Kirkhouse Trust

Stress Tolerant Orphan Legumes

MONOGRAPH SERIES

Dolichos

(*Lablab purpureus* L. Sweet)

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(Lablab purpureus L. Sweet)

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Monograph Series

Kirkhouse Trust

The Kirkhouse Trust (KT) is a UK-registered charity founded by Sir Edwin M. Southern to fund the improvement of legume crops that are important for food and nutrition security in African countries and India and to promote scientific education. The origins of KT are entwined with the development of Sir Ed's molecular biology company, Oxford Gene Technology (OGT). In 1997, Oxford University assigned Sir Ed's microarray patents to OGT in exchange for 10% of the equity. In 2000, OGT's income began to grow, and KT was registered as a charity and endowed with an initial donation from the company.

KT's funding model aims to address its twin objectives of improving legume crops, which are important for smallholder farming systems in target countries and raising national scientific capacity. KT has a hands-on strategy, with a team of international scientific consultants working closely with the Principal Investigators (PIs) and students they mentor, providing technological backup as needed, and hosting PIs and students for study visits in their laboratories.

The STOL consortium was established in 2018 under the Promoting India-Africa Framework for Strategic Cooperation Initiative in partnership with the Indian Council of Agricultural Research (ICAR), Department of Agricultural Research and Education (DARE), Ministry of Agriculture and Farmers Welfare, New Delhi, India. The programme aims to facilitate the introduction and exchange of stress-tolerant orphan legume varieties among partnering Indian and African institutions and assess the relative response of selected species to the higher levels of abiotic stresses expected because of climate change. Crops have been identified as potentially having a crucial role in adapting to climate change in arid parts of Africa and India, and selected species are likely to become the focus of KT breeding programmes in the medium to longer term.

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Citation:

Byregowda, M. and S. Ramesh. 2024. Dolichos (*Lablab purpureus* L. Sweet) Monograph. Stress Tolerant Orphan Legumes (STOL) Monograph Series. The Kirkhouse Trust, Oxfordshire, England, 58 pp.

Edited by: Prem Mathur and Robert Koebner

ISBN: 978-1-0685499-0-8

Cover Photo: Dolichos cultivation at Experimental Research Station, University of Agricultural Sciences, Bengaluru, Karnataka, India.

Credit: Dr. M. Byregowda

Published by: The Kirkhouse Trust

The Kirkhouse Trust SCIO
Unit 6, Fenlock Court
Blenheim Office Park
Long Hanborough, Witney
Oxfordshire OX29 8LN
England

https://www.kirkhousetrust.org/

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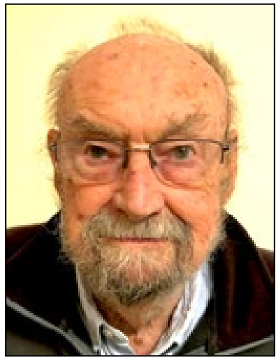

Roughly 2.5 billion people (30% of the world's population) live in semi-arid regions, and approximately a third of these people depend on agriculture for their food security and livelihood. Crop production in these regions has always faced challenges associated with excess heat, drought, a highly variable climate, land degradation, and a loss of biodiversity, which has been exacerbated in recent times by climate change, limited access to technology, poor market linkages, weak institutions, and lack of national and international partnerships. A possible strategy to cope with climate change is to switch from the cultivation of current crops to ones which are more drought-hardy. These include several minor legume crops, commonly known as orphan legumes, currently being grown to a limited extent in the drier regions of both Africa and Asia to provide food and nutritional security to households. These species have remained relatively neglected by both researchers and industry because of their limited economic importance in the global market.

To promote these orphan legumes, the Kirkhouse Trust initiated a consortium programme on "Stress Tolerant Orphan Legumes (STOL)" in partnership with several African countries and India. The STOL programme aims to facilitate the introduction and exchange of stress-tolerant orphan legume among partnering Indian and African institutions and assess the relative response of selected species and varieties to the higher levels of biotic and abiotic stresses expected because of climate change.

To facilitate the better understanding and cultivation of these new crops among Indian and African partners the STOL project is supporting the publication of a series of monographs for selected orphan legumes and Dolichos (*Lablab purpureus* L. Sweet) is one of such crops.

I congratulate the authors of this monograph Drs M. Byregowda and R. Ramesh from the University of Agricultural Sciences, Bengaluru, Karnataka, India for compiling and synthesising information to bring out the Dolichos monograph, which the Kirkhouse Trust is pleased to publish as part of the STOL monographs series. I am sure this publication will enlighten the policymakers, scientists, extension personnel, entrepreneurs and farmers for the improved production and consumption of dolichos bean across African countries as well as in India.

Professor Sir Edwin M. Southern
Founder & Trustee of the Kirkhouse Trust

PREFACE

In the recent decades, unprecedented scientific advances in agricultural research have resulted in significant improvements in agricultural production. However, much of this improvement has been achieved in the cereals. Meanwhile, despite the fact that legume species provide a significant source of protein and contribute to soil fertility, they have not received the level of financial support that their improvement requires. As a result, the productivity of most legume crops continues to be below par.

Dolichos bean (*Lablab purpureus* L. Sweet) is an ancient legume crop, cultivated for food and fodder and as a green manure species. Despite its multiple uses, along with its greater ability than most other legumes to withstand drought and to tolerate soils which are either acidic, saline or low in available phosphorus, the crop has remained under-exploited and qualifies as an 'underutilized crop' as evidenced from limited cropped area and efforts towards its genetic improvement. Enhancement of its economic value through the development of widely adopted and stable high yielding varieties with resilience to insect pests and diseases can be expected to promote the wider cultivation of dolichos bean. Some efforts to improve the status of this crop have been made in recent years, but the literature derived from them is scattered and not readily accessible. With this in mind, we have made an attempt to collate information, covering both genetic and non-genetic aspects, derived from both published materials and personal communications in the form of this monograph. We do not claim that its coverage is exhaustive, but we hope that it can serve as a reference document for researchers who work on dolichos improvement.

In writing this monograph, we wish to express our thanks to the Kirkhouse Trust, UK, headed by Prof. Sir. Edwin Southern, for providing financial support, and to Drs Prem Mathur and Robert Koebner, acting as consultants to the Kirkhouse Trust, for their critical review and comments.

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October 2024

1. INTRODUCTION

Dolichos (*Lablab purpureus* L. Sweet) is one of the first legume crops known to be cultivated in dry and semi-arid regions of Asia, Africa and America (Ayyangar and Nambiar, 1935). Archaeo-botanical findings indicate that it was cultivated in Karnataka (India) as early as 3500 BCE (Sasthry, 1952; Purseglove, 1968; Kay, 1979). The crop is currently grown in many parts of the world, including India, Bangladesh, Malaysia, Thailand, Indonesia, The Philippines, China, Japan, Egypt, Kenya, Tanzania, Uganda, Chad, Ethiopia, Sudan, Angola, Malawi, Mozambique, Zambia, Zimbabwe, Botswana, Namibia, Swaziland, South Africa, Côte d'Ivoire, Ghana, Niger, Nigeria, Senegal, Sierra Leone, Togo, Cameroon, Gabon, Rwanda, Madagascar, the Caribbean islands, Central and South America, Australia and Papua New Guinea. It has been successfully grown in the Southern United States (Texas, Florida, Georgia, Puerto Rico), even as far north as the Great Lakes and Canada. Minde *et al*. (2020) have detailed the global geographical reach of dolichos (Table 1).

Table 1: Native and introduced areas of dolichos bean cultivation.

Native	**Asia:** India and other south-east Asian countries **Africa:** Egypt; Sudan; East, West and South African countries	Maass *et al*. (2010)
Introduced	**Australia:** Northern New South Wales and Southern Queensland **Asia:** Malaysia, Indonesia, Philippines, China, Papua New Guinea **America:** Central and South American countries and Caribbean islands.	Maass *et al*. (2017), Maass *et al*. (2010), Savitha (2008), Mahadevu and Byregowda (2005)

The crop is cultivated in India and Bangladesh, as a backyard vegetable in Africa, Southeast Asia and China and as an ornamental plant in Europe and the Americas as well as a forage crop in Australia. It can be grown in regions where the rainfall varies between 200 and 2500 mm (Hendricksen and Minson, 1985; Cameron, 1988) and where the daily average temperature ranges from 18° to 30°C (Cook *et al*., 2005). It is typically grown from sea level up to an elevation of 1800-2100 masl (Cameron, 1988; Hendricksen and Minson, 1985). During germination and seedling establishment, the crop needs moisture in the form of either rainfall or irrigation (minimum of 10-20 mm). Once established, the plants are highly tolerant to drought conditions (Mayer *et al*., 1986; Schaaffhausen, 1963 a,b), and in particularly are more drought tolerant than other legumes such as common bean (*Phaseolus vulgaris*) and cowpea

(*Vigna unguiculata*) (Maass *et al*., 2010). Apart from its drought tolerance, the crop is valued as a multipurpose legume in crop-livestock systems where crop rotations are possible. It is grown both as a source of fresh immature pods and immature seeds, and as a pulse. Its biomass is used for fodder, green manure, hay, silage and as a cover crop. It is also produced as an ornamental plant in America and Europe (Anderson *et al*., 1996). The extensive root system formed by dolichos plants improves the physical structure of the soil, and the roots' association with nitrogen-fixing bacteria improves soil fertility.

Dolichos can grow in a variety of soils, from sand to clay, in a pH range of 4.5–7.5 (Cook *et al*., 2005; Valenzuela and Smith, 2002). The grain provides a good source of protein (20-25%), amino acids (lysine), vitamins (A, C and riboflavin) and minerals (Ca, Fe, Mg, S, Na and P), alcohols, phenols, steroids, essential oils, alkaloids, tannins, flavonoids, saponins, coumarins, terpenoids, pigments, glycosides and anthnanoids (Deka and Sarkar, 1990), which possess antidiabetic, antiinflammatory, analgesic, antioxidant, cytotoxic, hypolipidemic, antimicrobial, insecticidal, hepatoprotective, antilithiatic, antispasmodic effects (Al-Snafi, 2017).

