, South Perth, WA 6151, Australia
Department of Agriculture and Fisheries Primary Industries Building, 80 Ann St, Brisbane City, QLD 4000, Australia
Australian Centre for International Agricultural Research (ACIAR) 38 Thynne Street, Fern Hill Park BRUCE ACT, Australia
Commonwealth Scientific and Industrial Research Organization (CSIRO) Canberra, Australia
Grains Research and Development Corporation (GRDC) East Building, 4/4 National Circuit, Barton ACT 2600, Australia
United States Department of Agriculture National Institute of Food and Agriculture, Washington, DC, United States ofAmerica
Agriculture and Agri-Food Canada (AAFC) Minister of Agriculture and Agri-Food, Government of Canada
LEGATO (LEGumes for the Agriculture of Tomorrow) European Union
International Legume Society (ILS) Europe
Institut National de la Recherche Agronomique (INRA) National Institute of Agricultural Research Paris, France
Spanish National Research Council Madrid, Spain
Brazilian Agricultural Research Corporation Ministry of Agriculture, Livestock and Food Supply, Brazil
General Directorate of Agricultural Research and Policies Araştirma ve Teknoloji Geliştirme Kampüsü Fatih Sultan Mehmet Bulvarı No: 38, P.K.51Yenimahalle/Ankara 06170 Türkiye
World Vegetable Centre (Asian Vegetable Research and Development Center; AVRDC) Shanhua, Southern Taiwan
International Center for Agricultural Research in the Dry Areas (ICARDA) Dalia Building 2nd Floor, Bashir El Kassar Street, Verdun, Beirut, Lebanon 1108-2010, PO Box 114/5055, Beirut, Lebanon
International Center for Tropical Agriculture (CIAT) Km 17, Recta Cali-Palmira, Apartado Aéreo 6713, Cali, Colombia
International Institute of Tropical Agriculture (IITA) PMB 5320, Ibadan, Oyo State, Nigeria

Appendix B. Global production of major pulse crops (in '000 tonne)

Region/ Country	Dry bean	Broad bean	Pea	Chickpea	Pigeon pea	Cowpea	Lentil	Other pulses	Total
Europe	506.4	580.2	3 024.0	156.3	--	24.0	91.8	1 143.5	5 526.3
Africa	6 031.7	1 420.5	730.4	670.4	729.2	7 782.1	217.4	1 125.4	18 707.1
Western Asia	240.0	62.8	25.2	650.3	--	1 314.0	555.6	39.2	2 887.2
Central Asia	71.9	13.5	76.0	19.7	--	--	2.1	88.1	271.3
Southern Asia	4 009.8	5.4	839.1	9 895.4	3 039.6	14.2	1 543.8	1 534.1	20 881.5
Eastern Asia (mainly China)	1 441.1	1 586.1	1 567.3	10.0	--	13.2	150.0	133.3	4 900.9
Southeastern Asia	4 301.4	--	68.0	490.0	579.7	116.3	0.9	300.9	5 857.2
Oceania	53.0	297.5	262.8	813.3	--	--	327.3	513.2	2 267.1
Northern America (Canada and USA)	1 320.9	--	4 669.3	330.8	--	29.0	2 400.5	--	8 750.4
Central America	2 035.3	59.0	5.2	209.9	2.0	--	1.6	29.2	2 342.1
South America	3 402.1	139.5	181.5	59.6	0.5	19.0	11.0	2.4	3 815.4
Total production	23 413.5	4 164.6	11 448.7	13 305.7	4 350.9	9 311.7	5 301.9	4 909.5	76 206.4

Source: FAOSTAT (2013), Available at HTTP://WWW.FAO.ORG/pulses-2016/

Humans have been using pulses, and legumes in general, for millennia. Pulses currently play a crucial role in sustainable development due to their nutritional, environmental and economic values. The United Nations General Assembly, at its 68th session, declared 2016 as the International Year of Pulses to further promote the use and value of these important crops. Pulses are an affordable source of protein, so their share in the total protein consumption in some developing countries ranges between 10 and 40 percent. Pulses, like legumes in general, have the important ability of biologically fixing nitrogen and some of them are able to utilize soil-bound phosphorus, thus they can be considered the cornerstone of sustainable agriculture.

Pulses also play an important role in providing valuable products for animal feeding and thus indirectly contribute to food security. Pulse by-products are valuable sources of protein and energy for animals and they do not compete with human food. Available information on this subject has been collated and synthesized in this book, to highlight the nutritional role of pulses and their by-products as animal feed. This publication is one of the main contributions to the legacy of the International Year of Pulses. It aims to enhance the use of pulses and their by-products in those regions where many pulse by-products are simply dumped and will be useful for extension workers, researchers, feed industry, policy-makers and donors alike.

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