Lablab purpureus (L.) Sweet:
A promising multipurpose legume for enhanced drought resistance and improved household nutritional status in smallholder farming systems of Eastern Kenya



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Abstract

Smallholder farmers in the semi-arid regions of Eastern Kenya frequently face low yields or complete crop failures as a result of unreliable and highly variable rainfall, lack of irrigation facilities and poor soils. Legumes offer a number of benefits under these resource-constraint conditions and are traditionally integrated into mixed crop-livestock farming systems, the most prevalent systems in the region. *Lablab purpureus* is considered to be drought tolerant and was formerly a highly valued traditional crop for food and fodder in Africa and could therefore, have potential to help farmers manage risks today. However, nowadays, lablab's utilization by farmers is in steady decline, being outperformed by other leguminous species such as common bean (*Phaseolus vulgaris* (L.)) and cowpea (*Vigna unguiculata* (L.) Walp.). Underlying reasons might be partly attributed to lablab's poor eating qualities and relatively long growing period. Therefore, increasing adoption potential by farmers will require new germplasm that suits farmers' preferences beyond merely exhibiting great ability to cope with drought conditions. Production potential, the presence of drought adaptation mechanisms, and the eating quality of selected, potentially short-season lablab accessions were tested under environmental conditions of semi-arid Eastern Kenya. The lablab accessions (Q6880B, CPI 60795, CPI 52508, CPI 52513, CPI 52535, and CPI 81364) were grown on-station in a water-deficit as well as on-farm in a rainfed-only experimental setting. Data collection included time to flowering and maturity, biomass development and partitioning, grain yield production and nitrogen accumulation throughout the plants' development. Additionally, leaf area index development, transpiration and photosynthetic rate were determined. Finally, an organoleptic tasting was performed to identify suitable accessions for human consumption.

Among the earliest accessions to mature were Q6880B and CPI 81364, which took between 112 and 116 days after planting. Biomass dry matter (DM) and grain yields varied greatly across accessions, treatments and locations. DM yields exceeding 4000 kg DM ha^{-1} under rainfed conditions on-station were obtained from accessions CPI 60795 and CPI 81364. On-farm DM yields exceeding 3000 kg DM ha^{-1} were achieved by accessions Q6880B and CPI 81364. Additionally, both these accessions have proven to supply comparatively superior grain yields with >500 kg ha^{-1} on-farm and >1000 kg ha^{-1} on-station. The tasting identified the greatest acceptability for grains of accession CPI 81364. However, susceptibility of lablab to pests and diseases is a significant issue that requires management packages to be developed so that farmers may successfully cultivate this important food legume.

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Abbreviations and acronyms

Abbreviation	Description
%	percent
°C	degree Celsius
°E	east
°S	south
µmol	micromole
ANOVA	Analysis of Variance
BNF	biological nitrogen fixation
C	carbon
Ca	calcium
cg.	cultivar group
CO_2	carbon dioxide
CSIRO	Commonwealth Scientific and Industrial Research Organization
CV	coefficient of variation [%]
cv.	cultivar
d^{-1}	per day
DAP	days after planting
DM	dry matter [kg]
DNA	deoxyribonucleic acid
e.g.	for example
et al.	and others
FAO	Food and Agriculture Organization of the United Nations
FW	fresh weight
g	gram
h	hours
H_2O	water
ha	hectare
HCNp	hydrogen cyanide potential
HI	harvest index
ID	identification

Abbreviation	Description
i.e.	that is
K	potassium
KARI	Kenyan Agricultural Research Institute
kg	kilogram
km	kilometer
km^2	square kilometer
l	liter
LAI	Leaf Area Index
LWP	leaf water potential
m	meter
m^2	square meter
MA	morpho-agronomic
masl	meters above sea level
mg	milligram
min.	minute
mm	millimeter
mmol	millimol
N	nitrogen
Na	sodium
n.a.	not available
nm	nanometers
OA	osmotic adjustment
p	significance level $p \leq 0.05$
P	phosphorus
PAR	photosynthetic active radiation
pH	1:5 soil: water extract; measure of active hydrogen ion
ppm	parts per million
PS	photosynthetic rate [µmol m^{-2} s^{-1}]
R^2	coefficient of determination
ROS	reactive oxygen species
RGR	relative growth rate [g g^{-1} day^{-1}]

Abbreviation	Description
RWC	relative water content
s^{-1}	per second
SC	sandy clay
SAT	semi-arid tropics
SD	standard deviation
SL	sandy loam
ssp.	subspecies
T	transpiration rate [mmol m^{-2} s^{-1}]
TE	transpiration efficiency
TSP	triple superphosphate
US$	United States Dollar
WUE	Water Use Efficiency [kg DM ha^{-1} mm^{-1}]
Zn	Zinc

1 Introduction

Agricultural activities in the semi-arid regions of Eastern Kenya are mostly operated by smallholder farmers who run small mixed crop-livestock enterprises relying on low-inputs and rainfall only (Njarui and Wandera 2004; Mora-Vallejo et al. 2008; Muhammad et al. 2010; Njarui and Mureithi 2010; Claessens et al. 2012). Since these rural areas offer only limited income activities apart from agriculture, agriculture still plays an important role for income generation and serves as a major livelihood activity of the mainly rural-based population (Maingi et al. 2001; Gachimbi et al. 2002; Muhammad et al. 2010).

Besides poor soil fertility (Dixon et al. 2001; Macharia et al. 2011), water is the most limiting factor for crop production in these areas. Rainfall is generally low and highly variable, leading to low crop yields and even complete crop failures (Gachimbi et al. 2002; Muhammad et al. 2010; Silvestri et al. 2012). As a consequence of continous population growth and environmental restrictions, the pressure on land and resources is increasing the challenge of agricultural production in the semi-arid areas of Eastern Kenya (de Jager et al. 2001; Gachimbi et al. 2002; Macharia et al. 2011). Consequently, arable land is increasingly limited, and the need to increase agricultural productivity per unit land is, therefore, urgent for achieving food security today and in the future (Maingi et al. 2001; Gachimbi et al. 2002). In addition, the demand for dairy and meat products is constantly increasing (Pengelly and Maass 2001), but livestock nutrition in these regions is usually poor due to overgrazed pastures and lack of nutritious fodder, especially during dry seasons (Karachi 1997; Njarui and Wandera 2004; Njarui et al. 2004b; Macharia et al. 2010; Njarui and Mureithi 2010). Besides the need to increase crop production for direct human consumption, the demand for high quality forages to supplement pastures and crop residues especially during dry seasons must be met (Karachi, 1997; Njarui and Wandera 2004; Njarui et al. 2004a, 2004b; Njarui and Mureithi 2010; Macharia et al. 2011).

Facing these and future challenges, since impacts of climate change are even likely to enlarge areas affected by drought (Rao and Okwach 2005; Cooper et al. 2009; Guretzki and Papenbrock 2014), farming strategies using drought-tolerant germplasm to increase the resiliance of these dryland farming systems are urgently needed. Therefore, the identification of new crops or new crop genotypes that are particularly adapted to more arid conditions will be a major future

challenge (Rao and Okwach 2005; Whitbread et al. 2011; Guretzki and Papenbrock 2014). Furthermore, the selection of drought-tolerant crops for smallholder mixed crop-livestock farming systems are required to serve multiple needs (Njarui and Mureithi 2010; Guretzki and Papenbrock 2014).Well-adapted multipurpose legume species would fit these criteria (Karachi 1997; Pengelly and Maass 2001).

Traditionally, legumes have played an important role in farming systems of the study region of Eastern Kenya (Muthoni and Nyamongo 2010). New and more drought-tolerant germplasm is, however, needed to better cope with current and future environmental limitations (Whitbread et al. 2011). Legumes are cultivated throughout drought-prone areas and are frequently subject to water stress (Subbarao et al. 1995; Graham and Vance 2003; Bourgault and Smith 2010). However, despite their importance in diets especially in the developing world, limited effort has been put into increasing their drought tolerance and in understanding existing drought resistance mechanisms as compared to cereal crops (Subbarao et al. 1995; Turner et al. 2001; Graham and Vance 2003; Bourgault and Smith 2010). A greater understanding of drought resistance mechanisms in legumes is, therefore, crucial to focus breeding efforts that aim to increase the resilience of dryland farming systems (Subbarao et al. 1995; Bourgault and Smith 2010). Besides identifying drought-tolerant germplasm, another major challenge is to meet farmers' multiple criteria that are essential for widespread adoption and system integration (Snapp and Silim 2002). Legumes have the ability to simultaneously meet demands for human consumption as well as supply quality supplementary livestock feed and addtionally exhibit high potential for soil conservation strategies (Pengelly and Maass 2001; Bourgault and Smith 2010; Kimani et al. 2012). The most important characteristic, especially under N-deficient conditions, is the ability of legumes to fix atmospheric nitrogen (N) through their symbiosis with rhizobia and to contribute N to subsequent crops (Wortmann et al. 2000; Pengelly and Maass 2001; Nyambati et al. 2006; Ojiem et al. 2007; Maass et al. 2010). Additionally, legumes can help suppress the growth of weeds, recover deeply leached nutrients and add organic material to the soil, consequently improving soil chemical and physical properties (Wortmann et al. 2000; Pengelly and Maass 2001; Nyambati et al. 2006; Maass et al. 2010; Whitbread et al. 2011). In this way, legumes play an important role in maintaining soil fertility in low-input farming systems besides providing

food and fodder for humans and livestock where protein is especially in short supply (Deka and Sarkar 1990; Wortmann et al. 2000; Bourgault and Smith 2010).

Lablab (*Lablab purpureus* (L.) Sweet) is one of those multipurpose legumes known for its great genetic diversity (Karachi 1997; Tefera 2006; Maass et al. 2010; Whitbread et al. 2011). Reported to thrive across a wide range of environmental conditions, its genetic diversity may have led to a high phenological plasticity, playing an important role in the development of drought resistance mechanisms (Subbarao et al. 1995; Turner et al. 2001). These mechanisms include the ability of lablab to grow deep tap roots enabling the plant to reach deep residual soil moisture (NAS 1979; Duke et al. 1983; Smartt 1990; Karachi 1997; Maass et al. 2010; Whitbread et al. 2011; Guretzki and Papenbrock 2013). Lablab is considered to cope better with drough conditions compared to some of the more widely grown legumes such as common beans (*Phaseolus vulgaris* L.) or cowpeas (*Vigna unguiculata* L. Walp.) (Maass et al. 2010). Moreover, lablab is a traditional food and fodder crop in Africa, including Kenya (NAS 1979; Duke et al. 1983; Smartt 1990; Karachi 1997; Robertson 1997; Maundu et al. 1999; Maass et al. 2010; Whitbread et al. 2011), and offers great potential for smallholder farming systems in the semi-arid regions of Eastern Kenya (Karachi 1997; Osman 2007a).

Despite its earlier wide distribution in Kenya (Robertson 1997), today lablab is regarded as a minor and neglected crop; its cultivation area is in steady decline (Maundu et al. 1999; Maass et al. 2010). This may partly be attributed to the widespread utilization of long season lablab forage-type cultivars that fail to produce seeds when facing drought (Whitbread et al. 2011). In order to bring lablab back on farmers' fields, there is need to identify short-season varieties that are well-adapted to the environmental conditions in semi-arid areas and well-accepted by farmers (Pengelly and Maass 2001; Whitbread et al. 2011).

1.1 Research questions and hypotheses

This study was conducted in order to find evidence for answering research questions, from which the following hypotheses were derived:

- **i.** The *Lablab purpureus* accessions evaluated are promising short-season varieties, suitable for the environmental conditions in semi-arid Eastern Kenya.
- **ii.** *Lablab purpureus* shows great phenological and development plasticity, being especially useful in drought-prone areas.
- **iii.** *Lablab purpureus* is able to cope with limited water supply, while still yielding well and, therefore, ensuring better production compared to other grain legume options.
- **iv.** The *Lablab purpureus* accessions evaluated can be integrated into the existing eating habits and have the potential to replace commonly used *Lablab purpureus* cultivars.
- **v.** The diversity of growth characteristics in *Lablab purpureus* offers the potential for being a legume of multipurpose use, suitable to be integrated into smallholder mixed crop-livestock farming systems of semi-arid Eastern Kenya.

To test these hypotheses, different, potentially short-season lablab accessions have been evaluated regarding their yield potential in the semi-arid region of Eastern Kenya using a water-deficit trial with different water supply levels on-station, and additionally under rainfed conditions on a number of farms. The investigation of their yield potential under the predominant environmental conditions is crucial in order to identify niches for potential integration options into smallholder farming systems. Measures, therefore, included the determination of grain and biomass yields, as well as biomass development and partitioning over time, using ratios such as leaf/stem and harvest index. Additionally, leaf area index and the photosynthetic and transpiration rate were determined throughout the growing season. Thereby, a comprehensive picture of lablab's drought tolerance level and resistance mechanisms should be drawn. Moreover, lablab's ability to serve multipurpose uses was evaluated while conducting an organoleptic taste paneling with the local, participating farmers. For enhancing the likelihood of adoption, eating qualities play, among other factors, an important role. Whether, therefore, the lablab accessions evaluated offer potential for successful integration into current farming strategies should be quantified in this study.

2 State of the Art

2.1 The concept of drought resistance in legumes

Drought resistance is a broad term that has been used to describe adaptation mechanisms of crops to water-limited environments. Strategies of plants to persist through drought include dehydration avoidance and dehydration tolerance, leading to enhanced water conservation and/or more efficient water uptake (Levitt 1972; Turner et al. 2001; Hall and Naidu 2004; Blum 2005). Plants may also use more than one adaptation mechanism (Hall and Naidu 2004). According to Blum (2005), a genotype is considered to be relatively more drought-resistant if it produces better yields under severe drought stress conditions compared to other genotypes. Additionally, drought resistance in its physiological context interacts with the magnitude and the timing of stress (Blum 2005). Drought stress is defined as the condition when a plant's water demand is not met by the supply, leading to a reduced plant water status (Blum 2005).

Dehydration avoidance, defined as the plant's capacity to sustain a high plant water status or cellular hydration under the effect of drought, incorporates a broad spectrum of water saving mechanisms (Turner et al. 2001; Blum 2005). This includes the enhanced capture of soil moisture due to limited crop water loss and the conservation of cellular hydration despite the reduced plant water potential (Blum 2005). Strategies include the development of an efficient root system, early closure of stomata, increased plant osmotic adjustment (OA), reduced leaf area, reduced plant size, and altered leaf morphology (Blum 2005; Bourgault and Smith 2010).

Stomatal closure is the most universal response of plants to water stress, but stomatal behavior is complex; stomata are the sites of carbon dioxide uptake as well as the sites causing the greatest plant water loss (Bourgault and Smith 2010). An efficient root system may be the enlargement of roots to access deep residual soil moisture under drought conditions (Blum 2009).

Another mechanism seen for being crucial to maintain yield under drought conditions is a high OA (Blum 2009). OA is defined as the active accumulation of solutes by the plant in response to increasing water deficits while maintaining turgor or reducing the rate of turgor loss as water potential decreases (Turner and Jones 1980; Morgan 1984; Turner et al. 2001; Blum 2005; Bourgault and Smith 2010). High OA, therefore, seems to be positively correlated with deep soil

moisture extraction via efficient root systems as it improves the root capacity for water uptake (Blum 2009). Additionally, high OA was observed to delay leaf senescence and increase the remobilization of reserves in some grain legumes (Flower and Ludlow 1986; 1987; Leport et al. 1999; Turner et al. 2001), both being associated with yield-enhancing characteristics in drought-prone areas (Turner et al. 2001).

Furthermore, a reduction in plant size and leaf area, is seen as another major mechanism for moderating water use and reducing injury under drought stress though it is often connected with a reduced yield potential as well (Blum 2005; Blum 2009). A reduction in leaf area may be a result of reduced growth rates due to water stress, or can be seen as an adaptive mechanism related to a higher relocation of resources to root growth, or a conservation mechanism to reduce water loss from transpiration (Bourgault and Smith 2010). This applies also to the drought escaping strategy by ephemerals and early-flowering plants. Here, plants attempt to escape late-season stress and, their reduced branching may further ascribe the development of deeper roots (Hall and Naidu 2004; Blum 2005; Blum 2009). The selection for early-flowering plants has been highly successful in various crops (Hall et al. 1978; Hall and Patel 1985; Subbarao et al. 1995; Turner et al. 2001); the common bean is a well-known example (Graham and Vance 2003). However, selection towards early-flowering and determinate growth types results in a lack of capacity to respond to additional rainfall in more favorable seasons (Turner et al. 2001).