2. DESCRIPTION OF THE PLANT

2.1 Morphology and growth habit

Dolichos plants are typically indeterminate, climbing and branching, pubescent herbaceous perennials (although often grown as an annual). Plant height can reach up to 6 m in some of the climbing types. The plant produces a large tap root with many laterals and well-developed adventitious roots. Concerted breeding efforts have succeeded in developing varieties which are bushy and determinate, and which grow to a maximum height of 60 cm. Its leaves are alternate, trifoliolate; its leaflets are broadly ovate, entire, sub-glabrous or soft hairy. Its inflorescence comprises several racemes, which can extend to a length of up to 45 cm; in indeterminate types, the racemes are normally borne on axils of branches, while in determinate types, they are borne both on the axils and terminally. Each raceme produces many flowers, borne on a peduncle of length 4-23 cm, often compressed and glabrescent; the rachis length is 2-24 cm; the racemes produce flowers (each measuring about 5 mm long) at each node of the rachis. Pedicels are short, square and sparsely pubescent; the petals are white, pink, red or purple, grow to a length of 10 mm, and are finely pubescent; the bracteoles are 2-3 cm long; the calyx is four lobed; the stamens are diadelphous (9 + 1), the anthers are uniform; the ovary is sessile and forms up to six ovules; the style is incurved, 8 mm long and persistent; the stigma is glabrous. The pods vary with respect to both shape and colour; they are flat/oblong or inflated, 5-20 cm long by 1-5 cm wide, can be straight or curved, and typically contain 3-6 ovoid seeds of varying colour and size with somewhat compressed shape. The hilum is white, prominent, raised and extends over one third of the circumference of the seed. The seed coat varies in colour from white through reddish brown to black, with or without mottling. Seed germination is epigeal, primary leaves are opposite, simple and cordate.

2.2 Mode of reproduction and seed formation

Dolichos is predominantly a self-pollinating plant (Harland, 1920; Ayyangar and Nambiar, 1935; Choudhury *et al.*, 1989; Shivashankar and Kulkarni, 1989; Kukade and Tidke, 2014). However, up to 6-10% of seed is derived from an insect-mediated cross-pollination has been reported (Veeraswamy *et al.*, 1973). Flowers open generally two days after anther dehiscence, mostly during daylight hours (8 am to 5 pm), depending on weather conditions. Under natural conditions, like other grain legumes, up to 80% of the flowers drop. It takes around 30 days after fertilization for physiologically immature, but marketable seeds to be developed, and a further 25-30 days before physiologically mature seeds are formed.

2.3 Cytology

Dolichos bean is a diploid species, with a somatic chromosome number of 22 (Goldblatt, 1981). A detailed karyotype study has revealed that its chromosome complement comprises seven metacentric, three sub-metacentric, and one sub-telocentric pairs of homologous chromosomes. Chromosomes '2' and '7' carry a satellite on their short arm (She and Jiang, 2015).

3. TAXONOMY

3.1 Botanical names

Linnaeus chose the Ancient Greek word *δολιχός* (meaning "long") to describe a group of about 60 species of herbaceous plants and shrubs. The first scientific use of dolichos was given to *Dolichos lablab* (Britton and Wilson, 1924), a name which still is in use as a synonym for *Lablab purpureus*. The initial taxonomic status of dolichos was changed by Robert Sweet, who excluded it from the genus *Dolichos* and removed it to a novel genus *Lablab* (Sweet, 1826). At least 19 other synonyms have been proposed over the years (Westphal, 1975), namely *L. purpureus* L. Sweet; *D. lablab* L; *D. purpureus* L; *D. lablab* ssp. *ensiformis* Thunb; *D. cultratus* Thunb; *D. bengalensis* Jacq; *D. lablab* var. *hortensis* Schweinf & Muschler; *D. albus* Lour; *D. uniflorus*; *D. lablab* ssp. *bengalensis* Jacq; *L. niger* Medik; *L. vulgaris* Savi; *L. leucocarpos* Davi; *L. vulgaris* var. *niger* DC; *L. purpureus* ssp. *Purpureus* Verdc; *L. purpureus* ssp. *Uncinatus* Verdc; *L. purpureus* ssp. *bengalensis* (Jacq.) Verdc. *L. perennans* DC and *L. nankinicus* Savi. The complete taxonomical classification of dolichos is described below:

Domain	Eukaryota
Kingdom	Plantae
Phylum	Spermatophyta
Subphylum	Angiospermae
Class	Dicotyledonae
Order	Fabales
Family	Fabaceae
Genus	Lablab
Species	*purpureus*

3.2 Common names

Dolichos is called by several common names in major dolichos bean producing countries such as India, Bangladesh, Kenya and Australia. In India, it is called Sem, Ballar, Rajashimbi, Shim, Avare, Chikkidikai, Chapparadarvare, Avarai, Mochai, Aanamulu, Chikkudu, Avara, Machakotta, Wal, Pavata, Val and Sin bean. In

Table 2: Common names of dolichos bean.

Country/ Language	Common names	Country/ Language	Common names
English	Dolichos bean, Hyacinth bean, Bonavist bean, Lablab bean, Egyptian kidney bean, Indian bean, Common bean, Field bean, Pendal bean, Pole bean, Waby bean	Indonesia	Kara, Karaandong, Kara Gji, Kara krupauk, Kara lunjar, Kara unceng, Kara putih, Kara wedus
India (Hindi)	Sem, Ballar	Bangladesh	Lubiahshim
India (Bengali)	Rajashimbi, Shim	Kenya	njahe or njahi
India (Kannada)	Avare, Chikkidikai, Chapparadarvare	Myanmar	Pe-gyi
India (Tamil)	Avarai, mochai	China	Bian dou, Huo lianbiandou, Peng pi dou, Teng dou, Yan li dou, Que dou
India (Telugu)	Aanamulu, chikkudu	Grenada	Bunabis
India (Malayalam)	Avara, Machakotta	Philippines	Batao, Batau, Beglau, Parda, Agaya, Itab
India (Marathi)	Wal, Pavata	Costa Rica	Chimbolo Verde
India (Gujarati)	Val	Vietnam	Dauvan, Dall van
India (Assamese)	Sin bean	Thailand	Makpaeb, Ma paep, Thua paeb, Pae Jee, Pae Yee, Thua Lhuang, Thua Nhang
Ivory coast	Agni guangoahura	Malaysia	Kachang Kara, Kara-Kara, Kekara
Japanese	Fiji Mame, Fuji Mame, Ingen	East Africa	Fiwi bean, Kikuyu bean
Nepalese	Raaj Simii, Simii	Sudan	Kashrengeig
Caribbean	Saeme, Australian pea, Bannabees	Angola	Macape in Malag, Macululu
Vietnamese	Dâu van	Cyprus	Louria
Ethiopia	O- cala, Amora guaya, Gerenga	Mauritius	P.contor, P.coolis, P.dum sou, P.en tout temps, P.indien

Bangladesh, it is called as Lubiahshim, in Kenya as Njahe or Njahi and in Australia as Saeme, Australian pea and Bannabees (Table 2).

3.3 Wild relatives and interrelationships

Verdcourt (1970) classified dolichos under *L. purpureus* and recognized three sub-species within the genus *Lablab*, namely ssp. *bengalensis*, ssp. *purpureus* and ssp. *uncinatus*.

3.3.1 *L. purpureus* ssp. *bengalensis*

This taxon is found in most tropical areas of Africa, Asia and Americas. It is perennial in nature and produces pods which are flat/bloated, long and tapering, forming a long axis of seeds parallel to the suture of the pod (Fig. 1). It is predominantly grown for its soft and fleshy whole pod which are consumed as a vegetable. Due to its twining habit, the plants can be trained to grow on a pendal or a pole.

Fig. 1: *Lablab purpureus* sub-species *bengalensis*

3.3.2 *L. purpureus* ssp. *purpureus*

This taxon is grown in Asia as a field crop as a source of pulse, fresh seeds (consumed as a vegetable) and fodder. It is a semi-erect bushy perennial but is usually grown as an annual. It shows little or no tendency to climb. Its pods are tough, firm walled and parchment, are relatively short (up to 10 cm long by 4 cm wide) and abruptly truncated. The long axis of the seeds is perpendicular to the suture of the pod (Fig. 2). The pods emit a characteristic odour/fragrance.

Fig. 2: *Lablab purpureus* sub-species *purpureus*

3.3.3 *L. purpureus* ssp. *uncinatus*

This taxon is the only wild form within the genus *Lablab* (Fig. 3). It is believed to be the progenitor of both ssp. *bengalensis* and ssp. *purpureus* (Maass, 2016). It is of east African origin, forms relatively small pods (4 cm long by 1.5 cm wide), similar to those formed by *L. purpureus* ssp. *purpureus* (Adebisi and Bosch, 2004).

All the above sub-species are readily inter-crossable with one another (Byregowda, 2009). Two crosses were made between a ssp. *purpureus* variety HA 4 (Indian origin) and two African ssp. *uncinatus* accessions (CPI 31113 and CPI 60216) with a view to generating a population of informative recombinant inbred lines (Venkatesha, 2012).

Fig. 3: *Lablab purpureus* sub-species *uncinatus*

4. ORIGIN

4.1 Centres of diversity

Dolichos is probably of Indian origin and has been in cultivation since before 3500 BCE (Sasthry, 1952; Purseglove, 1968; Kay, 1979). The crop has likely spread from India to other tropical countries in Asia, Africa and Americas. Archaeological findings dated from 2000 to 1700 BCE at Hallur (Karnataka, India), and from 1200 to 300 BCE at Veerapuram (Andhra Pradesh, India) provide further evidence for the Indian origin of dolichos (Fuller, 2003; Fuller *et al*., 2007). As is the case with a number of crops of African origin, dolichos appears in the archaeological record in India long before its appearance in Africa (Blench, 2003). Deka and Sakar (1990) and Al-Snafi (2017) also believed that the wild forms of dolichos have originated in India and the crop was introduced into Africa during the 8th century CE.

Maass (2016) has hypothesized that African dolichos arose in Ethiopia, where it was possibly domesticated, and that India represents a secondary centre of diversity, based on the feral escapes from India, which appear to be intermediate between wild African accessions and the cultivated forms. Another, more minor secondary centre of diversity may have developed in North America driven by the selection of distinctive types for ornamental use.

4.2 Sites of domestication

Dolichos is widely distributed in the Indian sub-continent and beyond in East and Southeast Asia. Although there is a lack of any documented evidence, Maass *et al*. (2017) has postulated several potential pathways of the species' distribution across eastern, central and western Africa. Further, according to Blench (2003), dolichos along with its companion crops, sorghum and pearl millet was transported *via* ancient trade networks by mobile pastoralist societies along the Sahelian region of domestication. Fuller (2003) suggests its cultivation in West Africa from at least 850 CE. Carney and Rosomoff (2009) postulated its cultivation in Senegambia and Angola in the beginning of the transatlantic slave trade period (early 17th century CE).

Maass (2016) has suggested that dolichos may have been introduced from the Indian sub-continent to eastern and southern Africa, thereby contributing to its overall diversity. During the transatlantic slave trade period, dolichos could have been transported to Brazil and the Caribbean from either West Africa or Angola

(Carney and Rosomoff, 2009). In the 17th century CE, African slaves are known to have cultivated dolichos as a source of food in northeastern Brazil, several Caribbean islands and the American Carolinas (Maass, 2016).