Dehydration tolerance, defined as the relative capacity to sustain or conserve plant function in a dehydrated state, is a mechanism rarely found in crops as it requires plants to enter a quiescent or dormant state (Blum 2005). It describes the ability of plant cells to continue metabolism at a low leaf water status (Turner et al. 2001). Since dehydration tolerance is rarely found in plants, except the so called “resurrection plants”, it is suggested that both natural selection and breeding programs have been focused on dehydration avoidance rather than on dehydration tolerance (Blum 2005). However, the mechanism of stem reserve utilization for grain filling under drought stress can be seen as the most common form of an effective dehydration tolerance strategy and only few others are known (Blum 2005).

2.1.1 Developmental and phenological plasticity

A major factor influencing the efficiency of a plant's strategy to persist through drought conditions is the extent to which developmental and phenological plasticity is exhibited (Subbarao et al. 1995; Turner et al. 2001).

Development plasticity is defined by Subbararo et al. (1995) as "the ability to adjust the duration of different growth phases to suit moisture availability"; often referred to as phenological plasticity, which describes the degree of sensitivity to environmentally induced variation in growth and development of a plant (Subbarao et al. 1995; Alpert and Simms 2002). However, alterations in phenological development are sometimes assumed to be due to 'developmental instability', i.e., inexplicable developmental alterations (Alpert and Simms 2002).

Since developmental and phenological encompass the ability to recover from drought periods and to adjust canopy development according to moisture availability, both are important attributes in plants that need to be considered in developing cultivars with stable performance in drought-prone areas (Subbarao et al. 1995). Therefore, high levels of plasticity enable plants to adjust leaf area, stomatal conductance, and provide the ability to produce new leaves upon the relief of a drought period (Subbarao et al. 1995). Furthermore, it allows for flexibility in reproductive development; maturity is adjusted to soil moisture availability so that new flowers and pods can be produced when soil moisture status is more favorable (Mínguez et al. 1993; Subbarao et al. 1995; Turner et al. 2001). Those abilities may, therefore, lead to a greater probability of pod setting and grain production under intermitted drought conditions (Subbarao et al. 1995). Despite these advantageous features of genotypes exhibiting high levels of developmental and phenological plasticity, they are usually considered to be poor-yielding phenotypes and lack meaningful responses to inputs such as fertilizers and irrigation. Additionally, they are hard to mechanize since harvestable products are produced over an extended time period (Subbarao et al. 1995).

2.2 The Story of *Lablab purpureus* (L.) Sweet

2.2.1 Taxonomy, diversity and origin

Lablab purpureus (L.) Sweet belongs among other legumes such as soybean (*Glycine max* L. Merr.) and common beans (*Phaseolus vulgaris* (L.)) to the family of Fabaceae and is also known as Hyacinth bean, Egyptian kidney bean or Dolichos Lablab (Verdcourt 1979; The Angiosperm Phylogeny Group 2009).

The species is extremely diverse and taxonomically three subspecies (ssp.) are recognized, mainly based on differing characteristics of pods and seeds (Verdcourt 1971; Pengelly and Maass 2001; Maass et al. 2005; Tefera 2006). The first subspecies is the wild ssp. *unciantus* that is mainly distributed in East Africa and includes the variety *rhomboïdeus*. Additionally, the two cultivated subspecies, ssp. *purpureus* and ssp. *bengalensis* are recognized (Verdcourt 1970, 1971). However, for agricultural purposes, the concept of cultivar groups (cg.) has been used for some time, namely cg. Lablab, cg. Ensiformis, and cg. Bengalensis (Westphal 1974). The lablab species is known for being extremely diverse with over 200 genotypes being recognized, most of them remaining unnamed (NAS 1979). Genotypes are distinguished based on differences in size, shape and colors of pods, seeds, flowers and leaves, respectively (Duke et al. 1983; Hendrikson and Minson 1985).

Lablab is an ancient domesticated crop, widely distributed in Africa, the Indian sub-continent and Southeast Asia (NAS 1979; Smartt 1985; Maass et al. 2005; Maass et al. 2006), where it has been used as a grain legume and vegetable for more than 3500 years (Maass et al. 2005). Lablab is now widely distributed throughout the tropics and subtropics (Kimani et al. 2012), where it has become naturalized in some areas (Tefera 2006). Despite its large agro-morphological diversity in South-Asia, its origin, however, is considered to be in Africa, which is the only continent where wild plants in greater variation have been recorded to occur naturally (Verdcourt 1970; Smartt 1985, 1990; Maass et al. 2005, 2010). Lablab is, since the 1970s, listed as a minor and neglected crop in most areas, despite its long tradition, great diversity and its adoption to a diverse range of environmental conditions (NAS 1979; Smartt 1985; Pengelly and Maass 2001; Maass et al. 2006; Tefera 2006; Maass et al. 2010; Kimani et al. 2012). This has led to the threat of genetic erosion of naturally occurring and semi-domesticated lablab varieties in Africa (Maass

et al. 2010). Reasons are, among others, limited interest in research, and the decreasing cultivation area and demand in Africa due to the replacement by other leguminous species such as common bean and cowpea (Maundu et al. 1999; Tefera 2006). Additionally, poor flavor attributes and cooking qualities of some lablab genotypes may have led to reduced utilization and, therefore, have favored other legume species, especially for human consumption (Smartt 1985; Pengelly and Maass 2001; Maass et al. 2010).

2.2.2 Botanical plant description

Lablab is, most likely, the legume showing greatest variation in its form and growth habit (Piper and Morse 1915; FAO 1988a). This species is a summer-growing, rampant and vigorously twining herbaceous plant that is potentially perennial but frequently grown as annual or biennial crop (Piper and Morse 1915; Duke et al. 1983; FAO 1988a; Deka and Sarkar 1990; Hall and Naidu 2004). The trailing, glabrous or pubescent stems can reach 3 to 6 m in length (Duke et al. 1983). But apart from heavily twining genotypes, also bushy, semi-erect and prostrate forms exist (Piper and Morse 1915; Pengelly and Maass 2001; Tefera 2006).

Leaves are trifoliate; leaflets broad ovate-rhomboid formed and 7.5 to 15 cm long (Schaaffhausen 1963; Verdcourt 1979; Duke et al. 1983; FAO 1988a; Maundu et al. 1999). They are thin, acute at apex, almost smooth above and short-haired underneath (FAO 1988a). The petioles are long and slender. Variation in size and color is high, whereas variation in shape of the leaflets is limited (Piper and Morse 1915; Pengelly and Maass 2001).

The inflorescences are axillary erect, lax, fascicled, and of many-flowered racemes on rather elongated or short peduncles (Piper and Morse 1915; Schaaffhausen 1963; Maundu et al. 1999). Depending on the genotype, flowers may be white, pink, red or purple, and usually arise from prominent tubercular thickenings on the peduncle (Piper and Morse 1915; Schaaffhausen 1963; Duke et al. 1983; FAO 1988a). From there, up to four flowers are found at each node on an elongation raceme (Schaaffhausen 1963; Duke et al. 1983; FAO 1988a).

Pods are very variable in shape and color; they may be flat or inflated (Piper and Morse 1915; Duke et al. 1983; FAO 1988a). The length can vary from 5 to 20 cm, breadth from 1 to 5 cm (FAO 1988a). They are sometimes curved, with a curved beak and persistent style or even papery

straight, hairy or smooth (Duke et al. 1983; FAO 1988a). Also they may be septate, or non-septate, and usually contain three to six seeds each (Duke et al. 1983).

The seeds have a linear white, very obvious conspicuous hilum and a long aril; seed colors range from cream, reddish, and purplish to tan, brown or black (Piper and Morse 1915; Schaaffhausen 1963; FAO 1988a; Maundu et al. 1999; Guretzki and Papenbrock 2014). Usually seeds are 0.6-1.3 cm long and nearly as wide, flattened and oblong with rounded ends (Duke et al. 1983; FAO 1988a).

2.2.3 Agronomic characteristics

Lablab is known for its adaptation to a wide range of environmental conditions (Kimani et al. 2012), which can be to some extend explained by its great natural genetic diversity and distribution.

Found throughout the tropics and subtropics, ranging from 30° southern to 30° northern latitude, lablab is cultivated in arid, semi-arid and humid climates (NAS 1979; Duke et al. 1983; FAO 1988a; English 1999; Hill et al. 2006). The altitude range stretches from sea level up to 2500 meters above sea level (masl), but lower elevations are preferred, usually not exceeding 2000 masl (NAS 1979; FAO 1988a; Maundu et al. 1999; Aganga and Tshwenyane 2003, Tefera 2006).

Lablab thrives in regions where annual temperatures range between 18 and 30°C, the minimum required temperature for growth 3°C (Duke et al. 1983; FAO 1988a; Smartt 1990; Aganga and Tshwenyane 2003). High temperatures, on the other hand, have been shown not to affect the development of lablab (Schaaffhausen 1963; Duke et al. 1983; FAO 1988a; Smartt 1990; Liu 1996), however, light frosts can damage leaves but will not kill the plant if not occurring for a prolonged time period (Duke et al. 1983; FAO 1988b; Aganga and Tshwenyane 2003).

Due to extensive geographic distribution of lablab, it has been recorded from areas with 200 to 2500 mm of annual rainfall (Duke et al. 1983; FAO 1988a; Aganga and Tshwenyane 2003; Tefera 2006). However, for successful establishment and development of a deep root-system in drier regions, an initial irrigation during the first two to three months after sowing is seen to be essential, but not always feasible (Schaaffhausen 1963; Duke et al. 1983; Smartt 1990). Once established, lablab is a hardy, drought-resistant crop, which continues to grow, producing flowers

and seeds for many months and even staying green in the dry season (Piper and Morse 1915; Aganga and Tshwenyane 2003; Ayisi et al. 2004). This fact allows lablab to provide food, fodder, and soil protection at times when many other herbaceous plants have become desiccated (Schaaffhausen 1963; NAS 1979; Duke et al. 1983; FAO 1988a; Smartt 1990; Tefera 2006).

Lablab can be grown on a wide range of soil textures and types, varying from deep sands to heavy clays, provided that they are well drained (NAS 1979; Duke et al. 1983; Liu 1996; Mullen et al. 2003). Hence, lablab is said to exhibit tolerance to toxic aluminum soils and low-fertile soils (NAS 1979; Duke et al. 1983), and has been reported to grow in pH regimes ranging from 5.9 to 7.8 (Duke et al. 1983; Aganga and Tshwenyane 2003; Tefera 2006). However, performance seems particularly good on sandy loams with a pH of 6.5 and heavy clays with a pH of 5.0 (Duke et al. 1983). While showing tolerance to a great diversity of soil types, lablab does not tolerate water-logging or standing in brackish water (FAO 1988a; Aganga and Tshwenyane 2003; Mullen et al. 2003). Thus, lablab is promiscuous and nodulates easily, with lablab or cowpea-type Rhizobium spp., which are common in tropical and subtropical soils worldwide. Therefore, artificial inoculation is normally not needed (Duke et al. 1983; FAO 1988a).

2.2.4 Agricultural applications and multipurpose use

As a multipurpose legume, lablab is used as a pulse crop for human consumption, as a fodder crop for livestock, as a rotational and cover crop as well as a pioneer species to improve soil fertility and soil organic matter (Karachi 1987; English 1999; Hill et al. 2006). Additionally, it is even used as herbal medicine or for ornamental purposes (Maass et al. 2010). Thereby, lablab can be found in mixed or sole cropping systems, as part of home gardens or in crop rotation systems (NAS 1979; Maass et al. 2010). In intercropping systems, common companion crops include millet, groundnut, sorghum and maize (NAS 1979; Singh and Mishra 1988; Hill et al. 2006; Njarui and Mureithi 2010).

When used as human food, green pods, mature seeds and leaves are traditionally eaten as vegetables in Africa, south and south-east Asia (NAS 1979; Duke et al. 1983; Smartt 1985; Maundu et al. 1999; Pengelly and Maass 2001; Ayisi et al. 2004; Tefera 2006; Maass et al. 2010; Whitbread et al. 2011). Thereby, leaves but also flowers may be cooked and eaten like spinach (NAS 1979; Tefera 2006). Lablab sprouts are also eatable and, thereby, comparable to soybean or

mung bean sprouts but need to be cooked before consumption (NAS 1979; FAO 1988a; Tefera 2006). The mature seeds are sometimes soaked overnight before cooked thoroughly (Duke et al. 1983), which is important in reducing anti-nutritional factors such as hydrogen cyanide and trypsin activity inhibitors (NAS 1979; Duke et al. 1983; FAO 1988a). After soaking, cooking duration usually range from two to three hours and normally include several water changes (Maundu et al. 1999).

For livestock production, lablab can be used as a fodder crop, rather provided in form of hay, crop residues, silage, or directly grazed and, can be mixed with other feed (NAS 1979; Tefera 2006; Maass et al. 2010; Whitbread et al. 2011). Lablab can be fed to goats, cattle and hogs (NAS 1979; Duke et al. 1983) and, is sometimes being grazed by goats or cattle in intercropping systems after the first crop has been harvested (NAS 1979; Singh and Mishra 1988; Hill et al. 2006). If lablab is cut at times of high leafy biomass proportion, the hay is palatable and nutritionally comparable with alfalfa (*Medicago sativa* L.), although less digestible (NAS 1979; FAO 1988a). Incorporating lablab into grass pastures also improves quality, palatability, and digestibility of pastures (NAS 1979). However, lablab's suitability as a forage legume to be integrated into natural pastures has been reviewed critically by Macharia et al. (2010), where limitations in integration potential include lack of regeneration potential and the fact of some genotypes of being short-lived (Macharia et al. 2010).

Additionally, as lablab stays green during dry periods, it is providing palatable fodder, cut pastured or as silage (Duke et al. 1981; Aganga and Tshwenyane 2003).

In terms of soil amendments, lablab's dense green cover can help to protect the soil against desiccation and decreases erosion by wind and water when used as a cover crop (Mureithi et al. 2003). Additionally, the use as green manure offers great potential for soil conservation strategies and stabilization of chemical and physical soil properties (NAS 1979; Duke et al. 1983; FAO 1988a; Tefera 2006; Maass et al. 2010; Whitbread et al. 2011).

2.2.5 Potential reasons for the declining use of *Lablab purpureus*

Despite lablab's potential to serve as a multipurpose legume, its utilization is in steady decline and its acceptability by smallholder farmers in Kenya is usually low (Shivachi et al. 2012).

The utilization and extent of other leguminous species such as common beans and cowpeas is far greater than lablab generally, with this limitation being ascribed to lablab's comparable poor cooking and eating qualities (Shivachi et al. 2012). However, those attributes are crucial in farmer's selection processes for acceptable varieties (Shivachi et al. 2012). Prolonged cooking times are listed as one of the major factors responsible for under-utilization of leguminous species in many diets as those lead to increased energy costs and, further have negative impacts on the nutritive value (Shivachi et al. 2012). The taste of some lablab genotypes is further known to be accompanied by a bitter taste, a reduction thereof requires several water changes throughout the cooking, additionally resulting in loss of nutrients (Shivachi et al. 2012). However, taste characteristics and cooking times vary greatly across lablab genotypes, with tendency for dark-seeded lablabs taking comparatively longer to cook and posing a more pronounced bitter taste than light colored lablabs (Shivachi et al. 2012).