4.3 Areas of production and consumption

Although dolichos is produced in several countries, it is still considered to be a relatively neglected, underutilized and unexplored crop (FAO, 2018; Tyagi *et al*., 2018). However, in India and certain southeast Asian countries, the crop is grown over a considerable area and dolichos products are widely consumed; this has attracted a body of research directed to the crop's genetic enhancement and to the development of improved crop management practices. India is the major dolichos-producing country in the world; it is grown as source of tender pods in the states of Uttar Pradesh, Maharashtra, Madhya Pradesh, Gujarat, Haryana, West Bengal, Karnataka, Tamil Nadu, Andhra Pradesh and Telangana. Of these, Karnataka dominates (90% of the cultivation area). Although dolichos is also cultivated across Africa, no reliable data are available concerning the area or volume of production (Forsythe, 2019). The same is the case for Bangladesh.

5. NUTRITIONAL PROFILING

5.1 Seed

The nutritional composition of dolichos dry seeds and tender pods in Indian varieties has been characterized (Table 3) (Shivashankar and Kulkarni, 1989; Chetia *et al*., 2004; Kempanna *et al*., 2008). Kamatchi *et al.* (2010) investigated the proximate composition, mineral, vitamin, protein fraction, amino acid and fatty acid profiles of five varieties. The crude protein content ranges from 20.5 to 25.5%, levels comparable with that in the seed of chickpea and other *Vigna* spp. (Bravo *et al*., 1999). The crude lipid content ranges from 2.3 to 4.2% and the dietary fiber from 5.0 to 6.9%. The ash content ranges from 4.0 to 4.9%. The dry seed contains high levels of potassium, sodium, calcium, magnesium, copper, zinc, iron, phosphorus and manganese. In particular, the content of potassium is high in relation to the recommended dietary value of 1.55 g for infants and children (NRC/NAS, 1980). Albumins and globulins (4.6 - 7.4% and 10.9 - 14 5%, respectively) constitute the major bulk of the seed protein. The seed is also rich in unsaturated fatty acids and has low levels of saturated fatty acids; it has a particularly high content of linoleic acid.

Table 3: Nutrient composition of dolichos bean dry seeds and tender pods in Indian varieties.

Nutrient content (on 100 g basis)	Dry seed		Tender pod	
	Min	Max	Min	Max
Crude protein (g)	22.5	28.3	3.1	4.5
Crude fat (g)	1.6	2.2	0.3	1.0
Crude fibre (g)	6.0	10.6	1.0	2.0
Carbohydrate (g)	57.5	64.7	6.7	10
Ash (g)	1.7	3.8	0.9	1.3
Calcium (mg)	28.0	48.0	75.0	210.0
Iron (mg)	5.6	6.9	1.2	1.7
Phosphorus (mg)	330.0	415.0	50.0	68.0.
Potassium (mg)	10.0	15.0	74.0	275.0

5.2 Forage

The crude protein content in dolichos forage varies from 10.0% to 22.0% with a mean of 17.0% on a dry matter basis. In leaf, the crude protein content varies from 14.3% to 38.5%, while in the stem, the range is 7.0-20.1% (Murphy and Colucci, 1999). The average crude fiber content of the whole plant measured on a dry matter basis is 27.8%, with the average neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) values estimated as, respectively, 43.0%, 38.6% and 7.1%. The crude fiber content of dolichos biomass generally increases with plant maturity (Minson, 1990). The forage contains 39.4% carbohydrate, 28.1% fiber, 3.5% fat, 14.8% ash, 2.0% calcium and 0.3% phosphorus.

5.3 Anti-nutritional and toxic properties

The acceptability and utilization of dolichos biomass as fodder has been limited by the presence of concerning levels of certain anti-nutritional factors (Kamatchi *et al*., 2010). However, the *in vitro* protein digestibility of the biomass is high (64.4-70.3%). Tannins are known to inhibit the activity of some digestive enzymes and hence the presence of even a low level of these compounds is undesirable. The tannin content of dolichos is lower (<0.4g/100g) than that present in biomass of other domesticated legumes, including blackgram (*V. mungo*), greengram (*V. radiata*), chickpea (*Cicer arietinum*) and cowpea (*Vigna unguiculata*) (Khan *et al*., 1979, Rao *et al*., 1989). The total content of free phenolics ranges from 0.2-0.3 g/100 g, that of phytic acid from 0.3-0.4 g/100 g (Kataria *et al*., 1989) and that of hydrogen cyanide from 0.2-0.3 mg/100 g, which is two orders of magnitude below toxic levels (Oke, 1969).

6. USAGE

6.1 Human consumption

The commercial value of dolichos is underlined by its centuries long history of cultivation across southern India, where both fresh pods, immature seeds, dry seeds and split dried seeds are used in the preparation of various dishes. The dish called "*Hidikinavare*" (in Kannada language), considered as a delicacy in certain social gatherings, requires fresh seeds to be soaked overnight to allow for the easy removal of the seed coat. The separated cotyledons are also fried in oil to make a popular evening snack. During "*Makara Sankranti*" (the harvest festival in Karnataka), fresh pods are boiled in combination with groundnut pods and their seeds. Dolichos is favoured by urban populations on account of its aroma and nutritional value, as shown by the volume of sales at annual dolichos festival fairs, estimated to be worth US$300,000 over a period of 15 days in central Bangalore (Devaraj 2016) (Fig. 4). Compared to the value of dry seeds, the seasonal market for green pods and split immature seeds is particularly lucrative thanks to the demand for certain local traditional delicacies which have been improved upon to attract customers. A significant number of businesses are involved in the purchase of dolichos products, which are both sold domestically and exported.

Fig. 4: Customers thronging for dehulled dolichos bean seeds and fresh pod at local market, Bangalore, India.

In Bangladesh, both tender pods and green seeds are eaten boiled and incorporated into curries, while the mature seed is often consumed in the form of soup. Sprouted seeds are occasionally sun-dried and stored for use as vegetables. In Indonesia, dry seeds are cooked and either consumed directly or processed as bean curd (tofu). The pulse is also cooked with rice. As a delicacy, dry seeds are pounded into powder, mixed with spices and cooked. Leaves and flowers are consumed as a leafy vegetable similar to spinach. Sprouts from dolichos dry seeds are comparable to those from soybean and mungbean (Amkul *et al*., 2021). In Thailand, fresh pods and seeds are used to prepare variety of dishes. Fresh pods are boiled, and the seeds are then eaten as a snack, styled on the soybean product edamame; immature seeds are also fried and sold as a premium snack (Amkul *et al*., 2021). In tropical regions of Africa, immature pods are eaten raw or cooked and the mature beans used for various dishes; the Kikuyu people of Kenya hold dolichos in high esteem, serving it to celebrate weddings and other ceremonies.

The pod surface of many dolichos varieties emits a characteristic fragrance/ aroma. Indian consumers, especially in Karnataka, prefer highly fragrant varieties, which fetch a premium price in the market. Fernandes and Nagendrappa (1979) have used GC-MS to determine the chemical basis of this fragrance and concluded that the major contributing compounds are trans-2-dodecenoic acid and trans-2-tetra decenoic acid.

6.2 Forage and animal feed

Dolichos biomass provides a good source of palatable nutrients for livestock. It can either be grazed directly by animals, incorporated into grass-based hay or used as a feedstock to produce silage. In general, the digestibility of the biomass is highest when used as a green fodder and declines with maturity (Milford and Minson, 1968; Narayanan and Dabadghao, 1972). The average dry matter digestibility is 56%. Dolichos hay fed as a supplement to cattle on a basal diet of teff straw has been shown to increase rumen ammonia concentration, improve straw digestibility, speed up particulate passage rate, decrease mean retention time and improve intake (Abule *et al*., 1995). Livestock fed with dolichos-based forage exhibit increased weight and milk production during the dry season.

7. GENETIC RESOURCES

7.1 Gene banks

The largest collection of dolichos germplasm (1,443 accessions) is held in New Delhi by ICAR-National Bureau of Plant Genetic Resources (NBPGR), with a smaller collection (650 accessions) at the University of Agricultural Sciences, Bengaluru. The details of other dolichos collections are summarized in Tables 4 and 5 (https://www.genesys-pgr.org).

Table 4: Country-wise collection of dolichos bean genetic resources.

Country	Number of collections	Country	Number of collections
India	2093	Uganda	8
Kenya	197	Cambodia	8
Australia	193	Hungary	8
Bangladesh	176	Taiwan ROC	7
Thailand	85	Ecuador	6
Ethiopia	74	Guatemala	5
Zimbabwe	71	Oman	5
Philippines	42	Bhutan	4
Costa Rica	30	Denmark	4
Sudan	30	Madagascar	4
China	25	Russia	4
Indonesia	24	Vietnam	4
Zambia	24	Argentina	3
Brazil	23	Botswana	3
South Africa	22	Honduras	3
USA	21	Iran	3
Angola	18	Italy	3
Myanmar	16	Mozambique	3
Guinea	15	North Korea	3
Nigeria	15	Portugal	3
Peru	15	Bahamas	2

Country	Number of collections	Country	Number of collections
Malawi	13	DR Congo	2
Laos	12	Cuba	2
Spain	12	France	2
Colombia	11	Pakistan	2
Senegal	11	USSR	2
Nepal	09	Bolivia	1
Lebanon	01	Germany	1
Maldives	01	United Kingdom	1
Mexico	01	Georgia	1
Mali	01	Uzbekistan	1
Puerto Rico	01	Eswatini	1
Rwanda	01	Tunisia	1
Not specified	381	Singapore	1

Table 5: Institutes/countries-wise dolichos bean germplasm maintained.