Despite reports on poor cooking and eating qualities of lablab, management-related characteristics additionally may have led to decreased utilization of lablab in today's smallholder farming systems in Kenya. As labor is becoming another constraint in agricultural activities through income diversification, less labor-demanding crops are preferred. Most of the legumes, including lablab, need a good weed management throughout the growing season, in particular at early development stages (Kay 1979; FAO 1988b; Mullen et al. 2003). However, harvesting lablab is much more labor and time intensive than more widely grown legumes such as common bean (Duke et al. 1983). The common bean is an ephemeral, dying after a short life cycle. At this time, the plant is fully desiccated, and the whole plant can be taken for threshing. The pods easily open and grains can be collected. In contrast, lablab stays green even in prolonged dry periods and continuously produces new pods (Schaaffhausen 1963; Duke et al. 1983). This feature is often appreciated by livestock farmers, as lablab offers fresh and green livestock fodder during dry spells. However, in terms of seed production this means that pods have to be hand-picked frequently and over an extended time period as soon as they are dry (Kay 1979; Maundu et al. 1999). Therefore, the harvest of lablab is highly labor and time intensive.

2.2.5.1 Trypsin inhibitors and cyanogenic glycosides

As do other legumes, also lablab contains some anti-nutritional compounds such as trypsin inhibitors and cyanogenic glycosides (Deka and Sarkar 1990; Vijayakumari et al. 1995; Osman 2007a, 2007b). Thereby, the nutritional quality and digestibility of plant proteins is affected, limiting its suitability as a protein source (Osman 2007a). However, the amount of varies considerably across genotypes and environments (Osman 2007b; Guretzki and Papenbrock 2014). As a rule of thumb, the darker the seeds, the more likely to contain higher amounts of cyanide (Duke et al. 1983), which is often accompanied by the bitter taste (Duke et al. 1983; Smartt 1985; FAO 1988a; Shivachi et al. 2012).

Cyanogenic glycosides release cyanide in form of hydrogen cyanide (HCN) due to the process of degradation (Møller 2010; Guretzki and Papenbrock 2014). HCN consumption can cause poisoning or even death of animals and humans (Vetter 2000; Guretzki and Papenbrock 2014). However, besides the high variability of HCN contents among lablab genotypes, the content can considerably be reduced by soaking or cooking seeds in water as the HCN is water soluble (NAS 1979; FAO 1988a; Vijayakumari et al. 1995; Soetan 2012; Guretzki and Papenbrock 2014). The total HCN concentration in a plant is, however, a function of environmental growth conditions as well as plant physiological factors and is, therefore, highly variable (Guretzki and Papenbrock 2014). Additionally, fresh lablab seeds contain trypsin inhibitors which are inhibiting the activity of trypsin, a toxic that is exhibiting negative impacts on digestive processes and can effect growth and development of humans and livestock (Schaaffhausen 1963; Ryan 1990; Guretzki and Papenbrock 2014). However, under correct pre-treatment also the trypsin inhibitor level can be easily reduced. Hence, boiling in water and roasting ensures a strong or complete reduction in trypsin inhibitor activity (Schaaffhausen 1963; NAS 1979; FAO 1988a; Osman 2007b; Guretzki and Papenbrock 2014). Moreover, a recent study has shown a great bandwidth of both trypsin inhibitor activity and presence of HCN among several lablab accessions (Guretzki and Papenbrock 2014). Even though trypsin activity is not relevant for human diet, breeding efforts should be directed towards a low trypsin inhibitor activity as, when lablab is concerned as livestock feed, pre-treatments might be uneconomic (Bacon et al. 1995; Guretzki and Papenbrock 2014).

3 Material and Methods

3.1 The study area

The study area was in Machakos County, located in the semi-arid areas of Eastern Kenya predominately under the agro-climatic zones IV and V, classified as semi-arid to arid lands, respectively (Jaeztold et al. 2006; Karuma et al. 2011) (Figure 1 and Figure 2).

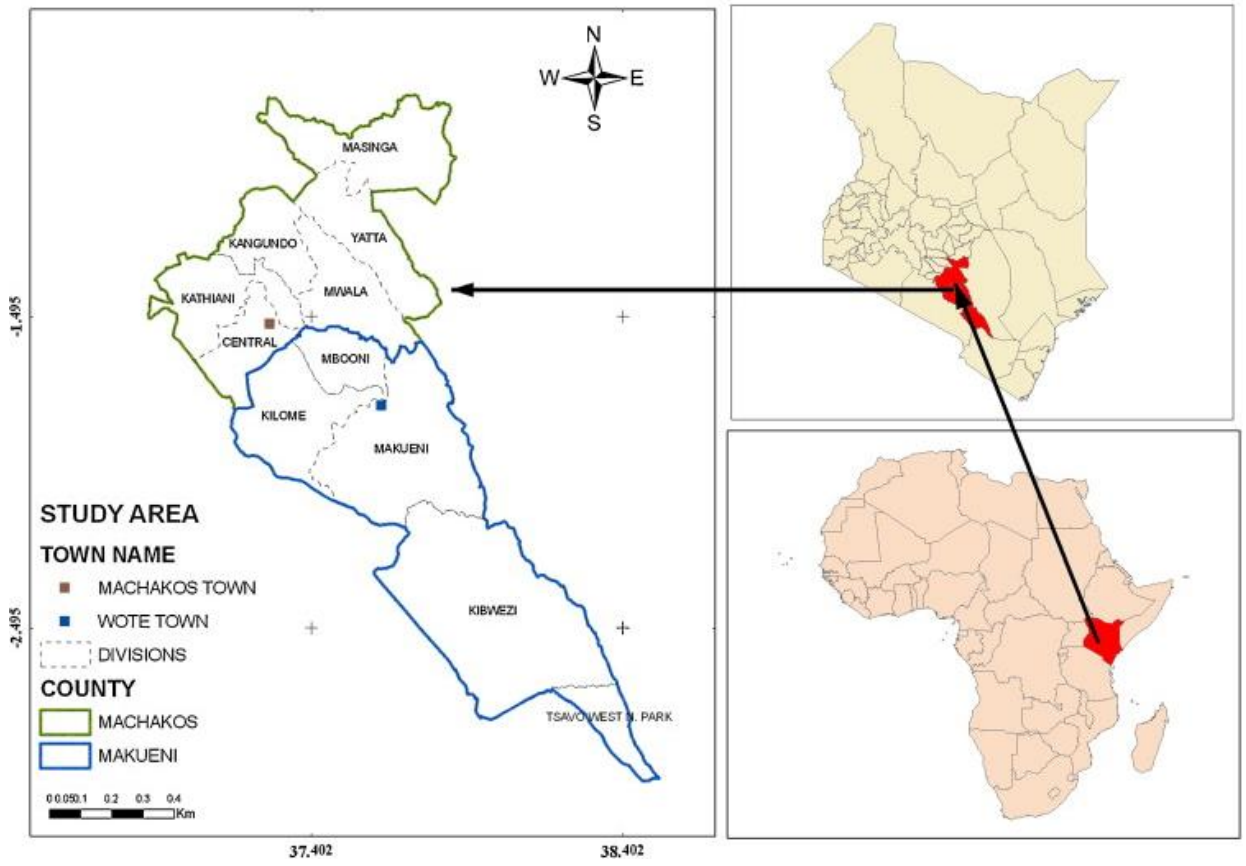

Figure 1 Location of Machakos County, Kenya (Map adapted from Wambugu 2011)

The classification of agro-ecological zones is based on the distribution and amount of annual rainfall leading to a range of months suitable for agricultural activities.

Elevation across Machakos County ranges from 400 to 2100 meters above sea level (masl) (Claessens et al. 2012). Therefore, the area presents pronounced environmental variations (Mora-Vallejo et al. 2008).

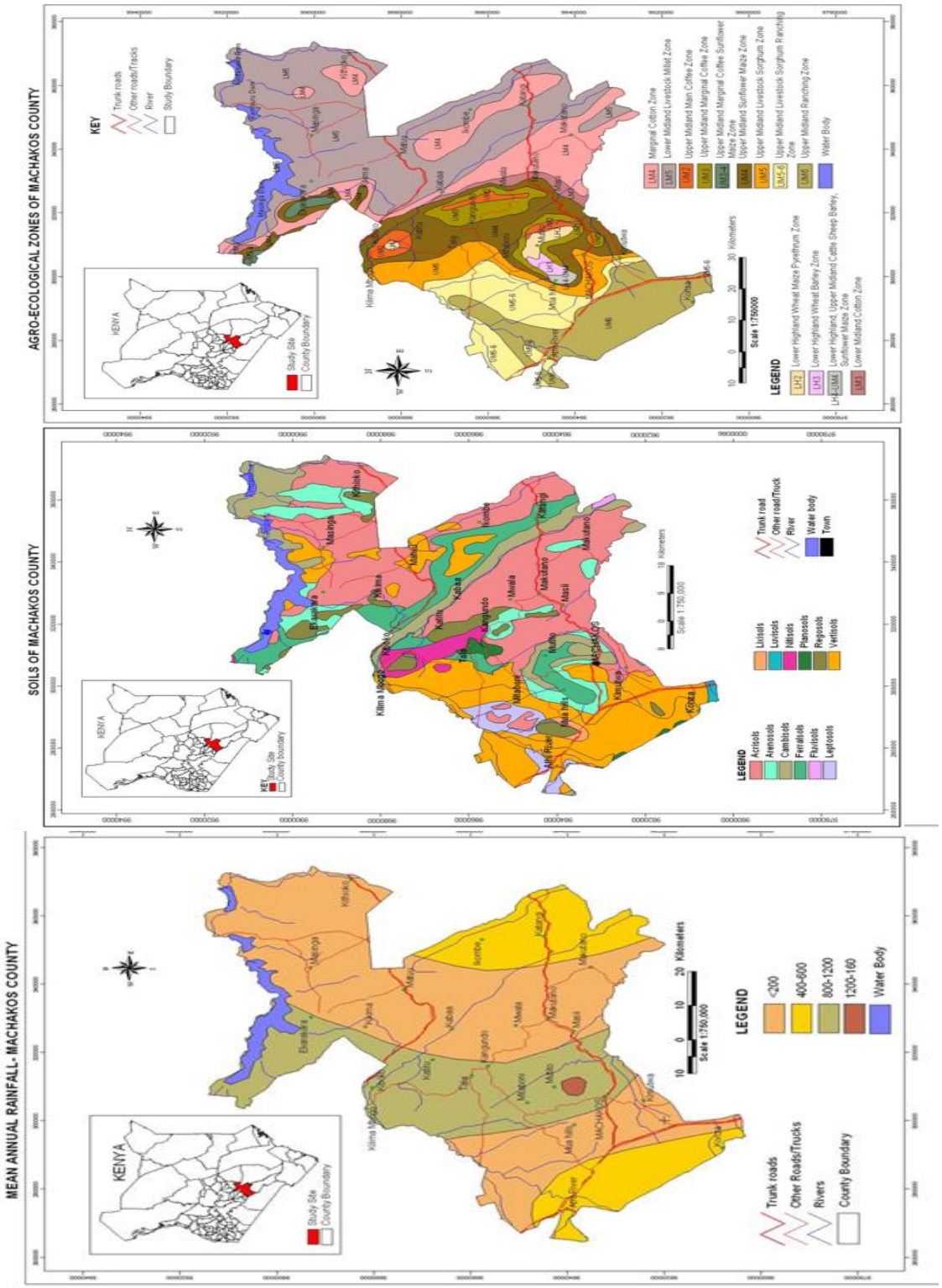

Figure 2 Rainfall regimes, soils and agro-ecological zones of Machakos County, Kenya (Gicheru and Ita 1987)

Most of the soils in Machakos County are deep to very deep, friable, with textures ranging from sandy clay loam to sandy clay (Mora-Vallejo et al. 2008; Claessens et al. 2012). The soils are classified as Vertisols in the south-western part of the county, as Acrisols in the north-eastern part and as Ferrasols and Cambisols in the highlands (Figure 2) (Gicheru and Ita 1987). Generally, the porous massive structure provides moderate to high water holding capacity and good drainage (Mora-Vallejo et al. 2008). However, soil fertility is mostly poor, and soils are predominately lacking main plant nutrients such as nitrogen, phosphorus, with additionally the organic carbon contents being low (< 1%) (Okalebo et al. 1992; Onduru et al. 2001; Njarui et al. 2004a; Mora-Vallejo et al. 2008; Claessens et al. 2012).

Soil nutrient management through application of manure and chemical fertilizers is practiced by farmers. However, relatively high costs of chemical fertilizers coupled with low returns and unreliable markets for agricultural products limit its use by most smallholders in Kenya (Mureithi et al. 2003; Mora-Vallejo et al. 2008; Claessens et al. 2012). Therefore, application of manure is more common (Mora-Vallejo et al. 2008; Claessens et al. 2012), though its benefits are usually limited due to poor handling of manure and poor quality manure resulting from poor feeds for livestock (Mureithi et al. 2003). Traced back to colonial times, most farmers use terrace cultivation for erosion control (Tiffen et al. 1994; Mora-Vallejo et al. 2008; Claessens et al. 2012). Additional, soil and water conservation measures include strips, contour farming and ridging (de Jager 2007; Mora-Vallejo et al. 2008; Claessens et al. 2012). Continuous cultivation due to the steady increase in land pressure leading to further diminishing land sizes per holding has put erosion and soil fertility decline as another threat in crop production (Njarui et al. 2004a). The abolishment of fallows on most smallholder land holdings is, additionally, worsening the situation (Mureithi et al. 2003). Moreover, most parts of the region lack irrigation facilities, making agriculture a risky business due to unreliable and highly variable rainfall (Njarui et al. 2004a; Mora-Vallejo et al. 2008).

The climate in the study area is characterized as semi-arid with a bimodal rainfall pattern, resulting in two distinct rainy and dry seasons. Mean annual rainfall ranges from 330 to 1260 mm with a high inter-seasonal rainfall variation (Tiffen et al. 1994; Karachi 1997, Mora-Vallejo et al. 2008; Claessens et al. 2012), with the coefficient of variation being 28% (Figure 2) (Rao and Okwach 2005). Rainfall is divided between the short rainy season from October/November till

January/February and the long rainy season from March till August/September (Tiffen et al. 1994; Karachi 1997; Mora-Vallejo et al. 2008). Almost 85% of the mean annual rainfall is received during those two rainy seasons (Rao and Okwach 2005). Even though the short and long rainy seasons receive similar amounts of rainfall, the short rainy seasons are more reliable and, therefore, more important for crop production (Rao and Okwach 2005). However, generally about 40% of all seasons receive less than 250 mm rainfall, while 27% of the recorded rainfall is in excess of 350 mm per rainy season (Dowker 1961; Rao and Okwach 2005). Drought events happen in cycles of four to five years, affecting two or more growing seasons, having great impacts on food security in that region (Tiffen et al. 1994; Mora-Vallejo et al. 2008). Mean annual temperatures vary from a mean minimum of 15°C to a mean maximum of 25°C, with the hottest months being October and February and the coolest month being July (Jaeztold et al. 2006; Mora-Vallejo et al. 2008; Muhammad et al. 2010).

Machakos County is located in the Eastern Province of Kenya and boarders Nairobi and Kiambu Counties to the West, Embu County to the North, Kitui County to the East and Makueni County to the South (Jaeztold et al. 2006). It covers a land area of 6208 km^2 with an estimated population of 1.098.584 people in 2009 (Claessens et al. 2012). According to the Central Bureau of Statistics, 60% of the population in Machakos County fell below poverty line, having less than of 1 US$ per person and day in 2001 (CBS 2003; Claessens et al. 2012).

Machakos County supports a wide range of agricultural activities, covering almost half the county's total surface area (Mora-Vallejo et al. 2008; Claessens et al. 2012). Rainfed, mixed crop-livestock farming systems are the dominating land use system, supporting the mostly small-scale semi-subsistence sector (Njarui et al. 2004a; Mora-Vallejo et al. 2008; Muhammad et al. 2010). These farms usually own between 1.5 and 6 ha of land, of which 1.5 to 3.5 ha are under continuous cultivation (de Jager et al. 2001; Claessens et al. 2012). Maize is the most important staple crop, complemented by a wide range of other food crops (common beans, millet and sorghum), vegetables (tomatoes and kales), fruit trees (mango, pawpaw, orange and banana) and tuber crops (cassava) (Mora-Vallejo et al. 2008; Claessens et al. 2012). Additionally, some coffee and cotton is found in this region, cultivated as cash crops (Claessens et al. 2012). However, for all crops yields are generally low and crop failure is a common problem (de Jager et al. 2001; Mora-Vallejo et al. 2008; Lal 2010; Claessens et al. 2012).