Countries/Institute	Number of accessions	Source of information
South American countries	134	Bioversity International (2008)
United States of America - United States Department of Agriculture (USDA)	52	GRIN (2009)
Europe	82	Bioversity International (2008); VIR (2009)
Oceania, including Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia	104	Bioversity International (2008)
Asian Vegetable Research and Development Center/ The World Vegetable Center (AVRDC), Taiwan	423	AVRDC (2009)
International Livestock Research Institute (ILRI), Ethiopia	223	Bioversity International (2008)
Sub-Saharan Africa including International Institute of Tropical Agriculture (IITA), Nigeria	67	Bioversity International (2008)

Countries/Institute	Number of accessions	Source of information
Kenyan National Gene Bank and Repository Centre at the Kenya Agricultural and Livestock Research Organization (KALRO-Muguga, Kenya	403	Bioversity International (2008)
South-east Asia countries	82	Bioversity International (2008) NIAS (2009)
China	410	Bioversity International (2008)
Philippines	209	Engle and Altoveros (2000)
Thailand	299	Amkul *et al*. (2021)
South Asia	93	Bioversity International (2008)
Bangladesh Agricultural Research Institute (BARI)	551	Islam (2008)
National Bureau of Plant Genetic Resources (NBPGR), New Delhi, India	1443	ICAR-National Bureau of Plant Genetic resources
Indian Grassland and Fodder Research Institute (IGFRI), Jhansi, India	250	Magoon *et al*. (1974) & personal communication from forage breeder
University of Agricultural Sciences (UAS), Bengaluru, India	650	Byregowda *et al*. (2015) Vaijayanthi *et al*. (2015a)

7.2 Characterization of diversity for agronomically important traits

Given the multiple economic uses of dolichos and its ability to resist biotic and abiotic stresses, the extent of the effort made to date to collect, conserve, characterize, evaluate and catalogue its genetic resources remains inadequate. Shivashankar *et al*. (1971, 1977), Viswanath *et al*. (1971, 1972) and Chikkadevaiah *et al*. (1981) collected, evaluated and catalogued a significant number of accessions, while Wang *et al*. (1991) included some dolichos materials in an evaluation of 14 legume species grown in Hainan (southern China). Xu *et al*. (1996) collected 32 accessions from a mountainous region of southwestern China to investigate their distribution, cultivation and morphological characteristics; the authors were able to recommend four entries for commercial production. Pujari (2000) and Shanmugam (2000) have established a collection of 60 accessions, comprising 22 improved lines and 38 local landraces collected across the Indian states of

Orissa, West Bengal and Andhra Pradesh. A substantial amount of variation with respect to fodder-related traits has recently been documented, based on the analysis of 1,865 accessions, made up of 1,435 from the NBPGR collection and 430 from the UAS, Bengaluru collection (Table 6). An evaluation of 249 Australian and Ethiopian accessions conducted by Maass *et al*. (2001), based on a common set of morphological and agronomic traits, uncovered considerable diversity within the materials from each country for time to flowering, seed weight and plant height. Both collections harbour a high proportion of ssp. *purpureus* accessions, as well as a fair representation of ssp. *uncinatus*.

Table 6: Estimates of variability for forage yield and its components.

Trait	Range	Mean
Days to 50% flowering	34 - 119	74
Plant height (cm)	29 - 227	90
Number of branches	03 - 13	08
Days to first harvest	87 - 274	134
Green fodder yield (g plant^{-1})	42 - 1352	410
Dry matter yield (g plant^{-1})	24 - 270	79

In 2018, the team based at UAS Bengaluru published "*Dolichoslogue- a catalogue of dolichos germplasm*" (Byregowda *et al*., 2015 and 2018), a document which summarizes the evaluation of 611 of their collection of 650 accessions with respect to 21 qualitative and 20 quantitative traits based on descriptors and descriptors states (**Appendix I**), in addition to responses to infection by major diseases (anthracnose and dolichos mosaic virus) (**Annexure I**) and infestation by major insect pests (pod borer complex and bruchids) (**Annexure II**). The extent of variability is summarized below:

Qualitative traits: A wide range of variability for plant growth, leaf, floral pod and seed traits has been documented (Byregowda *et al*., 2018). Majority of the accessions exhibited an indeterminate growth habit, produce dark green, slightly pubescent, ovate-shaped leaves and cream-coloured flower buds and white petals. Whereas, among accessions bearing erect, straight, moderately pubescent, slightly constricted, highly fragrant; short-beaked green pods are dominated.

Quantitative traits: Most of the traits, with the exception of leaf width, flower number per node, seed number per pod, locule number per pod, pod width and days to 50% flowering, had a high standardized range [(highest - lowest trait value)/trait mean] (Table 7).

Table 7: Descriptive statistics for different quantitative traits in dolichos bean.

Traits	Mean ± SE	Range		
		Max.	Min.	Standardized range
Days to 50% flowering	68.29±0.39	112.00	38.00	1.08
Leaf length (cm)	18.54±0.13	27.10	3.80	1.26
Leaf width (cm)	6.74±0.03	8.80	3.60	0.77
Racemes plants^{-1}	7.47±0.09	16.00	2.00	1.87
Raceme length (cm)	23.90±0.24	38.10	4.10	1.42
Nodes raceme^{-1}	9.13±0.08	14.00	2.40	1.27
Flower buds raceme^{-1}	14.00±0.19	31.50	2.00	2.11
Flower buds node^{-1}	3.28±0.02	4.20	2.00	0.67
Plant height (cm)	116.03±0.94	206.70	39.00	1.45
Primary branches plant^{-1}	4.52±0.04	8.00	2.00	1.33
Pods plant^{-1}	24.35±0.29	49.00	6.00	1.77
Pod length (cm)	4.97±0.03	9.20	3.20	1.21
Pod width (cm)	1.79±0.01	2.60	0.80	1.01
Seeds pod^{-1}	3.85±0.02	5.10	2.60	0.65
Locules pod^{-1}	3.89±0.02	6.10	2.80	0.85
Shelling %	47.99±0.32	111.50	26.40	1.77
Green pod yield plant^{-1}	108.26±1.32	243.00	33.30	1.94
Green seed yield plant^{-1}	60.20±0.66	116.30	20.30	1.59
100 dry seed weight (g)	21.00±0.20	45.60	9.80	1.70
100 fresh seed weight (g)	47.22±0.37	81.80	19.80	1.31

Responses to diseases and insect pests: While 36 accessions were resistant to dolichos mosaic virus, three were resistant to anthracnose. None of the accessions were either tolerant or moderately tolerant to infestation by the pod borer complex.

7.3 Characterization of diversity for sensory parameters

A set of 22 accessions curated by the Kenyan National Gene Bank and Repository Centre (KALRO-Muguga, Kenya) and two varieties obtained from farmers' fields were analyzed for sensory parameters by Quirien and Kent (2005), using a vertical mark on a 15 cm line scale. The odour score ranged from 2.7 to 3.6, with a mean of 3.12, while the score for bitterness ranged from 1.4 to 2.4, with a mean of 1.82. Based on the scores for bitter taste, accessions 13096, 11722, 12187 and 11705 have been recommended as parental materials for a breeding programme. The black, brown and speckled/mottled accessions had varying intensities (high, medium and low) of both odour and taste, showing no relationship of the level of bitterness and odour intensity with colour of seed. Accessions 10706 and 13096, both producing brown seeds, had the highest and lowest intensity for odour and bitter taste, respectively.

7.4 Development of a core germplasm set

Researchers at UAS, Bengaluru have developed a core set of 64 accessions, selected from the full set of 611 accessions (Vaijyanthi *et al*., 2015). A similar effort has been reported by both Bruce and Maass (2001) in Ethiopia (47/251 accessions) and Islam *et al*. (2014) in Bangladesh (36/484 accessions). Based on a two-year (2012 and 2014) evaluation of the UAS core set, some promising materials have been identified by Vaijayanthi *et al*. (2016a). The accessions selected based on multiple traits were trialed at several locations in the eastern, southern and central dry zones of Karnataka during 2015: accessions GL 250, FPB 35 and 'Kadalavare' were found to be widely adaptable across all of the tested agro-climatic zones (Vaijyayanthi *et al*., 2016b).

8. BREEDING

8.1 Breeding objectives

Globally, the average yield of dolichos crops is low; in countries outside India and Bangladesh, this is largely due to a lack of improved cultivars. The yield limiting factors include a low harvest index, a high rate of flower drop and a low rate of pod setting, susceptibility to lodging (in bushy types) and damage caused by various biotic and abiotic stressors. The major abiotic stresses are moisture deficiency, high temperatures during spring, and - at high elevation sites – by low temperatures during the winter. Biotic agents of stress include insects such as pod borers, pod bugs and aphids, fungi such as the causative agents of rust, anthracnose and powdery mildew, and yellow mosaic virus. In view of these, the major breeding objectives are: (i) improving the yield of tender pods, grain and fodder; (ii) promoting the use of determinate growth habit types; (iii) promoting the use of photoperiod insensitive types; (iv) increasing the host's resistance against disease and insect pests; and (v) improving the level of tolerance of abiotic stress.

8.2 Breeding methods

8.2.1 Hybridization

For the purpose of crossing, buds likely to open during the afternoon of the following day are emasculated by making a cut with a pair of forceps two thirds of the way up the bud's ventral side, allowing for the removal of the distal end of the bud. The next day, pollen collected from the male parent is dusted onto the stigma of the emasculated female flower. Based on the skill of the operator, more than 50 flowers per hour can be emasculated or pollinated, and a crossing success rate of 20-40% is achievable.

8.2.2 Conventional breeding

Introduction and selection: Introduced germplasm or purified selections from within a local landrace have provided the genetic material needed to develop cultivars adapted to local conditions. For example, the Australian cultivars 'Highworth' and 'Rongai' were introductions from India and Kenya, respectively.

Pure line selection: Typical landraces are genetically heterogeneous, favouring an improvement strategy based on the selection of pure lines. More recently, the UAS Bengaluru improvement programme has turned its attention to using controlled hybridization, which has allowed improved cultivars to be developed *via* selection within populations bred from crosses between parental materials identified by their harbouring of specific traits needed to solve important issues. Breeding lines and advanced material from those programmes have been released as improved cultivars and have found their way into the breeding programmes of other dolichos research centres in India.

Pedigree selection: The appropriate population size required for the effective use of the pedigree selection depends on the underlying genetics and heritability of the traits under consideration and the resources available to the breeding programme. Selection based on yield of individual plants has been shown to be ineffective (Erskine *et al*., 1990).

Bulk selection: Selection applied to bulked populations, often with some modification, has been a favoured breeding method because of its simplicity. Mass selection for seed size, shape and colour is simple to implement on such populations during generation advancement. An effective modified bulk method has been elaborated, whereby the populations are advanced in bulk to the F_4 generation, and this is followed by visual selection for desired plant and seed types. Bulks are retained in the breeding programme for advancement to the F_5 and F_6 generations with selection carried out at each generation for desired types. Populations of selected bulks are then evaluated for critical agronomic traits, for disease resistance, for seed quality traits and for yield. Promising selections need to be tested widely before they can be released as an improved cultivar.

Single seed descent (SSD) method: SSD is well suited to rapid generation advance in dolichos breeding provided the necessary facility (glasshouses or off-season nurseries) is available for growing the populations several times during the year. The primary advantages of the SSD method are the maintenance of genetic variation during generation advance and the minimal space requirement. Haddad and Muehlbauer (1981) have reported that more genetic variation was maintained by SSD compared to the same populations advanced by the bulk method.

The backcross method: Some dolichos breeders have implemented limited backcrossing in an effort to enhance the frequency of developing superior genotypes for use as pure line cultivars.

8.2.3 Marker-assisted selection

The use of genomic resources such as DNA markers in dolichos breeding is still in its infancy. Early generation DNA-based genotyping (RAPDs and AFLPs) has been used to characterize the genetic diversity of germplasm collections. The use of DNA markers in principle should accelerate the pace and enhance the precision of breeding dolichos, as is the case in other crops. At present, a large number of DNA markers are being developed and validated (Ramesh and Byregowda, 2016; Vaijayanthi *et al*., 2019). Once the association of DNA markers with genomic regions controlling economically important traits has been established and validated, such markers could be deployed for marker assisted breeding of dolichos.

8.2.4 Mutagenesis

Mutation breeding can be considered where a desired trait does not appear to exist in available germplasm. The approach is feasible where suitable screening methods are available and can be employed to evaluate large populations of plants. A number of effective physical and chemical mutagens are available, including X-rays, gamma rays, fast and slow neutrons, ethyl methane sulfonate, ethyl nitrous urea, methyl nitrous urea and sodium azide. Several researchers (Kamau *et al*., 2011; Kshirsagar *et al*., 2014; More and Jagtap, 2016; Harish Kumar *et al*., 2018; Undirwade and Kulkarni, 2019) have attempted to induce mutations either *via* gamma irradiation (200-600 Gy) or ethyl methyl sulphonate treatment (0.1-0.6 mM), and have reported the creation of variants producing grain of enhanced contents of protein and fibre, as well as some with the potential to produce high pod and seed yield.

Concerted efforts have led to the development and release of varieties in different countries. To quote a few, the University of Eldoret, Kenya has released four food-purpose varieties (ELDO KT – Maridadi, ELDO KT – Black 1, ELDO KT – Black II and ELDO KT – Cream) for commercial production in different regions. Similarly, Bangladesh has developed two vegetable-purpose varieties (IPSA Seam 1 and IPSA Seam 2). Australia has released four fodder-purpose varieties (Rongai, Endurance, Highworth and Koala), while USA (RioVerde) and China (Xiangbiandou 1) each have released one variety.

8.2.5 Potential biotechnological intervention

The conventional biotechnological tools such as development of double haploid and genetic engineering, and state-of-the-art genome editing, although promising, are yet to be used in dolichos.

9. AGRONOMY

9.1 Vegetable and pulse production

Short duration photoperiod insensitive varieties can be sown at any time of the year at a seed rate of 25-30 kg/ha. When grown as a pure crop, sowing is arranged in rows spaced 0.45 to 0.60 m apart (dependent on the level of soil fertility), with an inter-plant separation of 0.15 m. Since these plants are short in stature and develop a bushy form, no mechanical support is required. Flowering begins after 40-45 days. Tender pods are ready for harvest after 60-70 days, while mature seed is harvested after 95-100 days.

Long duration indeterminate 'typicus' types are cultivated mainly for their tender pods. Typically, seeds are sown on a ridge at a rate of 10-15 kg/ha; two or three seeds are dibbed together, with each row separated from its neighbour by 0.90 – 1.20 m and each sowing position within a row from its neighbour by 0.30 – 0.45 m (dependent on the level of soil fertility). After one month, the plants are thinned so that only one remains in each sowing position. The plants need to be provided with stakes to support climbing. Long duration indeterminate 'lignosus' types are typically grown as an intercrop with finger millet, sorghum, maize, pearl millet, groundnut, castor bean or cotton. Seeds (10-15 kg/ha) are sown in rows spaced 0.90 – 1.5 m (dependent on the level of soil fertility). In Sao Paulo (Brazil), maize and dolichos are frequently sown together, so that as the maize begins to mature, the dolichos plants start to vine; once the maize has been harvested, the dolichos plants completely cover the field.

9.2 Fodder production

Dolichos biomass is highly palatable to livestock, providing a good source of nutrients. It can be either grazed in pasture or grown as a companion crop with cereals or forage grasses. It is suitable for the production of either fresh biomass or hay, with or without the addition of maize silage. To increase fodder productivity and to improve pasture lands, cereal crops and range grasses can be mixed at a rate of 10-20% with dolichos seeds. Dolichos plants grow slowly at the initial stage and do not compete with cereal and range grasses. As the grasses mature, the dolichos plants start growing more vigorously, using the grass for vining support.

9.3 Crop management

To prepare land for sowing, the soil should be deep ploughed twice to form a fine tilth free of weeds. In India, the optimal time for sowing indeterminate types is the onset of the monsoon rains (June-July), which results in the crop coming into flower in November and being ready for harvest in January. However, with the development of photo-insensitive cultivars, the crop can now be grown throughout the year, allowing for the avoidance of flowering during the time when high temperature is expected. Soil fertility is important; ideally, soil should be checked for the content of nitrogen, phosphate, potassium and sulphur. If deficient, the appropriate fertilizer should be applied at planting. Inoculation with *Rhizobium* and phosphate-solubilizing bacteria is helpful for crop growth and economic yield. Since 40-60% of yield loss is due to weed competition, weed control, whether achieved by hand or by the use of herbicide, is recommended. Irrigation is sometimes required during the flowering and pod filling stages.

9.4 Control of diseases and insect pests

Dolichos production is constrained by several diseases. The major ones are leaf spot, rust, anthracnose, powdery mildew, dolichos mosaic virus disease and bacterial leaf spot. Production is compromised by several insect pests, of which the major ones are dolichos pod borer, gram pod borer, spotted pod borer, spiny pod borer, aphids, leaf hopper, pod bugs, whitefly, red spider mite and bruchids. The casual organisms and typical symptoms of the diseases and insect pests are summarized in **Annexure I** and **Annexure II**, respectively. Control of diseases and pests is possible using specific fungicides and insecticides, applied at the appropriate time.

9.5 Harvesting methods

Harvesting of immature pods is carried out manually on a need's basis. The best time to pick pods is in the morning or late afternoon. After harvesting the pods, the plants can be cut close to the ground, delivering 5-10 t/ha of biomass suitable as either livestock fodder or as green manure. Sun-drying the biomass results in high quality hay. For pulse purpose, dry pods are harvested manually at physiological maturity. The harvested dry pods are hand-threshed or mechanically. The seeds are sun-dried to reduce their moisture content to <12% and stored.

9.6 Seed production

Dolichos is a largely self-pollinating crop; the rate of insect-mediated cross pollination is <10 % (Veeraswamy *et al*., 1973). As a result, the production of genetically pure seed is technically straightforward. Basic seed is normally produced from plants grown under insect-proof nets. To minimize the risk of physical admixture, other classes of seed (breeder's seed, foundation seed and certified seed) are produced in plots isolated from one another by 10 m.

10. CURRENT RESEARCH PRIORITIES

A number of priority areas for ongoing research and development have been identified, as listed below:

Area of expansion: Particularly in Bangladesh and the eastern coastal regions of India, large cropping areas are left fallow following the harvest of rice. To exploit such fallow areas, research should focus on developing short duration dolichos varieties able to produce young pods for vegetable use within 60-70 days. The expansion of dolichos into such areas would contribute to the nutritional and income security of small and marginal farmers working in rain-fed ecosystems.

Novel traits: Improved, high yielding Indian cultivars bred for adaptation to drought could contribute to African food security in regions with similar climates. Genetically distant African landraces may represent a valuable source of resistance against various insect pests and diseases (and possibly other traits of interest) for dolichos improvement programmes carried out in India. The exploitation of closely related taxa, particularly ssp. *uncinatus,* is expected to result in the development of cultivars expressing enhanced levels of resistance to biotic and abiotic stresses and improved grain nutrient composition. An important focus for improvement programmes is the development of photoperiod insensitive varieties which are resistant to biotic and abiotic stresses, responsive to inputs and exhibit reduced flower and pod drop. In parallel, efforts should be made to develop determinate, bushy type varieties suitable for sole cropping, different cropping systems, relay cropping and machine harvesting. The improvement of climbing type varieties by breeding for a reduced inter-nodal distance and clustered podding is an additional priority. For all growth habit types, enhancing nitrogen fixing ability will be a desirable breeding goal.

Conservation of PGR: A tremendous level of genetic diversity is still present in dolichos. The collection and assessment of germplasm can therefore be expected to support the efforts of breeders to improve the crop's productivity. While collection activity is being pursued in the Indian subcontinent, this is not the case in Africa or elsewhere in Asia. It would be desirable to put in place a system encouraging the ready international exchange of germplasm among the relevant researchers.

Development of distinctness, uniformity and stability (DUS) guidelines: For the legal protection of any crop variety from unlawful commercial exploitation, an official system for variety registration (such as the Indian Protection of Plant Varieties and Farmers Rights Authority) needs to be established wherever the crop is commercially grown. The registration of a new variety is based on DUS criteria, for which development of descriptors and DUS test guidelines is a pre-requisite. While descriptors (Byregowda *et al*.) have been developed (**Appendix I**), DUS test guidelines are yet to be developed in India.

Molecular breeding: The use of DNA-based markers has become ubiquitous in crop breeding programmes across the world, but these are not well developed as yet for dolichos. Thus, a pressing research priority is currently to assemble a sufficient number of informative markers, based either on microsatellite or single nucleotide polymorphism technology.

11. RESEARCH CENTRES

The following research centers are currently engaged in the dolichos improvement programme:

Institution	Specialization and research activities	Website
University of Agricultural Sciences (UAS), Bengaluru, India	Germplasm collection, evaluation, conservation and utilization	www.lablab.org
	Conventional and marker-assisted improvement	www.uasbangalore.edu.in
CSIRO, Australia	Breeding for forage purpose	www.csiro.au
IITA, Nigeria	Germplasm collection, Conservation and utilization, Breeding for biotic and abiotic stresses	www.iita.org
Bangladesh Agriculture Research Institute (BARI), Bangladesh	Genetic improvement using conventional and genomic tools	www.bari.gov.bd
Indian Institute of Vegetable Research (IIVR), Varanasi, Uttar Pradesh, India	Breeding for vegetable purpose	www.iivr.org.in
Indian Institute of Horticulture Research (IIHR), Hessaragatta, Bangalore, India	Genetic improvement	www.iihr.res.in
Tamil Nadu Agricultural University (TNAU), India	Genetic improvement using conventional and genomic tools	www.tnau.ac.in
Kenya Agriculture Research Institute (KARI), Kenya, Africa	Germplasm collection, evaluation and breeding for African countries	www.kalro.org www.ilri.org
USDA-ARS, USA	Conservation and improvement	www.ars.usda.gov

BIBLIOGRAPHY

Abule, E., N.N. Umunna, I.V. Nsahlai, P.O. Osuji, and Y. Alemu. 1995. The effect of supplementing teff (*Eragrostis tef*) straw with graded levels of cowpea (*Vigna unguiculata*) and lablab (*Lablab purpureus*) hays on degradation, rumen particulate passage and intake by crossbred {Friesianx Boran (zebu)} calves. Livestock Production Science. 44:221-228.