3.2 Climatic conditions during the evaluation period

During the period of evaluation (from 5th November 2013 till 8th March 2014), the total amount of received rainfall summed to 353.6 mm, of which 72% fell in November and December (Figure 3 (a)). The driest month during the evaluation period was January with only 1.4 mm of total rainfall. Temperatures, considering highest and lowest daily mean, ranged from a maximum of 25.5°C to a minimum of 16.4°C (Figure 3 (b)). During the evaluation period, minimum night time temperature did not fall below 11°C and was not above 39°C during day time.

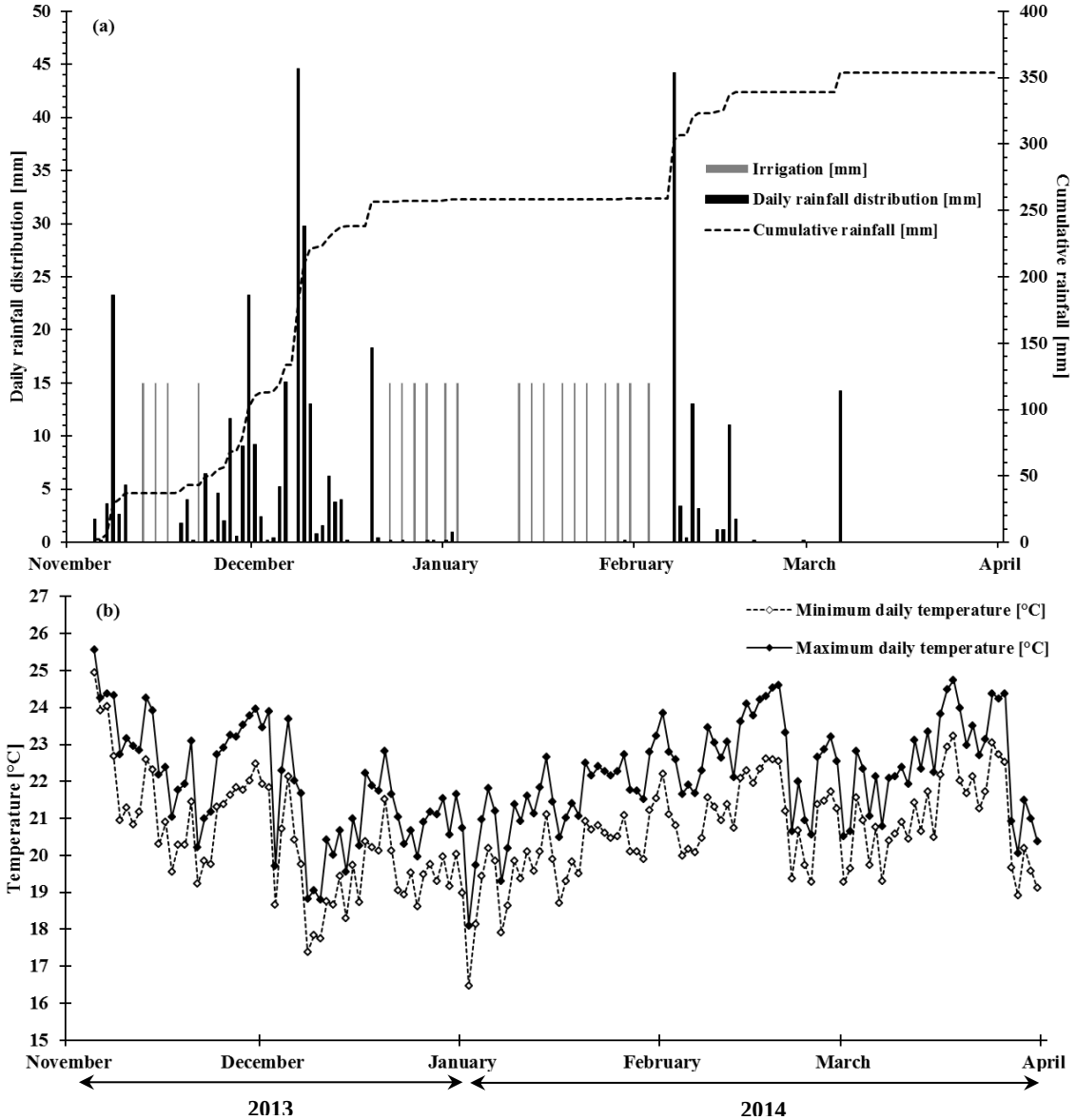

Figure 3 Climate chart, short rainy season 2013/14 recorded at KARI Katumani

3.3 Selected *Lablab purpureus* germplasm

For the on-station and for the on-farm experiments, six different *Lablab purpureus* accessions were used. The different accessions, Q6880B, CPI 60795, CPI 52508, CPI 52513, CPI 52535 and CPI 81364, were provided by the Australian Tropical Crops Genetic Resource Centre, Department of Primary Industries, Biloela, Queensland (http://www.dpi.qld.gov.au/26_4380.htm) and, are part of the germplasm collection characterized and classified by Pengelly and Maass in 2001. Deriving from this germplasm collection, 33 relatively early-flowering lablab accessions have been selected and evaluated by Whitbread et al. in South Africa in 2011. On the basis of the pre-selection of relatively early flowering accessions by Whitbread et al. (2011), most differing lablab accessions regarding seed color and growth habit were selected for this study (Table 1). Therefore, growth habits ranged from rather bushy to spreading or heavily spreading, seed colors from black over reddish to tan (Table 1).

Table 1: Plant physiological data of evaluated *Lablab purpureus* accessions in days after planting (DAP) and their respective morpho-agronomic types (MA type) according to Pengelly and Maass (2001); adapted from Maass et al. (2005)[1] and Whitbread et al. (2011)[2]

Accesion ID	Origin	Form	MA type	Flowering (DAP) *	Maturity (DAP) **	Flower colour	Seed colour
Q6880B	ex Brazil [1]	semi-domesticated [1]	RB-8 [1]	43-65 [2]	65-102 [2]	purple	black
CPI 60795	ex India [1]	semi-domesticated [1]	RB-8 [1]	59-65 [2]	75-99 [2]	purple	black
CPI 52508	Mozambique [1]	semi-domesticated [1]	RB-8 [1]	very early [1]; 60 [2]	100 [2]	white [1]	red [1]
CPI 52513	ex Zambia [1]	semi-domesticated [1]	RB-8 [1]	52-73 [2]	91-99 [2]	white	green
CPI 52535	ex India [1]	cultivated [1]	RB-3 [1]	very early [1]; 65-66 [2]	100 [2]	white [1]	tan [1]
CPI 81364	ex USA [1]	semi-domesticated [1]	RB-8 [1]	59-61 [2]	74-102 [2]	white	tan

* at 50% of flowering

** at physiological maturity when 90% of the pods are brownish

The selected accessions showed 50% flowering between 50-60 days after planting (DAP) and physiological maturity between 70 and 100 DAP (Table 1) (Whitbread et al. 2011). The characterization into morpho-agronomic types by Pengelly and Maass (2001) included time to flowering, seed characteristics and plant size (Table 1). Besides the interest in detecting appropriate short-season varieties, especially the seed color was considered to be an important attribute to evaluate in Eastern Kenya, as commercially available and marketed *Lablab purpureus* ('Njahe' in Kikuyu language) grains are predominantly black (Muhammad et al. 2003).

3.4 KARI Katumani: Water-deficit trial

The on-station field experiment was conducted at the Kenyan Agricultural Research Institute (KARI) in Katumani, Machakos County, Kenya (S 01°34.5584, E 037°14.4295), 1600 masl and, during the short rains of 2013/14 (November 2013– March 2014).

3.4.1 Soil properties

At the KARI Research Station, the soil is classified as a chromic Vertisol according to the Kenya Soil Survey Report from 1987, which is well drained and reddish to dark brown in color (Gicheru and Ita 1987). Texture ranges from clayey loam to sandy clay, additionally, the analysis showed a clay texture throughout the profile but an increased sand content in the surface layers (Table 2).

Table 2 Analysis of soil texture, and soil chemical characteristics, taken prior to the sowing of the *Lablab purpureus* accessions at KARI Katumani, Kenya

Soil texture analysis		**Soil depth [cm]**			
		0-15	**15-30**	**30-60**	**60-90**
Sand	[%]	68.00	69.00	62.50	50.50
Clay	[%]	25.30	23.50	31.50	40.00
Silt	[%]	6.70	7.50	6.00	9.50

Soil chemical analysis[1]		**Soil depth [cm]**			
		0-15	**15-30**	**30-60**	**60-90**
pH		6.62	6.54	6.10	5.83
Organic carbon (C)	[%]	0.72	0.67	0.55	0.37
Total nitrogen (N)	[%]	0.08	0.07	0.06	0.05
Phosphorus (P)	[ppm]	33.75	31.25	20.00	15.00
Potassium (K)	[me%]	0.87	0.81	0.65	0.35
Calcium (Ca)	[me%]	1.82	1.73	1.90	1.10
Zinc (Zn)	[ppm]	2.36	1.63	1.18	1.04

[1]pH (1:5 soil:water extract); plant-available phosphorus with Mehlich 3 test

Due to the clayey texture throughout the profile, the soil tends to waterlogging during short and excessive rainfall events but provides good drainage during most of the season's rainfall (Gicheru and Ita 1987). This is mainly attributed to its increased sand content in the upper soil layers that is suppressing its shrinking and swelling ability. The soil was slightly acid with a pH ranging from 5.83 to 6.62 and, was lacking main plant nutrients such as nitrogen (N), phosphorus (P), calcium (Ca) and zinc (Zn) (Table 2). Additionally the organic matter content was low (Table 2).

3.4.2 Experimental design

The experimental design was a split plot layout, completely randomized within each split plot, including four replications of each lablab accession and treatment. The experimental setting was a water-deficit trial. The water treatments included rainfed, partly irrigated until 90% flowering and fully irrigated until physiological maturity. Physiological maturity was reached when 90% of the pods had turned brownish. A drip irrigation system was installed to ensure a minimum water supply of 50 mm water per week for the respective plots and was given in addition to rainfall. Individual plots were 5 m by 1.5 m to provide enough plants for destructive biomass measurements throughout the growing season (Figure 4). Between plots, a distance of 1 m was set to limit neighbor plot effects. The total experiment included 72 individual plots (Annex 1).

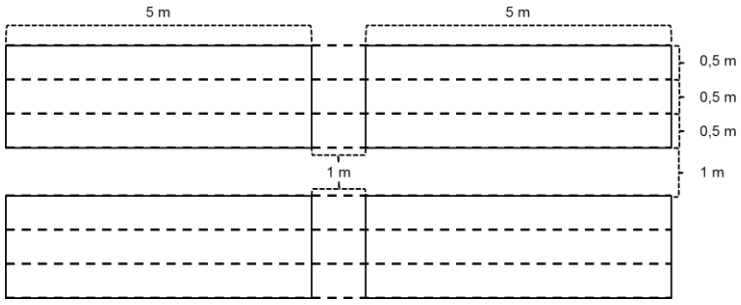

Figure 4 Plot design of the experimental setting at KARI Katumani, Kenya

Seeds were sown at a depth of 50 mm with a row-spacing of 0.5 m and an inter-row-spacing of 0.3 m, which then adds to 6.7 plants m^{-2} and 66,667 plants ha^{-1}. To achieve a uniform plant stand, three seeds were sown in each hole and seedlings were thinned to the desired plant density two weeks after emergence. Sowing took place on 6th November 2013 with the onset of the short rains. All seeds were inoculated with *Rhizobium Phaseoli* Strain USDA 3605 prior to sowing to facilitate and ensure uniform emergence. Additionally triple superphosphate (TSP, 20.75% phosphorus (P)) was applied at planting at a rate of 15 kg P ha^{-1} as well as Urea (46% nitrogen (N)) at a rate of 10 kg N ha^{-1} to ensure uniform seedling establishment.

The use of pesticides was according to need during the entire growing period. To control leaf eating insects during vegetative growth, Duduthrin (active ingredient: Lambdacyhalothrin 17.5 g/l) was sprayed at a rate of 1 l per 200 l of water. At flowering-stage, Thunder (active

ingredient: Imidacloprid 100 g/l + Beta-cyfluthrin 45 g/l) at a rate of 20 ml per 15 l of water as well as Marshal (active ingredient: 35% Carbosulfan) at a rate of 50 ml per 15 l water were mixed and applied together in equal proportions in order to control aphids. Additionally all plots were kept mechanically weed-free during the entire growing period by hand hoeing to minimize competition for light, water and nutrients.

3.4.2.1 Irrigation and rainfall summary

Total amount of rainfall during the evaluation period of 122 days was 353.6 mm. Until time to physiological maturity, the rainfed water treatment received a total amount of 339.3 mm (Table 3). The partly irrigated water treatment received a total water supply ranging between 519.3 and

Table 3 Rainfall and Irrigation Summary of the different water-treatments at KARI, Katumani, Kenya

Water treatment	Rainfall [mm]	Irrigation [mm]	Total [mm]
Rainfed	339.3	0	339.3
Partly irrigated	339.3 - 353.6	180	519.3 - 533.6
Fully irrigated	339.3 - 353.6	345	684.3 - 698.6

533.6 mm, the fully irrigated water treatment a total between 684.3 and 698.6 mm (Table 3). The ranges in water supply are a result of differences in time to reach flowering and physiological maturity among the accessions. Therefore, additional rainfall or irrigation water has been received by some accessions.

3.4.3 Agronomic measurements

3.4.3.1 Plant development and growth analysis

Plant development stages such as time to emergence, time to 90% flowering of the plant stand and time to physiological maturity were recorded for each of the six lablab accessions. Additionally, destructive plant biomass samples were taken four weeks after planting (28 DAP), at flowering (70 DAP), at physiological maturity (144-122 DAP) and, additionally, at 42 and 85 DAP. The destructive biomass samples were collected by choosing and cutting two random plants of each plot and separating them into their plant parts, meaning into leaf, stem, buds and

flowers, and pod parts. At physiological maturity, pods were also separated into pod wall and grain; additionally, the number of leaves, nodes, pods and seeds per pod were recorded. Thereby, biomass samples were collected among all replications and water treatments of the lablab accessions.

After separation, samples were dried in an oven for 48 h at 60°C to further assess dry matter (DM) weight. From this, biomass DM yield ha^{-1} and grain yield ha^{-1} were calculated using the following equations:

$$\boldsymbol{Plants\ ha^{-1} = (no.of\ plants\ in\ one\ row\ over\ 5\ m/5) * distance\ between\ rows * 10\ 000} \quad (1)$$

$$\boldsymbol{Biomass\ DM\ ha^{-1} = plants\ ha^{-1} * total\ weight\ of\ one\ plant} \quad (2)$$

This data was used to determine the increase of total dry weight per unit time per unit existing total dry weight (Poorter and Remkes 1990). Here, the efficiency of existing biomass to produce new biomass should be quantified and, differences among lablab accessions and water treatments detected. This was done by using the relative growth rate (RGR) approach.

$$\boldsymbol{RGR = (W_2 - W_1/t_2 - t_1) * 1/W} \quad (3)$$

Where W_1 and W_2 are the total dry weights, stated in g, of the sample plants at times t_1 and t_2 in days after planting (DAP). W represents the arithmetic mean of W_2 and W_1. The RGR is therefore given in g g^{-1} d^{-1}.

Other common values to evaluate crop productivity and assimilate partitioning are harvest index (HI) and leaf/stem ratio. In particular the HI has been used to quantify yield increases due to agronomic and/or genetic improvements as it presents the weight of a harvested product as a proportion of the total biomass weight of a crop (Turner 2004). Therefore X is the grain yield in kg ha^{-1} at harvest and Y the total biomass in kg ha^{-1}. Values range from 0 to 1. The higher the value, the greater is, therefore, the share of grain in the total plant biomass.

$$\boldsymbol{HI = X/Y} \quad (4)$$

The leaf/stem ratio, however, is especially useful for assessing the suitability as livestock feed and was determined at flowering and maturity. Furthermore, plant biomass samples were grinded to assess total nitrogen (N in %) content. Here, total N was determined for all plant parts individually to evaluate N accumulation during plant development. Additionally, total N and carbon (C) contents were used to determine the C/N-ratio, which is an important value linked to digestibility and degradation time.