Adebisi, A.A. and C.H. Bosch. 2004. *Lablab purpureus* (L.) sweet. In: Grubben, GJH and Denton, OA (eds). Plant Resources of Tropical Africa (PROTA), No. 2, Vegetables. Wageningen, The Netherlands: PROTA Foundation, pp. 343–348.

Al-Snafi, A.E. 2017. The pharmacology and medical importance of *Dolichos lablab* (*Lablab purpureus*) - A review. IOSR Journal of Pharmacy. 7(2): 22-30 22.

Amkul, K., J.M. Sookbang and P. Somta. 2021. Genetic diversity and structure of landrace of lablab (*Lablab purpueus* L. Sweet) cultivars in Thailand revealed by SSR markers. Breeding Science. 71: 176-183.

Anderson, N.O., P.D. Ascher and K. Haghighi. 1996. Congruity backcrossing as a means of creating genetic variability in self-pollinated crops: seed morphology of *Phaseolus vulgaris* L. and *P. acutifolius* A. Gray hybrids. Euphytica, 87(3):211-224.

Ayyangar, G.N. and K. Kunhi Krishnan Nambiar. 1935. Studies in *Dolichos lablab* (Roxb.) and (L.) - the Indian field and garden bean. I. In Proceedings of the Indian Academy of Sciences, Section B (Vol. 1, No. 12, pp. 857-867). Indian Academy of Sciences.

Blench, R. 2003. The movement of cultivated plants between Africa and India in prehistory. In: Neumann K, Butler EA, Kahlheber S (eds) Food, Fuel and Fields: Progress in African Archaeobotany. Africa Praehistorica 15. HeinrichBarth-Institut, Köln. 273-292.

Bravo, L., P. Siddhuraju and F. Sauvo-Calistico. 1999. Composition of under exploited Indian pulses, comparison with common legumes. Food Chem. 64:85-102.

Britton, N.L. and P. Wilson. 1924. Botany of Porto Rico and the Virgin Islands. Sci. Surv. Porto Rico 5:424.

Bruce, C. and B.L. Maass. 2001. *Lablab purpureus* L. Sweet- diversity, potential and determination of a core collection of this multi-purpose tropical legume. Genetic Resources and Crop Evolution. 48:261-272.

Byregowda, M. 2009. Annual Report: Genetic enhancement of dolichos bean through integration of conventional breeding and molecular approaches and farmers participatory plant breeding. University of Agricultural Sciences, Bangalore, India and Kirkhouse Trust, United Kingdom.

Byregowda, M., G. Gireesh, S. Ramesh, P. Mahadevu, and C.M. Keerthi. 2015. Descriptors of Dolichos bean (*Lablab purpureus* L.). J. Food Legumes. 28(3):203-214.

Byregowda, M., S. Ramesh, C.M. Keerthi, G.A. Mary Reena, B.S. Rajendra Prasad, P.V. Vaijayanthi, B.V. Pavitra Vani, G.N. Veerkumar, G. Girish, M. Mahadevu, R. Ramachandra and K. Chalapath Reddy. 2018. Dolichoslogue – A Catalogue of Dolichos Bean (*Lablab purpureus* L. Sweet) Germplasm.

Cameron, D.G. 1988. Tropical and subtropical pasture legumes. Queensland Agricultural Journal. March-April:110-113.

Carney, J. and R.N. Rosomoff. 2009. *In the shadow of slavery: Africa's botanical legacy in the Atlantic world*. Univ. of California Press.

Chetia, A., C.R. Sarkar, and I. Borua. 2004. Effect of cooking on nutritional quality of Field bean (*Dolichos lablab* L.) seeds: Bioprospecting of commercially important plants. Proceedings of National Symposium on Biochemical approach for utilization and exploitation of commercially important plants. Jorhat, India. 12-14 November 2004: 168-176.

Chikkadevaiah, S.G., K. Shrivashankar, K. Virapakshappa and S.R. Hiremath. 1981. Heterosis in field bean. *Lablab purpureus* L.). Indian J. Genet. 41(3):366-367.

Chowdhury, A.R., M. Ali and M.A. Quadir. 1989. Aspects of Pollination and Floral Biology of Lablab Beans (*Lablab perpureus* L. Sweet). Journal of the Japanese Society for Horticultural Science. 58(3):665-671.

Cook, B.G., B.C. Pengelly, S.D. Brown, J.L. Donnelly, D.A. Eagles, M.A. Franco, J. Hanson, B.F. Mullen, I.J. Partridge, M. Peters and R. Schultze-Kraft. 2005. Tropical forages: an interactive selection tool. *Lablab purpureus*. CSIRO, DPI & F(Qld), CIAT, and ILRI, Brisbane.

Deka, R.K. and C.R. Sarkar. 1990. Nutrient composition and anti-nutritional factors of *Dolichos lablab* L. seeds. Food Chemistry. 38:239-246.

Devaraj, V.R. 2016. Economic importance of hyacinth bean (*Lablab purpureus* (L.) Sweet): An Indian perspective. Legume Perspectives 13:37-38.

Engle, L.M. and N.C. Altoveros. 2000. Collection conservation and utilization of indigenous vegetables: proc. of a workshop, AVRDC, Shanhua, Tainan, Taiwan, 16-18 August 1999. Asian vegetable Research and Development Center (AVRDC), Shanhua, Taiwan. pp 142.

Erskine, W., J. Isawi and K. Masoud. 1990. Single plant selection for yield in lentil. Euphytica. 48:113-116.

FAO. 2018. Future Smart Food Rediscovering hidden treasures of neglected and underutilized species for Zero Hunger in Asia, Executive summary, Bangkok, 36 pp. https://doi.org/http://www.fao. org/3/I8907EN/i8907en.pdf

Fernandes, A.F. and G. Nagendrappa. 1979. Chemical constituents of Dolichos bean (field bean) pod exudates. J. Agric. Food Chem, 27(4):795-798.

Forsythe, C. 2019. Exploring the viability of re-introducing *Lablab purpureus* (L.) Sweet as a multifunctional legume in northern Tanzania. 1-79. https://stud.epsilon.slu.se.

Fuller, D.Q. 2003. African crops in prehistoric South Asia: a critical review. Food, fuel and fields: Progress in African archaeobotany. pp. 239-271.

Fuller, D.Q., N. Boivin, R. Korisettar. 2007. Dating the Neolithic of South India: new radiometric evidence for key economic, social and ritual transformations. Antiq. 81:755-778.

Genesys (2013-2015). *Lablab purpureus*. Bioversity International / Global Crop Diversity Trust/ Secretariat of the International Treaty on the Plant Genetic Resources for Food and Agriculture. https://www.genesys-pgr.org.

Goldblatt, P. 1981. Cytology and the phylogeny of Leguminosae. In: Polhill, R.M., Raven, P.H. (Eds.), Advances in legume systematics, part 2. Richmond, U.K.: Royal Botanic Gardens, Kew. 427-463.

Haddad, N.I. and F.J. Muehlbauer. 1981. Comparison of random bulk population and single-seed-descent methods for lentil breeding. Euphytica. 30: 643-651.

Harish Kumar, S.M., Ghawade, Shivaputra and M.L. Meghwal. 2018. Effect of Gamma Radiations on Growth, Yield and Quality Traits of Dolichos Bean (*Lablab purpureus* L.). Int. J. Curr. Microbiol. App. Sci. 6: 853-859.

Harland, S.C. 1920. Inheritance in Dolichos lablab L. Part I. J. Genet. 10:219-226.

Hendricksen, R.E. and D.J. Minson. 1985. *Lablab purpureus* - A Review. Herbage Abstracts. 55:215-227.

Islam, M.T. 2008. Morpho-agronomic diversity of hyacianth bean [*Lablab purpureus* (L)] accessions from Bangladesh. Plant Genetic Resources Newsletter. 156: 73-78.

Islam, N., M.Z. Rahman, R. Ali, A.K. Azad and M.K. Sultan 2014. Diversity analysis and establishment of core subset of hyacianth bean collection of Bangladesh. Pakistan J. Agric. Res., 27 (2):99-109.

Kamatchi, K.B., S.P. Tresina, V.R. Mohan and V. Vadivel. 2010. Nutrient and chemical Evaluation of raw seeds of five varieties of Lablab bean (L.) Sweet. Advances in Bioresaerch. 1(1).

Kamau, E.M., M.G. Kinyua, O. Kiplagat and L. Gohole. 2011. Gamma radio sensitivity determination for lablab (*Lablab purpureus*) bean. Plant Mutation Reports. 2 (3):46-54.

Kataria, A., B.M. Chauhan, and D. Punia. 1989. Antinutrient and protein digestibility (*in vitro*) of mungbean effected by domestic processing and cooking. Food Chem. 32:9-17.

Kay, D.E. 1979. Hyacinth bean - Food Legumes. Crop and Product Digest No. 3. Tropical Products Institute. xvi:184-196.

Kempanna, C., T.K. Siddaramegowda and M. Byregowda. 2008. Global research digest on dolichos bean (*Lablab purpureus* L.) A review. Kirkhouse Trust, Oxford, UK.

Khan, M.A., I. Jocobsen and B.D. Eggum. 1979. Nutrutive values of some improved varieties of Legumes. J. Sci, Agric. 30:395-400.

Kshirsagar, J.K., V.V. Dalvi, S.G. Bhave, U.B. Pethe and S.G. Mahadik 2014. Induced Mutagenesis in Lablab Bean (*Lablab purpureus* L. Sweet var. Typicus). Research Journal of Agricultural Sciences 5(6): 1215-1218.

Kukade, S.A. and J.A. Tidke. 2014. Reproductive biology of Dolichos lablab L. (Fabaceae). Indian J. Plant Sci. 3:22–25

Maass, B. 2016. Domestication, origin and global dispersal of *Lablab purpureus* (L.) Sweet (Fabaceae): current understanding. Legume Perspectives 13:5. https://www.researchgate.net/publication/283634749.

Maass, B. L., R.H. Jamnadass, J. Hanson and B.C. Pengelly. 2001. Determining sources of diversity in cultivated and wild *Lablab purpureus* related to provenance of germplasm using amplified fragment length polymorphism (AFLP). Genet. Resour. Crop Evol. 52:683-695.

Maass, B., O. Robotham, and M. Chapman. 2017. Evidence for two domestication events of hyacinth bean (*Lablab purpureus* (L.) Sweet): A comparative analysis of population genetic data. Genetic Resources and Crop Evolution 64 (6):1221-30. 10.1007/s10722-016-0431-y.