3.4.3.2 Leaf area index

The leaf-area-index (LAI) is defined as the area of leaves per unit area of soil surface (Ramirez-Garcia et al. 2012) and is, therefore, a useful indicator to evaluate and monitor plant biomass and canopy development. For LAI measurements, the AccuPAR PAR/LAI Ceptometer (Decagon Devices, model LP-80) was used weekly. This device calculates LAI by measuring light interception in plant canopies. Its photo-sensors measure the photosynthetic active radiation (PAR) in the 400-700 nm waveband, the spectrum portion that plants use for photosynthesis. Additionally the zenith angle, a fractional beam measurement value as well as a leaf area distribution parameter were used by the device to calculate LAI. The leaf area distribution parameter was set to be 2.46, which is also used for common beans (User Manual, Decagon Devices, model LP-80). To reduce errors caused by canopy structure variations, it is important to take a sufficiently large number of samples. When measurements are performed in row crops, it is important to capture a good row-to-row representation of the entire below-canopy PAR environment both under plants and between rows. Therefore, the device was put diagonal from mid-row to mid-row and a sufficiently large number of sample values were taken before saving the average. Usually a minimum of six individual measurements is required before taking the average. One summary measurement value per individual plot was taken, leading to four measurement values per accession and water treatment. However, the LAI measurements were performed until 83 days after planting (DAP) only as from that time onwards the intended plant density was not represented well by most plots.

3.4.4 Plant physiological analysis

3.4.4.1 Photosynthetic activity

Plant physiological processes influencing a plant's drought tolerance mainly depend on the efficiency of transpiration (in mmol m^{-2} s^{-1}) and photosynthetic rate (in µmol m^{-2} s^{-1}). To estimate the transpiration efficiency (TE), therefore, both rates were measured once a week using the non-destructive sensitive gas exchange measurement LCpro-Pro^{+} Portable. Here, the measurement device is controlling the leaf environment with help of a chamber in which the leaf is clipped. Therefore, the device can measure a number of parameters within this chamber and, in the

following, calculate the photosynthetic and transpiration rate as well as the stomata conductivity of a leaf (ADC BioScienfitic Ltd.; *www.adc.co.uk*).

The LCpro-Pro^{+} is determining the photosynthetic rate deriving from the following equation:

$$\boldsymbol{A = u_s \Delta c} \qquad \textit{(5)}$$

Where u_s is the mass flow of air per m^2 of leaf area in mol m^{-2} s^{-1} and Δc is the difference in CO_2 concentration through the chamber in µmol mol^{-1} with a corrected dilution. Values for photosynthetic activity range from 0 to 100 µmol mol^{-1}. The transpiration rate as follows:

$$\boldsymbol{E = \Delta e u_s / p} \qquad \textit{(6)}$$

Where, Δe is the differential water vapor concentration in mbar with corrected dilution, and p the atmospheric pressure in mbar. Prior to the measurements, the device was used to estimate the light saturation point of *Lablab purpureus*. This indicates the greatest light intensity that is used by lablab for photosynthesis the most (Figure 5). Here, the light saturation point was found to be

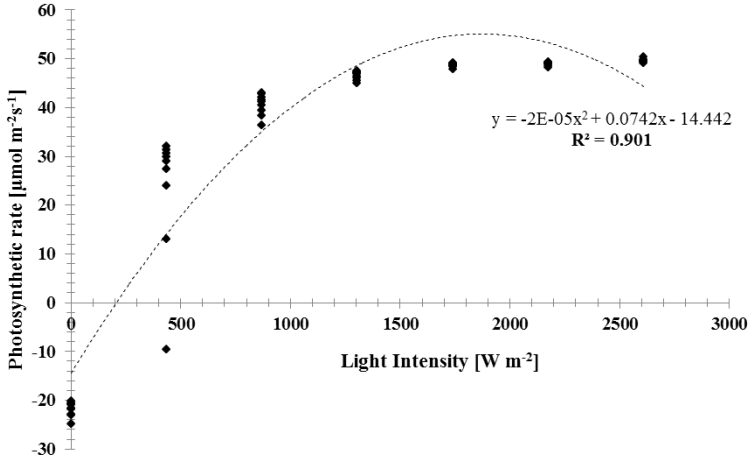

Figure 5 Test curve for the estimation of the light intensity point in *Lablab purpureus;* tested at different light intensity levels and with a high number of replications

at a light intensity of 2000 µmol $m^{-2}s^{-1}$, which then was used for the weekly measurements. For each measurement event, a fully expanded and developed leaf that is facing the sun was selected randomly from two plants per accession and treatment. The leaf was further clipped into the leaf chamber of the device. Individual plants were measured for eight or rather five minutes, while measurements were recorded for every minute. The number of records per plant was mainly limited through the battery capacity of the device. The recorded data was stored automatically in the internal SRAM.

3.5 Participatory research: *Lablab purpureus* acceptance study and organoleptic taste paneling

The participatory on-farm field experiments, consisting of 16 farm sites across Machakos County (Figure 6), were carried out simultaneously during the same rainy season (Figure 2). In this participatory research, experimental fields were visited regularly every two to three weeks, and plant biomass samples were taken at flowering and physiological maturity of the six *Lablab purpureus* accessions evaluated individually. Additionally, household interviews were conducted using questionnaires to gather basic socio-economic data but also data referring to the perceived performance of the lablab accessions tested. Furthermore, a blind taste paneling of the lablab accessions was performed with all participant farmers.

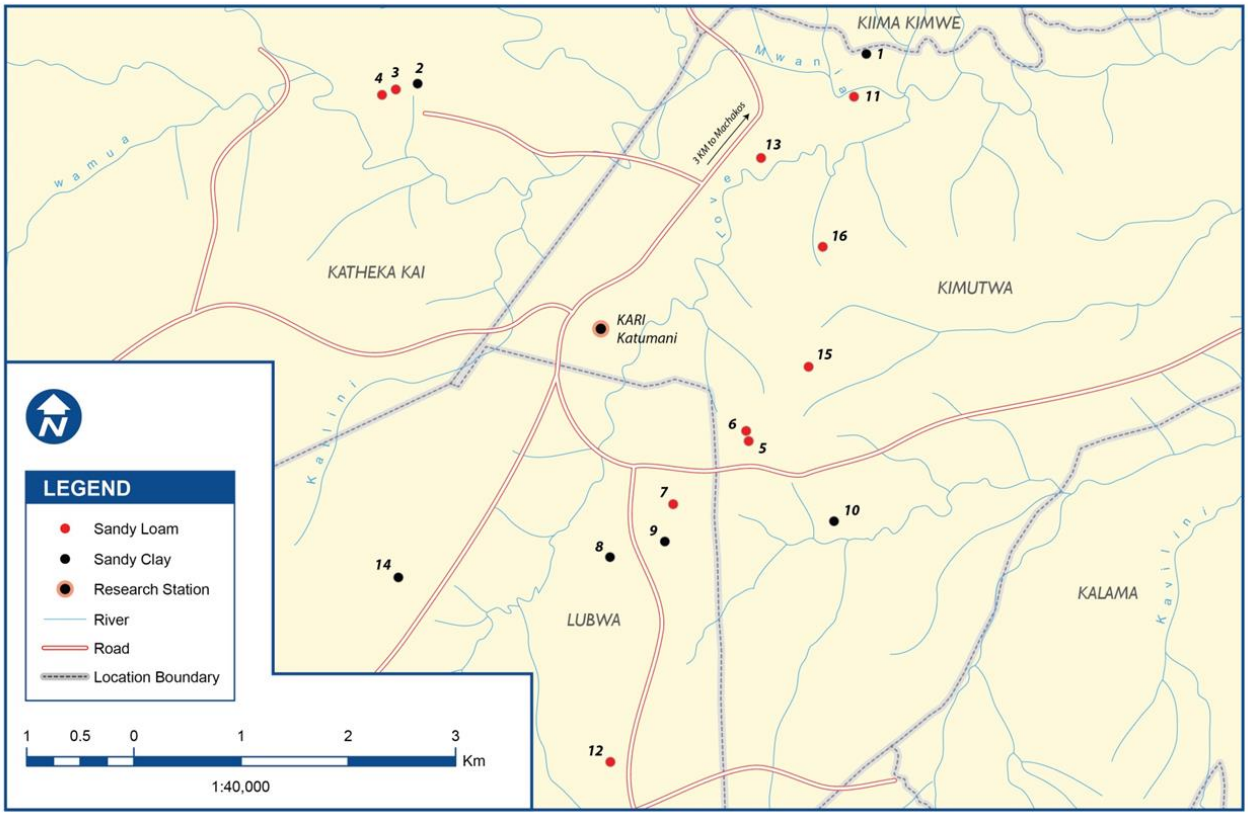

Figure 6 Location of the experimental farm sites (n=16) across Machakos County, Kenya; map elaborated by Nicholas Koech (Remote Sensing & GIS Analyst: Soils, Water and Landscapes, International Center for Tropical Agriculture (CIAT) Kenya) based on own GPS-data

3.5.1 Soil properties and clusters

Prior to sowing soil samples were taken from each of the farm sites. According to texture, the farm sites were grouped into two major soil groups; sandy loam (SL) and sandy clay (SC) (Table 4). Sand content of the sandy loam exceeded 70% in the first soil layer (0- 15 cm), whereas the clay content of the sandy clay exceeded 30% in the same layer.

Table 4 Analysis of soil texture, pH, mineral nitrogen (N), organic carbon (C), plant-available phosphorus (P) and exchangeable potassium (K) concentrations prior to sowing of lablab purpureus accessions at the participatory farm sites (n= 13); [0-15 cm]

Soil type	Farmer	Farm-ID	pH [1]	Sand [%]	Silt [%]	Clay [%]	Organic C [%]	Total N [%]	P [ppm][2]	K [me%]
Sandy loam	P. Ndunda	**3**	6.38	76.00	8.00	16.00	1.37	0.14	330.00	2.16
	J. Muinda	**4**	6.64	76.00	6.00	18.00	1.03	0.11	165.00	0.88
	B. Mutua	**5**	6.86	72.00	4.00	24.00	0.85	0.09	50.00	0.82
	J. Mbaluka	**7**	6.68	70.00	8.00	22.00	1.30	0.13	25.00	1.06
	H. Kioko	**11**	6.56	74.00	4.00	22.00	0.89	0.09	40.00	0.60
	T. Kitolo	**12**	5.88	78.00	4.00	18.00	0.72	0.08	25.00	0.18
	S. Mulwa	**13**	7.09	70.00	8.00	22.00	1.32	0.13	19.00 *	1.60
	A. Njeri	**15**	6.50	80.00	2.00	18.00	1.14	0.12	50.00	1.30
	J. Nbeke	**16**	6.57	74.00	4.00	22.00	1.00	0.1	30.00	1.10
	Mean		**6.57**	**74.44**	**5.33**	**20.22**	**1.07**	**0.11**	**89.38**	**1.08**
Sandy clay	S. Muiva	**1**	7.57	52.00	10.00	38.00	1.31	0.13	25.00 *	1.60
	B. Mbaluco	**2**	6.31	52.00	10.00	38.00	0.80	0.08	105.00	0.74
	A. Mtunga	**8**	7.01	60.00	6.00	34.00	1.10	0.11	4.00 *	1.16
	A. Mueithya	**10**	6.52	64.00	6.00	30.00	1.42	0.15	30.00	1.10
	Mean		**6.85**	**57.00**	**8.00**	**35.00**	**1.16**	**0.12**	**67.50**	**1.15**
	Overall Mean		**6.66**	**69.08**	**6.15**	**24.77**	**1.10**	**0.11**	**85.00**	**1.10**

[1]pH (1:5 soil:water extract); [2]plant-available phosphorus with Mehlich 3 test; *plant-available phosphorus with Olsen test

Furthermore, the organic carbon (C) content in the sandy clay soils was found to be slightly higher, but still below recommendations, indicating organic matter content to be relatively low on most farm sites. In contrast, the phosphorus (P) content was found to be slightly higher on the sandy loams on average but, still below recommendations as well. However, some farms had comparable high P contents on the sandy loam indicating a great variance across farm-sites.

Despite these differences in soil texture and the differences in C and P content, most of the soils tend to be slightly acidic and are lacking main plant nutrient such as nitrogen (N) and mostly phosphorus (P) with the organic C content being low as well. However, potassium (K) content was found to be adequate to high across most farm sites.

3.5.2 Field experiment

At each of the 16 different farm sites an individual plot was established, 5 m by 2.5 m or 10 m by 2.5 m in size (Figure 7, A and B). Hence, one row per lablab accession was planted and labeled for later comparisons. The row and inter-row spacing was set according to the on-station experiment, 0.5 m and 0.3 m, respectively.

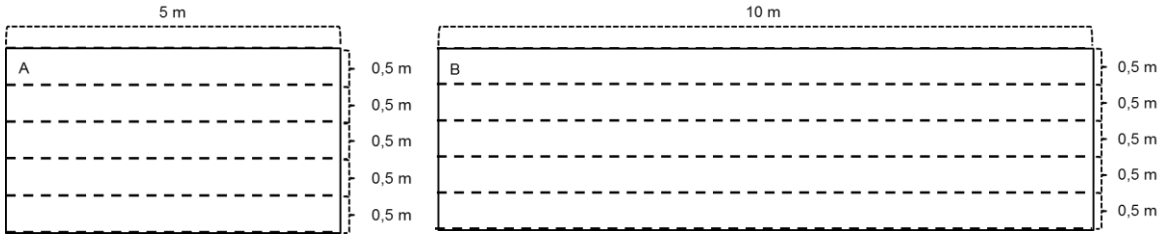

Figure 7 Plot design of the experimental setting at the farm sites in Machakos County, Kenya

Sowing started on the 6th of November with the onset of the rains and was finished three consequent days thereafter. Identical to the on-station experimental setting, three seeds were sown into each hole and thinned to the desired plant density two weeks after emergence. In cases of emergence failure, gaps were re-filled to ensure a uniform plant stand. As with the on-station experiment, triple superphosphate (TSP, 20.75% phosphorus (P)) at a rate of 15 kg P ha^{-1} as well as Urea (46% nitrogen (N)) at a rate of 10 kg N ha^{-1} were applied at planting to ensure successful seedling establishment.

Additional treatments included the use of pesticides according to need by using Duduthrin (active ingredient: Lambdacyhalothrin 17.5 g/l) to control leaf eating insects as well as Thunder (active ingredient: Imidacloprid 100 g/l + Beta-cyfluthrin 45 g/l) and Marshal (active ingredient: 35% Carbosulfan) to control aphids. During the entire growing period each individual plot has been treated with pesticides three times; five, nine and thirteen weeks after planting. The farmers were encouraged to keep the plots weed-free until maturity of the plants by using hand hoes. However, due to other liabilities and labor shortage, the quality of weeding varied among the farm sites.

3.5.3 Plant development and growth analysis

As for the on-station field experiment, on-farm plant biomass development was evaluated by taking destructive plant samples at flowering and physiological maturity. As accessions differed

in time to flowering and time to maturity, destructive plant biomass samples were taken according to the development stage of each accession at each farm site. In the following, grain and biomass yields ha^{-1} were calculated individually, according to accession and farm-site. Samples were separated; different plant parts were counted and subsequently dried and weighed as described for the on-station plant sampling. From the 16 farm sites, agronomic data from three sites with the farm-ID's 6, 9 and 14 were left out, as poor weeding had severely decreased the potential biomass and grain yield of the six lablab accessions studied.

3.5.4 Participatory research tool: Questionnaire

Part of the participatory research was to determine the production potential of the different lablab accessions under various soil and management conditions and, additionally, their suitability to be integrated into existing cropping systems. Here, especially farmers' preferences for crop selection should be identified. Furthermore, basic socio-economical household data should be collected. This task was fulfilled by developing and conducting questionnaires, in total three household questionnaires. All questionnaires were developed in English, but translated into Swahili. This should avoid misunderstandings leading to more exact answers and easier communication in case of any upcoming discussion.

The first questionnaire was conducted during the planting of the lablab accessions (Annex 3). The intention was to collect basic socio-economic household data referring to farm structure and activities, details about cropping system, used crop varieties, seed source and awareness about *Lablab purpureus*. Considering *Lablab purpureus*, farmers should name any advantages or disadvantages they are aware of, which have led to inclusion or exclusion of lablab from their cropping strategy (data not shown).