Maass, B.L., M.R. Knox, S.C. Venkatesha, T.T. Angessa, S. Ramme and B.C. Pengelly. 2010. *Lablab purpureus*—a crop lost for Africa? Trop. Plant Biol. 3: 123-135.

Magoon, M.L., Amar Singh and K.L. Mehra. 1974. Improved field bean for dry land forage. Indian Farming. 24(2):5-7.

Mahadevu, P. and M. Byregowda. 2005, Genetic improvement of Dolichos bean (*Lablab purpureus* L.) through the use of exotic and indigenous germplasm. Indian J. Plant Genet. Resour. 18:1-5.

Mayer, L., D.R. Chandler and M.S. Taylor. 1986. *Lablab purpureus* - A fodder crop for Botswana. Bulletin of Agricultural Research in Botswana No. 5:37-48.

Milford, R. and D.J. Minson. 1968. The effect of age and method of hay making on the digestibility and voluntary intake of the forage legumes *Dolichos lablab* and *Vigna sinensis*. Australian J. Experimen. Animal Husbandry. 8:409-418.

Minde, J.J., P.B. Venkataramana and Matemu, A.O. 2020. *Dolichos Lablab*- an underutilized crop with future potentials for food and nutrition security: a review. Critical Reviews in Food Science and Nutrition, 0(0), 1-13.

Minson, D.J. 1990. Forage in Ruminant Nutrition. Academic Press, Inc. Toronto. 483 pp.

More, A.D. and S.S. Jagtap. 2016. Induction of Morphological Leaf Mutations in *Lablab purpureus* (L.) Sweet through Chemical and physical mutagens. Int. J. Curr. Microbiol. App. Sci. 5(10): 592-597.

Murphy, A.M. and P.E. Colucci. 1999. A tropical forage solution to poor quality ruminant diets: a review of *Lablab purpureus*. Livest. Res. Rural Dev. 11(2).

Narayanan, T.R. and P.M. Dabadghao 1972. Forage crops of India, ICAR, New Delhi. pp. 71-73.

NRC/NAS 1980. National Research Council Committee on Dietary Allowances. Recommended dietary allowances 9th edn. National Academy of Science Press. Washington, DC. USA.

Oke, O.L. 1969. The role of hydrocyanic acid in nutrition. *World review of nutrition and dietetics*, 11: 170-198.

Pujari, I. 2000. Elucidation on genetic variability in country bean with conventional and molecular strategies. MSc (Agri.) Thesis, OUAT, Bhubaneswar.

Purseglove, J.W. 1968. Tropical Crops, Dicotyledons. Vol L London, UK; Longmans Greens and Company Ltd. pp 273-276.

Quirien van O. and T. Kent 2005. Sensory evaluation techniques In: Methods in Development Research: Combining Qualitative and Quantitative Approaches (eds) Campbell JR, Holland J. *Kent, Great Britain*, 107-118.

Ramesh, S. and M. Byregowda. 2016. Dolichos bean (*Lablab purpureus* L. Sweet, var. *lignosus*) genetics and breeding – present status and future prospects. Mysore J. Agric. Sci. 50(3):481-500.

Rao, N.B.S., Y.G. Deosthale and K.C. Panth. 1989. Nutritive value of Indian foods, Hyderabad, India. National Institute of Nutrition, Indian Council of Medical Research.

Sasthry, B.N. 1952. *Dolichos lablab* L. The wealth of India-raw materials. 3: 104-106.

Savitha, B.N. 2008. Characterization of avare (*Lablab purpureus* (L.) Sweet) local collections for genetic. http://krishikosh.egranth.ac.in/bitstream/1/82563/1/th9751.pdf

Schaaffhausen, R.V. 1963a. *Dolichos lablab* or Hyacinth bean; Its uses for feed, food and soil improvement. Economic Botany. 17:146-153.

Schaaffhausen, R.V. 1963b. Economical methods for using the legume *Dolichos lablab* for soil improvement, food and feed. Turrialba. 13:172-178.

Shanmugam, A. 2000. Characterization of a country bean germplasm: Morphological, biochemical and molecular approaches. M.Sc. Thesis, OUAT, Bhubaneswar.

She, C. and X. Jiang. 2015. Karyotype analysis of *Lablab purpureus* (L.) Sweet using fluorochrome banding and fluorescence *in situ* hybridisation with rDNA probes. Czech J. Genet. Plant Breed. 51:110-116.

Shivashankar, G, I. Srirangasayi, C. Kempanna and S.R. Viswanatha. 1971. Day-Neutral varieties of *Dolichos lablab* L. Mysore J. Agric. Sci. 5:216-218.

Shivashankar, G. and R.S. Kulkarni. 1989. Field bean (*Dolichos lablab* L. var. *lignosus* Prain). Indian Hort. 34, pp. 24-27.

Shivashankar, G., Chikkadevaiah S.R. and S.R. Hiremath 1977. Germplasm of field bean. Indian J. Genet. 37:353-371.

Sweet, R. 1826. Sweet's *Hortus Britannicus*: or a catalogue of plants cultivated in the gardens of Great Britain. James Ridgeway, London.

Tyagi, R.K., A. Agrawal, A. Pandey, K.S. Varaprasad, R.S. Paroda and R.K. Khetarpal. 2018. Underutilized crops for food and nutritional security in Asia and the Pacific. https://doi.org/http://www. apaari.org/web/wp-content/uploads/downloads.

Undirwade, G.P. and G.B. Kulkarni. 2019. Effect of mutagens on seed germination, seedling height and survival of plants in Hyacinth bean (*Lablab purpureus* L.) sweet. Bioscience Discovery. 10 (3):129-133.

Vaijayanthi, P. V., S. Ramesh, M. Byregowda, A. Mohan Rao, C.M. Keerthi, and G.A. Marry Reena. 2015. Genetic variability for morpho-metric traits in dolichos bean (*Lablab purpureus*L.). J. Food Legumes, 28(1):5-10.

Vaijayanthi, P.V., S. Ramesh, M. Byregowda, A. Mohan Rao and C.M. Keerthi. 2016a. Identification of traits specific accessions from a core set of Dolichos Bean (*Lablab purpureus* L. Sweet) Germplasm. J. Crop Improv. 30(2):244-257.

Vaijayanthi, P.V., S. Ramesh, M. Byregowda, A. Mohan Rao, H.K. Ramppa and Chinnamade Gowda. 2016b. Identification of selected germplasm accessions for specific/wide adaptation coupled with high pod productivity in Dolichos bean (*Lablab purpureus* L. Sweet). Mysore J. Agric. Sci. 50(2): 376-380.

Vaijayanthi, P.V., Chandrakant and S. Ramesh. 2019. Hyacinth bean (*Lablab purpureus* L. Sweet): Genetics, Breeding and Genomics. In: Al-Khayri, J., Jain, S., Johnson, D. (eds) Advances in Plant Breeding Strategies: Legumes. Springer, Cham.

Valenzuela, H. and J. Smith. 2002. Sustainable agriculture green manure crops. SA-GM-7. Cooperative Extension Service, College of Tropical Agric. and Human Resources, Univ. of Hawaii at Manoa. http://www.ctahr.hawaii.edu/oc/freepubs/pdf/GreenManureCrops/lablab.pdf.

Veeraswamy, R., V.K. Kunjamma Krishi, G.A. Palaniswami. and V.P.A. Rajasekaran. 1973. Development of Lablab Co. 6, Co. 7 and Co. 8 – Three short term varieties for all seasons. Madras Agric. J. 60:1339-1341.

Venkatesha, S.C. 2012. Molecular characterization and development of mapping populations for construction of genetic map in Dolichos bean [*Lablab purpureus* L. (Sweet)]. Ph.D. thesis to University of Agricultural Sciences, Bangalore, India.

Verdcourt, B. 1970. Studies in the Leguminosae-Papilionoïdeae for the 'Flora of Tropical East Africa': III. Kew Bull. 24:379-447.

Viswanath, S.R., R. Siddarammappa, G. Sivashankar and P. Suresh. 1972. Study of variability for protein content in *Dolichos lablab* L. Mysore J. Agric. Sci. 6:56-58.

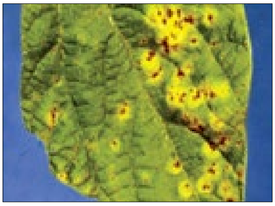
Viswanath, S.R., G. Shivashankar and A. Manjunath. 1971. Non-season bound *Dolichos lablab.* L. with new plant type. Curr. Sci. 40(24):667-688.

Wang, F.J., T.Y. Wang and F.N. Wang. 1991. Germplasm resources of grain legumes in Hainan Island. Crop Genet Resour. 1:7-10.

Westphal, E. 1975. The proposed retypification of *Dolichos lablab*. a review. Taxon. pp. 189-192.

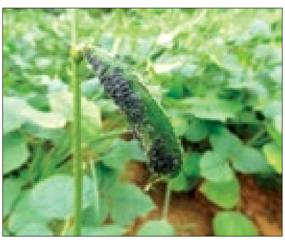
Xu-Xiangshang, D.E. Tehg You, Chen XueQun, Y.D. Teng and X.Q. Chen. 1996. Germplasm resources of *Dolichos lablab* in north-eastern and south-western China. Crop Genet. Resour. 3:20-21.

ANNEXURE I: Diseases, their casual organisms and damage symptoms in dolichos bean.

Disease name	Symptoms of damage	
Leaf spot (*Alternaria alternata*)		Symptoms include round, brown spots with concentric rings on leaves. Spots often have a yellow halo and can crack through the middle. As the disease progress, spots begin to merge together, and large necrotic areas are created.
Rust (*Uromyces appendiculaters*)		Red and black pustules appear on the lower leaf surfaces. Severely infected leaves turn yellow, wilt, and then drop off the plant. Stem and pods may also be infected.
Anthracnose (*Colletotrichum lindemuthianum)*		Elongated dark-brown or black sunken lesions about ½ inch in diameter develop on stems, pods and seedling leaves (cotyledons) but are most prominent on pods.
Powdery mildew (*Erysiphe polygonii*)		White to grayish patches is formed on both sides of the leaves and all portions of the above ground pods. It is seed as well as soil-borne spread by wind and rain. Leaves may turn yellow and die, while pods either do not set or remain small.

Dolichos bean mosaic virus disease		Viral disease transmitted by aphids. Infected leaves turn yellowish green, wrinkled and stiff. Though it rarely kills the plant, the growth is retarded, and plants do not produce pods, or bear deformed pods. It is a seed-borne disease
Bacterial leaf spot (*Xanthomonas campestris* pv phaseoli)		Light greenish-yellow circles that look like halos form around a brown spot or lesion on the plant. With age, the lesions may join as the leaf turns yellow and slowly dies. Leaves infected with blight turn brown and drop quickly from the plant.