The second questionnaire was conducted at flowering of the lablab accessions tested (Annex 4). It contained questions regarding the frequency of weeding performed by the farmers, but mainly on the agronomic performance of the lablab accessions compared to more widely grown legumes such as common beans, cowpea, pigeon pea (*Cajanus cajan* (L.) Millsp.), and mung bean (*Vigna radiata* L. R. Wilczek). Performing this, farmers could choose between very poor over fair and very good each time compared to a frequently grown legume, individually for several agronomic characteristics. Also the most and least desirable lablab accession should be named.

The third and last household questionnaire was conducted during the harvest of the lablab accessions (Annex 5). Especially this questionnaire was designed to identify any disadvantages connected with lablab cultivation over more widely used legumes, including yielding, growing period and labor demand for cultivation. Also, farmers were encouraged to think of the most limiting factors for agricultural production in this area and what could be done to overcome this problem. Finally, the lablab accessions should be ranked by the farmers according to their potential suitability as a fodder crop, human feed or soil amendments, or as a combination of these.

3.5.5 Organoleptic taste paneling

In addition to the agronomic evaluation by taking plant samples and the performance evaluation using questionnaires, a blind taste paneling for all participating farmer was conducted at KARI Katumani. The aim of the blind taste panel was to identify lablab accessions with great agronomic potential that are, additionally, providing good eating qualities. For these organoleptic taste assessments the six lablab accessions were prepared as well as a commercially available black-seeded cultivar developed and marketed by KARI, DL 1002. The organoleptic tasting included a grain, pod and leaf dish of every used lablab accession (Annex 6-8). The questionnaires were developed in English but during the tasting translated to Swahili or Kamba, the language of the local Kamba tribe.

3.5.5.1 Preparation of the dishes

The different meals were prepared plain, meaning that apart from cooking oil and small amounts of salt necessary for the preparation, no additional ingredients were added. Thereby, any falsifications in taste should be avoided. To further avoid confusion during the preparation of the dishes, a complete randomized design was created, leading to the labeling of all used pots and bags in which the plant material was collected. To perform this tasting, seven different “Jikos” (Swahili for ‘cooker’) were used. Using “Jikos” is the traditional way of cooking as most farmers still do not have access to fuel or gas to run modern cooking equipment’s. “Jikos” produce heat by burning self-made charcoal. Those “Jikos” were placed outside the dining room to avoid any inconveniences due to smoke development.

For the grain dishes, the grains were soaked in water over night, then washed and cooked in fresh water with one teaspoon of salt for about 40 minutes until the grains were soft.

For the pod dishes, the pods were washed, the fibrous stalk was removed and the pod further sliced. Together with one teaspoon of salt, they were cooked for about 20 minutes and after they were soft, the water was removed and the pods were fried with cooking oil for about another 10 minutes.

For the leaf dishes, the leaves were washed and sliced. Together with one teaspoon of salt they were cooked for about 10 minutes until they were soft. Subsequently the water was removed and the leaves fried with some cooking oil for about 5 minutes.

3.5.5.2 Implementation of the tastings

The meals were placed in small servings on medium-sized plates and displayed with an anonymous label on a table of the dining room at KARI Katumani. However, only small servings at the time were provided and they were frequently replaced as they lose heat very fast and, therefore, attributes of taste and texture change. This should, consequently, results in equal servings in terms of quality for every panelist.

The panelists were then invited to take a sample of about one teaspoon of the prepared meals of the different lablab accessions for taste evaluation. After every tasting, the panelists were requested to rinse their mouth with water and to clean the teaspoon. Questions to appearance, odor, texture and taste were asked immediately after the tasting of each accession and dish type.

3.5.5.3 Data generation

The panelists were requested to freely give their opinion by rating the accessions for the considered traits on a scoring questionnaire. Traits included appearance odor, texture, taste and overall acceptability. The questionnaire included options for five acceptability levels for each trait: “dislike extremely” (1), “dislike moderately” (2), “neither like or dislike” (3), “like moderately” (4), and “like extremely” (5). The setting was equal for the grain, pod and leaf organoleptic taste assessment.

3.6 Statistical analysis

3.6.1 Plant development and growth analysis

The data recorded on plant biomass development, final biomass and grain yield production, LAI development and photosynthetic activity were analyzed by using a number of programs and transformations.

Simple boxplots on biomass and grain yield were performed using the statistic software "*R*" (www.r-project.org). The Free Software "*R*" is a language and environment for statistical computing and graphics that provides a wide variety of statistical and graphical techniques and classical statistical tests (www.r-project.org).

Figures on growth development, including relative growth rate (RGR) and leaf area index (LAI), were performed using *Microsoft Excel 2010*. *Microsoft Excel 2010* was also used to calculate simple statistical parameters, such as the arithmetic mean, standard deviations (SD) as well as the coefficient of variance stated in percentages (CV %).

The determination of significant differences was performed using the statistical software program *sas* (www.sas.com). To ensure variance homogeneity and the normal distribution of the data, a Box-Cox-Transformation was performed and in the following a mixed linear model applied. Significant differences were then identified using the Tukey-Method at $p \leq 0.05$. Therefore the data analysis is based on the Box-Cox transformed data; additionally the lower and upper confidence intervals are indicated.

However, obvious outliers needed to be excluded from the data analysis to ensure variance homogeneity and the normal distribution of the data. In terms of the biomass yield evaluation of the on-station field experiments, the fourth replication of accession CPI 52513 under rainfed conditions at the time of flowering was excluded. Additionally the fourth replication of the biomass yield of CPI 52535 under fully irrigated conditions and of CPI 81364 under partly irrigated conditions, at physiological maturity.

3.6.2 Questionnaire and organoleptic taste paneling analysis

A frequency table was developed from all questionnaires, including the household questionnaires and the taste paneling questionnaires, filled by the farmers.

In case of the organoleptic tasting, the likelihood of an accession's acceptance at a given acceptability level was calculated by dividing the number of panelists, who rated for that accession at that acceptability level, by the overall number of panelists, who evaluated that accession. The cumulative probability was calculated by summing up all previous acceptability levels. By this, the hedonic scores could be displayed together with the coefficient of variance in percentages (CV %) and the standard deviation (SD). Significant differences were obtained by applying the mixed model analysis in *sas* and in the following the Tukey-Method to identify differences ($p \leq 0.05$). However, this analysis was only factorial, meaning no threefold interactions were allowed.

In case of the household questionnaires, frequency tables were used to display simple socio-economic household data, cropping structures and acceptability of each lablab accession on the basis of agronomic evaluation.

4 Results

4.1 Agro-morphological description and phenological development

Detailed agronomic and botanical as well as phenological information about the evaluated short-season lablab accessions is greatly lacking in current literature. Therefore, average plant height, growth habit as well as leaf and pod color, time to flowering and physiological maturity were recorded to be added to the agro-morphological characteristics obtained from the literature (Table 1). Findings from the present study show, that, accessions Q6880B, CPI 81364 and CPI 60795 were relatively early flowering and maturing in comparison to the other accessions studied. 90% of flowering was accomplished between 56 and 63 days after planting (DAP) and, physiological maturity between 112 and 116 DAP (Table 5). Accession CPI 52535 flowered and

Table 5 Morpho-agronomic characteristics of six *Lablab purpureus* accessions evaluated in Machakos County; time to flowering and physiological maturity in days after planting (DAP); leaf and pod color categorized according to the Royal Horticultural Society (http://www.rhs.org.uk/)

Accession ID	Leaf colour [1]	Pod colour [1]	Plant height [cm]	Growth type	Flowering (DAP) *	Maturity (DAP) **
Q6880B	Group Green 137 A/B	Group Green 143 A/B	50-60	erect, compact	56-63	112-116
CPI 60795	Group Green 137 A/B	Group Green 137 B/C	40-50	decumbent, slightly spreading	56-63	112-116
CPI 52508	Group Green 137 A	Yellow Green Group 145 A/B	40	erect, bushy	64-70	113-118
CPI 52513	Group Yellow Green 146 A/137 C	Group Green 143 A	50-60	erect, slightly spreading	64-70	113-118
CPI 52535	Group Green 137 B/C	Yellow Green Group 147 A	55-65	decumbent, heavy spreading	66-70	114-122
CPI 81364	Group Green 137 A/B	Yellow Green Group 147A/B	50	erect, bushy	56-63	112-116

1 according to the Royal Horticultural Society (http://www.rhs.org.uk/); *90% of flowering; **when 90% of the pods have turned brownish

matured latest, 90% of flowering was only after 66 to 70 DAP, physiological maturity only after 114 to 122 DAP. Accessions showed further great differences in plant morphology, in particular in growth type and plant height. Accessions Q6880B, CPI 52508 and CPI 81364 had a more erect, compact to bushy growth type, with maximum plant height ranging between 40 and 60 cm. Inflorescences of these accessions were produced on long peduncles reaching above canopy level. Both accessions CPI 60795 and CPI 52535 showed a more decumbent growth pattern, slightly and heavily spreading, respectively. Accession CPI 52535 reached the greatest plant

height >60 cm with a great, voluminous share of leafy biomass. Inflorescences of CPI 52535 and CPI 52513 were produced on short peduncles located just above ground surface level (Annex 2). Leaf color of the six lablab accessions showed only slight differences. Accessions CPI 52513 and CPI 52535 had the most different leaf colors compared to the remaining accessions (Table 5). Accession CPI 52535 had an outstanding matt grey-green leaf color, as a result of the soft and hairy leaves. On the other hand, pod color, shape and size differed greatly across the evaluated lablab accessions (Figure 8). The largest pods were produced by accessions Q6880B and

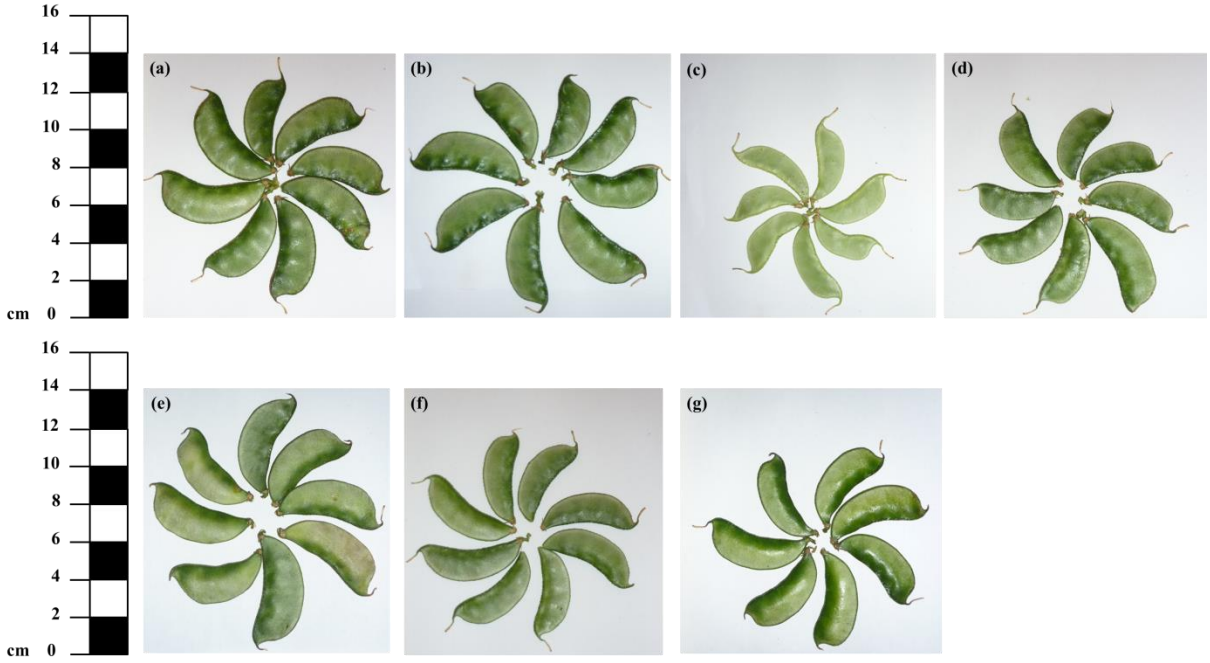

Figure 8 Pod shape, size and color of six *Lablab purpureus* accessions evaluated plus the KARI lablab cultivar DL 1002; (a) Q6880B, (b) CPI60795, (c) CPI52508, (d) CPI52513, (e) CPI52535, (f) CPI 81364, (g) DL1002

CPI 52535, rather small pods were produced by accessions CPI 52508, CPI 60795 and CPI 81364 (Figure 8). Accession CPI 52508 had the most distinct pod shape and color, where the color was a light-green and the shape more circular than the pods from the remaining accessions. All lablab accessions showed a rather indeterminate growth pattern. With unexpected additional rainfall during the dry spell, most accessions started to re-grow and initiated a second flowering. Depending on the environmental conditions throughout the growth period, growth pattern may, therefore, alter from annual to short-lived perennial.

4.2 KARI, Katumani: Water-deficit trial

4.2.1 Plant biomass development and yield

The destructive biomass samples throughout the growing period of the six lablab accessions evaluated showed no pronounced differences until the time of flowering, 70 days after planting (DAP), between accessions and water treatments, reaching around 2500 kg DM ha^{-1} (Figure 9).

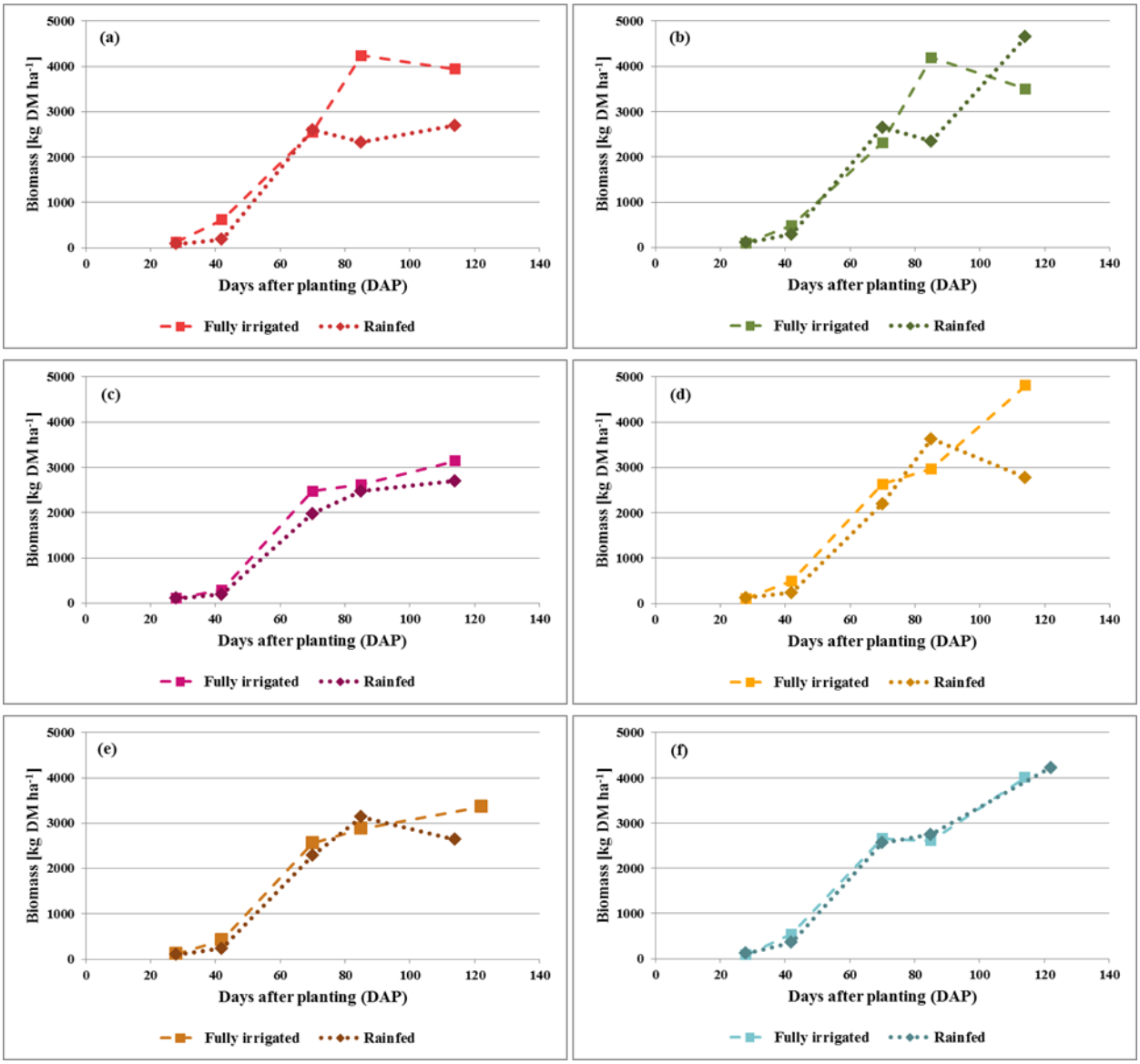

Figure 9 Above ground biomass development of six *Lablab purpureus* accessions evaluated under two water treatments at KARI Katumani, assessed by destructive sampling; (a) Q6880B, (b) CPI 60795, (c) CPI 52508, (d) CPI 52513, (e) CPI 52535, (f) CPI 81364

At the time of flowering, the water treatments only had an effect on accessions CPI 52508 and CPI 52513, showing a slight biomass reduction under rainfed conditions. However, after the time of flowering until the time of physiological maturity, differences between accessions and water treatments were more pronounced, showing differences in biomass yield potential and production efficiency under rainfed conditions. Thereby, the water treatments seemed to have the greatest effect on accessions Q6880B and CPI 52513 where great biomass yield reductions were determined in the rainfed treatment (Figure 9). Almost no difference in biomass yield between the different water treatments but with a high average yield of around 4000 kg DM ha^{-1} was observed in accession CPI 81364 (Figure 9).

4.2.1.1 Biomass yield at flowering and maturity

In general, the biomass production at 90% flowering and physiological maturity of the lablab accessions did not show significant interactions between the accessions and water treatments (Table 6). However, biomass yields indicate great variances in biomass yield potentials among the accessions under rainfed conditions, represented by a high coefficient of variance (CV) of

Table 6 Above-ground dry matter production of six *Lablab purpureus* accessions evaluated under two water treatments at the time of flowering and physiological maturity at KARI, Katumani; no significant differences ($p \leq 0.05$) according to Tukey test were found

Plant development stage	Accession ID	Dry matter production [kg DM ha^{-1}]					
		Fully irrigated	Confidence interval		Rainfed	Confidence interval	
			lower	upper		lower	upper
90% flowering	**Q6880B**	2549.6	1880.6	3474.0	2601.5	1918.2	3545.8
	CPI 60795	2313.9	1709.4	3147.8	2648.3	1952.1	3610.7
	CPI 52508	2472.4	1824.5	3367.0	1975.9	1463.3	2681.1
	CPI 52513	2633.8	1941.7	3590.7	2195.3	1623.1	2983.8
	CPI 52535	2561.8	1889.4	3490.9	2283.3	1678.1	3105.5
	CPI 81364	2654.9	1956.9	3619.9	2557.9	1886.5	3485.4
	CV %	**4.9**			**11.3**		
physiological maturity*	**Q6880B**	3941.1	2886.5	5409.2	2695.4	1986.3	3676.0
	CPI 60795	3497.3	2566.4	4790.4	4645.9	3393.5	6394.5
	CPI 52508	3139.9	2308.2	4293.1	2701.2	1912.8	3839.1
	CPI 52513	4807.4	3509.5	6620.6	2773.4	2042.8	3784.1
	CPI 52535	3367.4	2374.9	4806.2	2636.6	1943.6	3594.5
	CPI 81364	4004.1	2624.9	6167.4	4223.8	3090.0	5804.0
	CV %	**15.8**			**27.6**		

*** when 90% of the pods have turned brownish**

27.6% at maturity (Table 6). In contrast, the effect of the water treatments on biomass yield among the accessions at flowering was marginal, indicated by low CV values being 4.9 and 11.3% for the fully irrigated and rainfed water treatment, respectively (Table 6). Under fully irrigated conditions, mean biomass yields at maturity ranged between 3139.9 and 4004.1 kg DM ha^{-1}, whereas under rainfed conditions, differences among accessions were much greater, ranging between of 2636.6 and of 4645.9 kg DM ha^{-1} (Table 6). Most severe reduction in biomass yield between water treatments was observed in accession CPI 52513, where the biomass yield dropped from 4807.4 to only 2773.4 kg DM ha^{-1} under rainfed conditions. Similar, high biomass yields were achieved by accession CPI 81364 for both water treatments; ranging between 4004.1 and 4223.8 kg DM ha^{-1} (Table 6).

4.2.1.2 Plant biomass partitioning: leaf/stem ratio

Legumes are well known to drop leaves towards the end of their growth cycle. This phenomenon is reflected by the pronounced decrease of the leaf/stem ratio from flowering to physiological maturity (Table 7). However, this effect was not significant, whereas significant differences among accessions and water treatments were found at individual plant development stages

Table 7 Leaf/Stem ratio of six *Lablab purpureus* accessions evaluated under two water treatments at KARI, Katumani; different letters indicate significant differences ($p \leq 0.05$) among accessions and between water treatments by development stage, respectively, according to Tukey test

Plant development stage	Accession ID	leaf/stem ratio					
		Fully irrigated	Confidence interval		Rainfed	Confidence interval	
			lower	upper		lower	upper
90% flowering	**Q6880B**	0.824 **c**	0.626	1.053	0.943 **c**	0.729	1.190
	CPI 60795	1.019 **bc**	0.794	1.277	1.057 **a-c**	0.827	1.320
	CPI 52508	1.322 **a-c**	1.058	1.620	1.821 **ab**	1.500	2.178
	CPI 52513	1.041 **a-c**	0.813	1.302	1.194 **a-c**	0.946	1.475
	CPI 52535	0.935 **c**	0.722	1.181	1.025 **bc**	0.799	1.284
	CPI 81364	0.974 **c**	0.756	1.226	0.935 **c**	0.722	1.181
	CV %	**16.4**			**28.9**		
physiological maturity*	**Q6880B**	0.392 **a-c**	0.268	0.545	0.351 **a-c**	0.236	0.495
	CPI 60795	0.162 **b-d**	0.092	0.257	0.159 **b-d**	0.090	0.254
	CPI 52508	0.319 **a-d**	0.210	0.455	0.156 **b-d**	0.080	0.265
	CPI 52513	0.296 **a-d**	0.192	0.427	0.120 **cd**	0.062	0.201
	CPI 52535	0.284 **a-d**	0.170	0.432	0.141 **cd**	0.077	0.229
	CPI 81364	0.659 **a**	0.430	0.946	0.499 **ab**	0.355	0.673
	CV %	**47.7**			**64.4**		

*when 90% of pods have turned brownish

(Table 7). As already shown with biomass yield (Table 6), also differences in leaf/stem ratio at the time of flowering were minimal among accessions and water treatments. The leaf/stem ratios ranged from 0.824 (Q6880B, fully irrigated) to 1.821 (CPI 52508, rainfed). Accession CPI 52508 obtained the highest leaf/stem ratio at flowering among accessions and between water treatments, being significantly different in the rainfed water treatment from accession Q6880B and CPI 81364 (Table 7). Additionally, the high leaf/stem ratio of accession CPI 52508 under rainfed conditions and at flowering was significantly different from accessions Q6880B, CPI 52535 and CPI 81364 under fully irrigated conditions. At physiological maturity, the different water treatments showed an effect on leaf/stem partitioning, resulting in lower ratios under rainfed conditions compared to the fully irrigated water treatment (Table 7). Accession CPI 81364 obtained highest leaf/stem ratios, both under fully irrigated and rainfed conditions, thus, being significantly different from CPI 60795 under fully irrigated conditions and, from CPI 52513 and CPI 52535 under rainfed conditions (Table 7).

4.2.2 Grain yield production

In terms of grain production, the accessions differed greatly. Accession CPI 52535 obtained lowest grain yields among accessions and between water treatments, being only 217.6 kg ha^{-1} under rainfed and, 642.1 kg ha^{-1} under fully irrigated conditions (Table 8). Thereby, grain yield of accession CPI 52535 was found to be only one eighth of the highest grain yield among all accessions. Accessions CPI 52513 and Q6880B obtained highest grain yields under fully irrigated conditions, with 1928.1 and 1485.6 kg ha^{-1}, respectively (Table 8). Thus together with accession

Table 8 Grain yield of six *Lablab purpureus* accessions evaluated under two water treatments at KARI, Katumani; different letters indicate significant differences ($p \leq 0.05$) among accessions and between water treatments according to Tukey test

Accession ID	Grain yield [kg ha^{-1}]					
	Fully irrigated	Confidence interval		Rainfed	Confidence interval	
		lower	upper		lower	upper
Q6880B	1485.6 **ab**	964.5	2220.6	1131.0 **ab**	718.6	1722.5
CPI 60795	1214.5 **ab**	776.1	1840.5	2032.4 **a**	1351.0	2976.5
CPI 52508	662.8 **bc**	402.3	1049.6	805.2 **a-c**	459.5	1342.8
CPI 52513	1928.1 **ab**	1276.7	2833.2	865.5 **a-c**	537.8	1343.8
CPI 52535	217.6 **c**	106.8	410.2	642.1 **bc**	388.6	1019.3
CPI 81364	1276.4 **ab**	673.6	2269.8	1113.9 **ab**	706.9	1698.2
CV %	**53.7**			**45.0**		

CPI 60795 and CPI 81364 grain yields were significantly different from that of accession CPI 52535 (Table 8). Under rainfed conditions, accessions CPI 60795 and Q6880B obtained highest grain yields, being 2032.4 and 1131.0 kg ha^{-1}, respectively (Table 8). Therefore, grain yields of accessions CPI 60795 and CPI 52535 were significantly different. A comparable high quantity of grain yield was obtained from accessions Q6880B and CPI 81364 across the water treatments (Table 8). The greatest reduction in grain yield between the water treatments was recorded for accession CPI 52513, where grain yield was reduced by 50% from 1928.1 to only 865.5 kg ha^{-1} under fully irrigated and rainfed conditions, respectively (Table 8). Whereas the inverse was recorded for accession CPI 60795; here grain yields under rainfed conditions treatment exceeded grain yields obtained in the fully irrigated treatment greatly, by 2032.4 to 1214.5 kg ha^{-1}.

4.2.2.1 Accession effect on grain yield

Additionally, differences among accessions across water treatments were proven to be significant (Figure 10). The mean grain yields of lablab accessions Q6880 and CPI 60795 were significantly different from those of CPI 52508 and CPI 52535; additionally, those of accessions CPI 52513

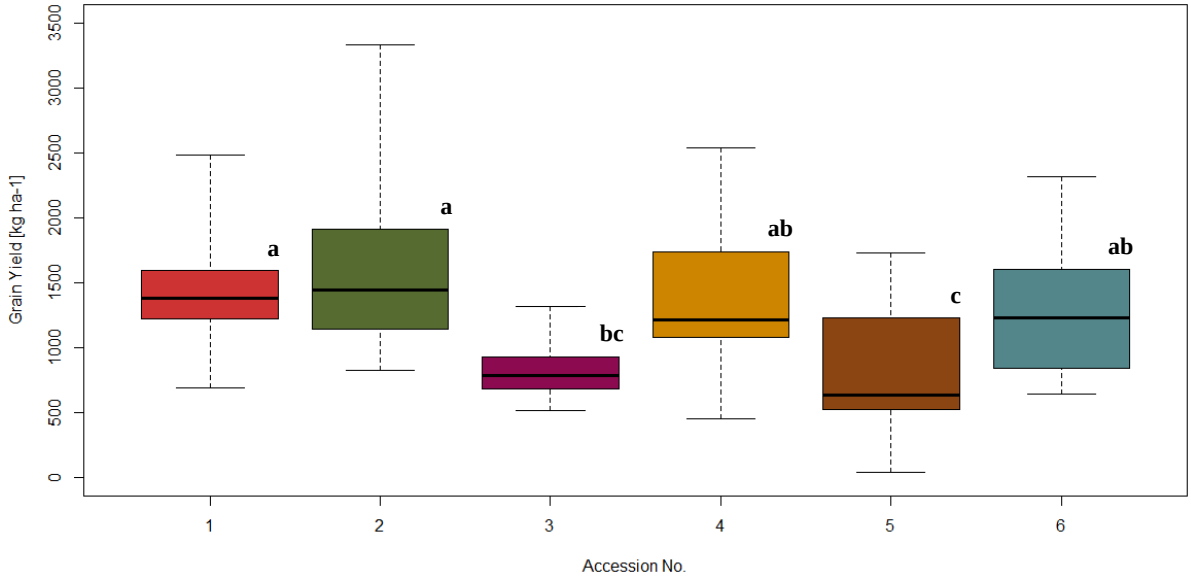

Figure 10 Differences in grain yield between six *Lablab purpureus* accessions across two water treatments evaluated at KARI, Katumani; 1 (Q6880B), 2 (CPI 60795), 3 (CPI 52508), 4 (CPI 52513), 5 (CPI 52535), 6 (CPI 81364); different letters indicate significant differences ($p \leq 0.05$) among accessions according to Tukey test

and CPI 81364 from that of CPI 52535 (Figure 10). The highest mean grain yield was obtained by accession CPI 60795 reaching about 1500 kg ha^{-1}. However, this accession showed the greatest variance as well. The lowest mean grain yield was achieved by accession CPI 52535 with only about 500 kg ha^{-1} (Figure 10).

4.2.2.2 Harvest index

In case of the harvest index (HI), another common measure to evaluate the share of grain on the total plant biomass, no significant differences were found, despite fairly high variation among accessions. This is illustrated with the coefficient of variance (CV %), being 37.6 and 22.7% in the fully irrigated and rainfed water treatment, respectively (Table 9).

Corresponding to the results of biomass and grain production, accession CPI 52535 had the lowest HI in both water treatments, being only 0.114 and 0.254 under fully irrigated and rainfed conditions, respectively (Table 9). The highest HI was achieved by accession CPI 52513 being 0.401 under fully irrigated conditions, and by accession CPI 60795 with 0.429 under rainfed conditions (Table 9). Almost similar HI values in the water treatments were achieved by accession Q6880B, being 0.378 under fully irrigated and 0.417 under rainfed conditions (Table 9). HI values were not found to be consistently lower under rainfed conditions compared to values derived from accessions under fully irrigated conditions.

Table 9 Harvest index (HI) of six *Lablab purpureus* accessions evaluated under two water treatments at KARI, Katumani; no significant differences ($p \leq 0.05$) according to Tukey test were found

Accession ID	Fully irrigated		Rainfed	
	HI	SD	HI	SD
Q6880B	0.576	0.090	0.430	0.079
CPI 60795	0.519	0.092	0.758	0.093
CPI 52508	0.266	0.065	0.407	0.132
CPI 52513	0.723	0.093	0.391	0.084
CPI 52535	0.087	0.043	0.279	0.069
CPI 81364	0.486	0.200	0.431	0.080
SD	0.229		0.161	
CV %	**51.7**		**35.9**	

4.2.3 Plant growth analysis

4.2.3.1 Leaf area index development

The maximum leaf area index (LAI) at the time of flowering aligned with the peak in biomass production (Figure 9), was achieved by accession CPI 52513, being 2.5 under fully irrigated conditions, the lowest LAI with a value of 1.1 from the rainfed accession CPI 52535 (Figure 11).