ANNEXURE II: The major insects and their damage symptoms in dolichos bean.

Insect name	Symptoms of damage	
Dolichos pod borer (*Adisura atkinsoni)*		Larva bores inside the pod and feeds on the seeds within. Larva remains inside the pod. Infested pods can be easily be identified by bores with serrated holes.
Gram pod borer (*Helicoverpa armigera*)		Larva feeds on flower buds and flowers and then attacks pods. Internal tissues are eaten severely and completely hollowed out. While feeding, the caterpillar typically thrust its head inside leaving the rest of the body outside. Infested pods can easily be identified by bores with round holes.
Spotted pod borer (*Maruca testulalis*)		Larva feeds on flower buds and flowers and causing premature flower dropping.Infestedflowersandpodsare webbed together. At later stage, they feed on the seeds of tender pods. The damaged pod has a large emergence hole made by the pupating larva.
Spiny pod borer (*Etiella zinckenella*)		Feeds on the flowers causing premature flower dropping and young pods. Older pods marked with a brown spot where larvae enter.
Bean Aphids (*Aphis craccivora*)		Both nymphs and adults suck the sap from leaves, buds, flowers and pods. Curling may occur for infested leaves and at advanced stage, plants may wither and die. Plants remain stunted and sooty molds grow on the honey dew excreted by these insects.

Leaf hopper (*Empoasca kerri*)		The infected leaves show pale yellow coloration. In case of heavy infestation, the leaves curl. The leaf edges turn light pinkish brown. Stunted growth of plant, cupped and crinkled leaves, burnt appearance of leaf margins are symptoms of damage.
Pod bugs (*Riptortus pedestris*)		Nymphs and adults suck the sap from seeds of developing pods through pod wall. Affected pods show clear brown spots on the pods, seeds become shriveled and lose viability. Shedding of green pods. Poorly filled pods with shriveled grains inside.
Whitefly (*Bemisia tabaci*)		Nymphs and adults suck sap and excrete honeydew. A secondary infection develops when a black sooty mould fungus grows on the sticky honeydew. Under very heavy infestations, plants lose vigour and damage is manifested under severe moisture stress, causing leaf wilting and failure to set seed.
Red spider mite (*Tetrancychus cinnabarinus*)		Red spider mite feeds on leaves. Severe mite injury produces browning and loss of colour in the leaves i.e. yellowing, bronzing and curling of leaves.
Bruchid (*Callosobruchus chinensis*)		In the early stages, the eggs are seen on the surface of the seeds. The insect develops within the seed. Adults emerge through windows in the grain, leaving round holes on the surface of the seed

APPENDIX I: Descriptors and descriptor states of dolichos bean.

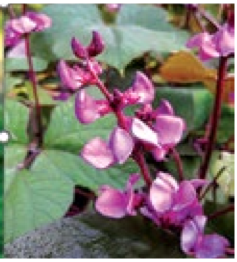
Sl. No.	Descriptor	Descriptor states/scale
1.	**Vegetative**	
1.01	Emerging cotyledon colour	1 = white, 2 = green, 3 = purple
1.02	Hypocotyl colour	1 = green, 2 = purple
1.03	Stem pigmentation	0 = no pigmentation, 3 = localized to nodes, 5 = Extensive, 7 = Almost solid
1.04	Leaf vein colour	Fully developed primary leaves (on inner leaves) 1 = green, 2 = purple
1.05	Leaf anthocyanin	0 = Absent, 2 = Present
1.06	Leaf colour	1 = pale green, 3 = green, 5 = dark green, 7 = purple, 9 = dark purple
1.07	Leaf hairiness (on inner surface)	0 = globorous, 3 = low pubescent, 5 = moderately puibescent, 7 = highly pubescent
1.08	Leaf length	Measured on the terminal leaflet of third trifoliate leaf (middle portion of the leaf) from 10 plants (cm)
1.09	Leaf width	Measured on the terminal leaflet of third trifoliate leaf (middle portion of the leaf) from 10 plants (cm)
1.10	Leaflet length	Measured on the terminal leaflet of third trifoliate leaf from pulvinous to leaf tip from 10 plants (cm)
1.11	Leaf shape	1 = Round, 3 = Ovate, 5 = Ovate-lanceolate, 7 = Lanceolate, 9 = Liner-lanceolate
1.12	Growth habit	1 = Determinate, 2 = Semi determinate, 3 = Indeterminate, 4 = Others (specify)
1.13	Primary branches	Average from 10 randomly chosen plants

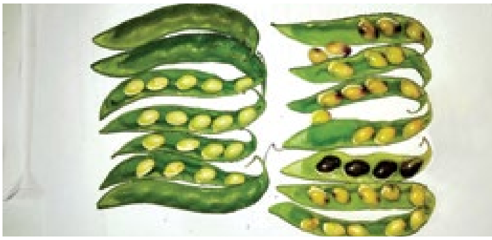
Sl. No.	Descriptor	Descriptor states/scale
1.14	Secondary branches	Average from 10 randomly chosen plants
1.15	Branch orientation	3 = Short and erect lateral branches 5 = Branches tending to be perpendicular to main stem, medium in length 7 = First lateral branches long and spreading over ground
1.16	Plant height	Measured on 10 random matured plants for cotyledon scar to tip of plant (cm)
2.	**Inflorescence**	
2.01	Days to 50% flowering	Days from sowing to 50% of the plant produce flower
2.02	Flower bud length Gust before opening)	Average of 10 randomly chosen buds (mm)
2.03	Flower bud width (just before opening)	Average of 10 randomly chosen buds (mm)
2.04	Flower bud colour	1 = White, 2 = Cream, 3 = Light Yellow, 4 = Pink, 5 = Purple
2.05	Standard petal colour	1 = White, 2 = Cream 3 = Light Yellow, 4 = Pink, 5 = Purple
2.06	Wing petal colour	1 = White, 2 = Cream, 3 = Light Yellow, 4 = Pink, 5 = Purple
2.07	Keel petal colour	1 = White, 2 = Cream, 3 = Light Yellow, 4 = Pink, 5 = Purple
2.08	Number of flower buds/raceme	Average of 10 randomly chosen racemes
2.09	Number of racemes/ plant	Average of 10 randomly chosen plants

Sl. No.	Descriptor	Descriptor states/scale
2.10	Raceme length	Average of 10 randomly chosen plants (cm)
2.11	Peduncle length	Average of 10 randomly chosen racemes (cm)
2.12	Raceme position/ emergence	3 = Within foliage, 5 = Intermediate, 7 = complete emergence from leaf canopy
2.13	No. of nodes/raceme	Average from 10 randomly chosen racemes
2.14	No. of buds/node	Average from 10 randomly chosen racemes
3.	**Fruit**	
3.01	Fresh pod curvature	0 = Straight, 3 = Slightly curved, 5 = Curved
3.02	Fresh pod pubescence	0 = Glabrous, 3 = Moderately pubescent, 5 = Pubescent
3.03	Fresh pod beak length	Average of 10 randomly chosen pods (cm)
3.04	Fresh pod fragrance	1 = Short Break, 2 = Medium length, 3 = Long beak, 4 = Thick beak
3.05	Fresh pod length	0 = Absent, 1 = Low, 2 = Medium, 3 = high
3.06	Fresh pod width	Average of 10 randomly chosen pods (cm)
3.07	Fresh pod constriction	Average of 10 randomly chosen pods (cm)
3.08	Fresh pod colour	0 = No constriction, 3 = Slightly constricted, 5 = constricted
3.09	Fresh pod attachment	1 = White, 2 = Cream, 3 = Green, 4 = Green with purple suture, 5 = Purple, 6 = Dark Purple, 7 = Red
3.10	Number of fresh pods /plant	1 = Erect, 2 = Intermediate, 3 = Pendant
3.11	Number of locules/ fresh pod	Average number of pods from 10 randomly chosen plants

Sl. No.	Descriptor	Descriptor states/scale
3.12	Number of seeds/ fresh pod	Average of 10 randomly chosen pods
3.13	Fresh pod shelling Percentage	Average of 10 randomly chosen pods
3.14	Fresh pod coat thickness	Average of 10 pods chosen at random
3.15	Days to fresh pod harvest	Average of 10 randomly chosen pods (mm)
3.16	Fresh pod yield	Days taken when fresh pods are ready to harvest
3.17	Plant Pod color at physiological maturity	Average of 10 randomly chosen plants (g)
3.18	Dry pod coat thickness	3 = Tan, 5 = Brown, 7 = others (specify)
3.19	Dry pods	Average of 10 randomly chosen pods (mm)
3.20	Shelling percentage	Average of 10 pods chosen at random
4.	**Seed**	
4.01	Fresh seed colour	1 = Green, 2 = Cream, 3 = Purple, 4 = Brown, 5 = Black
4.02	Fresh seed hilum colour	1 = White, 2 = Tan, 3 = Others (specify)
4.03	Fresh seed length	Average of 10 seeds chosen at random (mm)
4.04	Fresh seed width	Average of 10 seeds chosen at random (mm)
4.05	Fresh seed shape	1 = Round, 2 = Oval, 3 = Flat, 4 = Other (specify)
4.06	Fresh 100 seed weight	Average weight of 100 seeds chosen at random (g)
4.07	Fresh seed yield plant	Average of 10 plants chosen at random (g)
4.08	Fresh seed dhal recovery	Average of 10 seeds chosen at random (%)

Sl. No.	Descriptor	Descriptor states/scale
4.09	Fresh seed coat thickness	Average of 10 seeds chosen at random (mm)
4.10	Dry seed colour	1 = White, 2 = Green, 3 = Cream, 4 = Purple, 5 = Brown, 6 = Black
4.11	Dry seed hilum colour	1 = White, 2 = Tan, 3 = Others (specify)
4.12	Dry seed length	Average of 10 seeds chosen at random (mm)
4.13	Dry seed width	Average of 10 seeds chosen at random (mm)
4.14	Dry seed thickness	Average of 10 seeds chosen at random (mm)
4.15	Dry seed shape	1 = Round, 2 = Oval, 3 = Flat, 4 = Others (specify)
4.16	Dry 100 seed weight	Average weight of 100 seeds chosen at random (g)
4.17	Dry seed texture	3 = Smooth, 5 = moderately ridged, 7 = markedly ridged
4.18	Dry seed coat thickness	Average of 10 seeds chosen at random (mm)
4.19	Dry seed dhal recovery	Average of 10 seeds chosen at random (%)
4.20	Dry seed yield plant	Average of 10 plants chosen at random (g)





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ISBN: 978-1-0685499-0-8