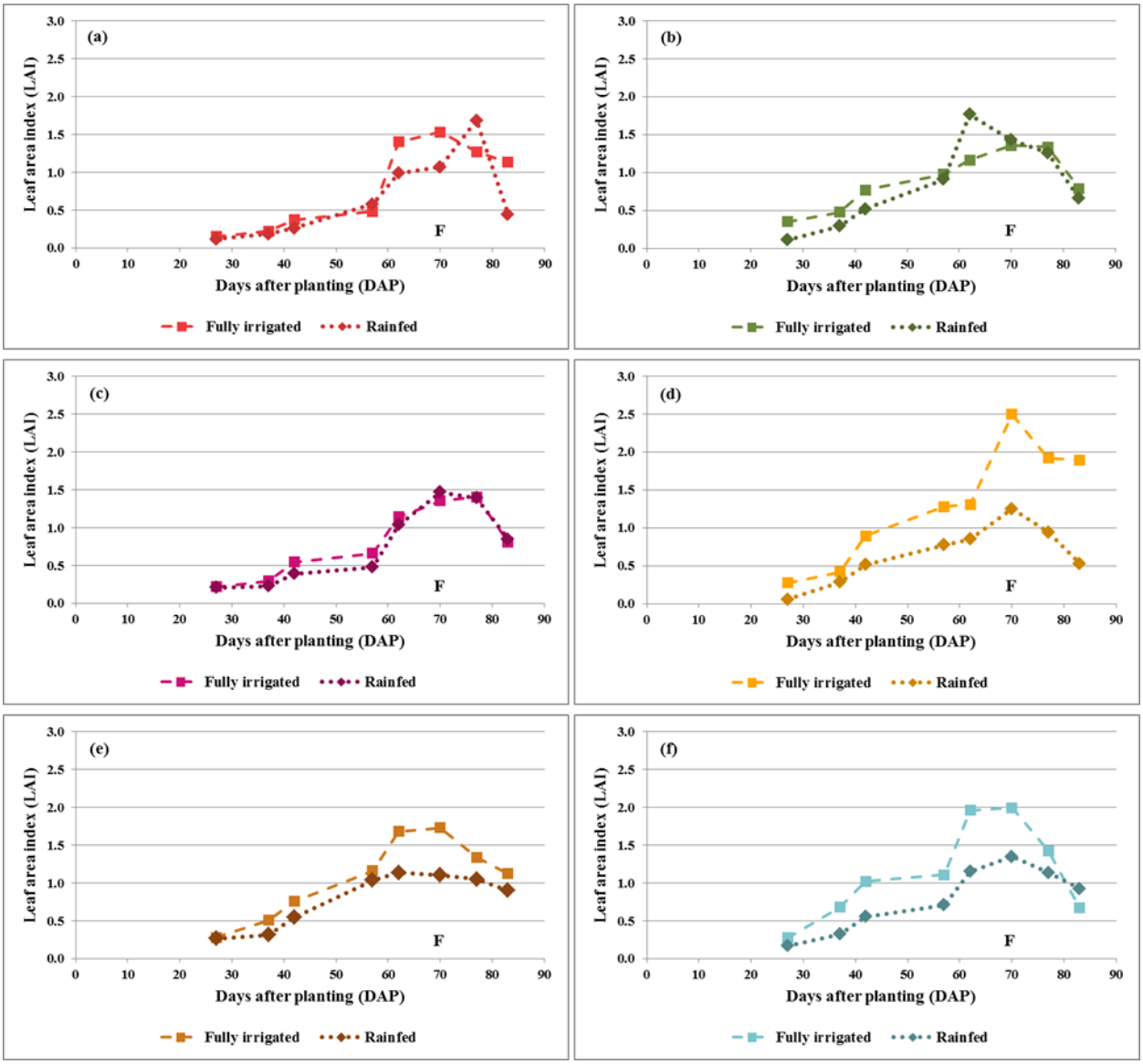

Figure 11 Leaf Area Index (LAI) development of six *Lablab purpureus* accessions evaluated under two water treatments at KARI, Katumani; (a) Q6880B, (b) CPI 60795, (c) CPI 52508, (d) CPI 52513, (e) CPI 52535, (f) CPI 81364; F: time of 90% flowering

The greatest difference between water treatments was recorded for accessions CPI 52513, CPI 52535 and CPI 81364, with LAI being greatly reduced under rainfed conditions compared to the fully irrigated water treatment (Figure 11). Whereas differences in LAI development between the water treatments were less pronounced in accessions Q6880B, CPI 60795 and CPI 52508, the overall pattern were similar (Figure 11).

However, towards the time of physiological maturity, differences in LAI between fully irrigated and rainfed conditions narrowed in most of the lablab accessions, except for CPI 52513 (Figure 11). There, the final LAI was again highest with a value of 2.0 (Figure 11). The lowest final LAI was obtained by accession Q6880B under rainfed conditions with a LAI of 0.4 (Figure 11).

4.2.3.2 Relative growth rate

The relative growth rate (RGR) helps to quantify the efficiency of the existing biomass in producing new biomass. All evaluated accessions showed a downward sloping RGR over time (Figure 12). RGRs under rainfed conditions followed a flatter trend compared to those of the fully irrigated water treatment, meaning leafy biomass gains were smaller under rainfed than under fully irrigated conditions.

Within the first month of plant growth, accessions showed RGRs ranging between 0.10 and 0.14 g g^{-1} d^{-1} in the fully irrigated water treatment, with accession Q6880B showing the highest and accession CPI 60795 showing the smallest RGR, being 0.14 and 0.10 g g^{-1} d^{-1}, respectively (Figure 12). The highest RGR under rainfed conditions was obtained by accession CPI 52513 with almost 0.14 g g^{-1} d^{-1} (Figure 12). The greatest differences between the water treatments were found in accession Q6880B, under fully irrigated conditions a RGR of 0.14 g g^{-1} d^{-1} was obtained, whereas under rainfed conditions only a RGR of 0.08 g g^{-1} d^{-1} was obtained (Figure 12).

At the time of flowering, the RGRs were reduced by more than 75% in most of the accessions, indicating that the production of non-photosynthetic active tissue such as flowers and roots gained more importance. However, all accessions showed a slight increase in RGR after flowering which corresponds to the unexpected rains during the dry spell leading to new setting of leaves and inflorescences (Figure 12). In general, differences among accessions and between

water treatments were not greatly pronounced, apart from accession Q6880B. However, RGRs in accession CPI 81364 showed the slightest difference between treatments, supported by the coefficient of determination (R^2) being highest among accessions and between treatments (Figure 12).

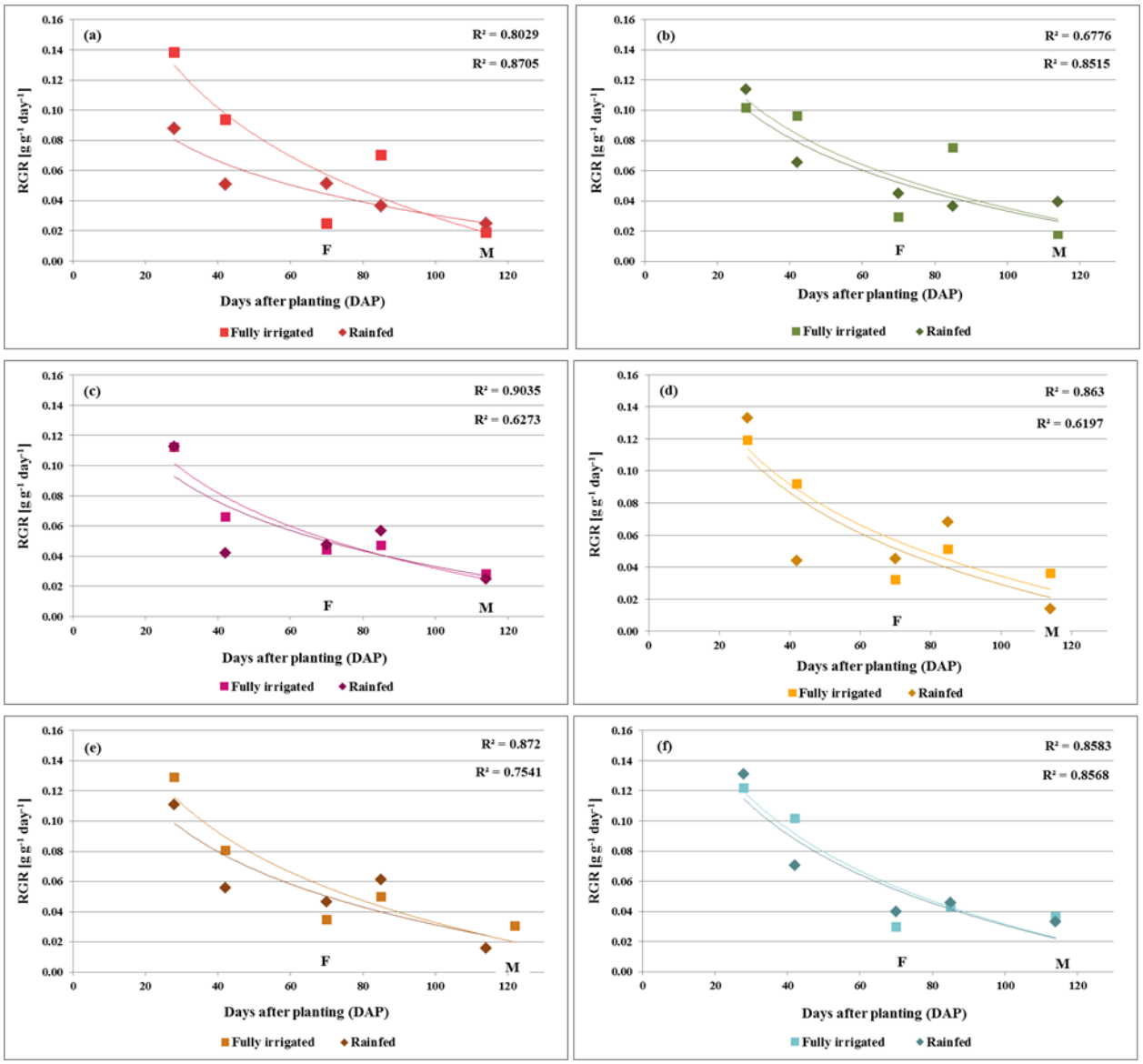

Figure 12 Relative Growth Rate (RGR) of six *Lablab purpureus* accessions evaluated under two water treatments at KARI, Katumani; (a) Q6880B, (b) CPI 60795, (c) CPI 52508, (d) CPI 52513, (e) CPI 52535, (f) CPI 81364; the upper coefficient of determination (R^2) always refers to the fully irrigated water treatment, the lower to the rainfed water treatment; F: time of 90% flowering; M: physiological maturity

4.2.3.3 Transpiration efficiency under drought and non-drought conditions

Especially under stress conditions, in this case the effects of drought, plants need to adjust their stomata conductance to remain productive on the one hand, but also to minimize water losses on the other. Therefore, transpiration efficiency increases rather when the photosynthetic rate is increased but the transpiration rate maintained, or when the photosynthetic rate is maintained and the transpiration rate reduced.

Differences in specific transpiration efficiency were not significant among the lablab accessions

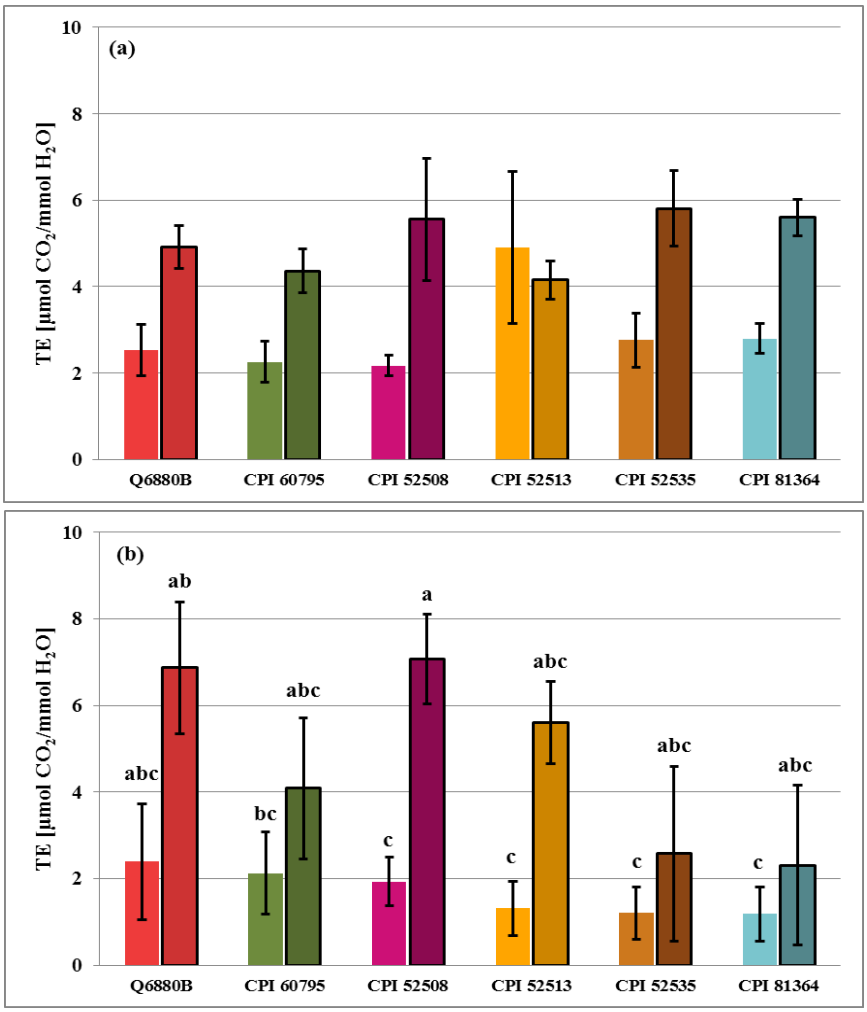

Figure 13 Transpiration efficiency (TE) of six *Lablab purpureus* accessions evaluated under two water treatments at KARI, Katumani; (a) 69 days after planting (DAP), (b) 83 DAP; non-lined bars represent the fully irrigated, lined bars the rainfed water treatment; variation is presented by standard deviation (SD); different letters indicate significant differences ($p \leq 0.05$) among accessions and between water treatments according to Tukey test

and between the different water treatments under non-drought stressed conditions, at 69 DAP where rainfall was sufficient (Figure 13 (a)). However, the bars indicate a tendency to higher transpiration efficiency (TE) among the accessions in the rainfed water treatment compared to the lower values among the accessions in the fully irrigated water treatment, however, standard deviations were partly extremely high (Figure 13 (a)). In comparison, under drought-stressed conditions, at 83 DAP when irrigation was needed to ensure a minimum supply of 50 mm water weekly for the fully irrigated water treatment, differences were significant (Figure 13 (b)). The effect of the water treatments was significant on accession CPI 52508, where the TE of the rainfed plants exceeded the transpiration efficiency of the fully irrigated plants by far (Figure 13 (b)). Additionally, the TE of rainfed CPI 52508 was significantly different from that of the remaining lablab accessions under fully irrigated conditions (Figure 13 (b)).

4.2.3.4 Nitrogen allocation during plant development

At the time of flowering, the C/N ratio was greater by more than 50% in stem biomass compared to leaf biomass among all accessions (Table 10). Low C/N ratios indicate a relatively higher content of nitrogen (N) compared to carbon (C). The C/N ratio in leaves ranged between 10.12 (CPI 52535, fully irrigated) and 11.68 (Q6880B, fully irrigated), whereas in stems it ranged from

Table 10 Nitrogen and carbon allocation, and the C/N ratio of six *Lablab purpureus* accessions evaluated under two water treatments at the time of flowering at KARI Katumani, Kenya

Accession ID	Plant part	Nitrogen and carbon allocation					
		Fully irrigated			Rainfed		
		N %	C %	C/N ratio	N %	C %	C/N ratio
Q6880B	**Leaf**	3.58	41.78	**11.68**	3.66	41.74	**11.40**
	Stem	1.64	39.81	**24.30**	1.62	40.23	**24.91**
CPI 60795	**Leaf**	3.58	39.42	**11.02**	3.83	41.81	**10.92**
	Stem	1.82	39.97	**21.92**	1.79	40.62	**22.66**
CPI 52508	**Leaf**	3.59	41.24	**11.48**	3.50	41.19	**11.78**
	Stem	1.96	39.52	**20.13**	1.87	38.98	**20.89**
CPI 52513	**Leaf**	4.09	41.41	**10.12**	3.90	41.92	**10.74**
	Stem	1.93	40.22	**20.84**	2.01	40.59	**20.18**
CPI 52535	**Leaf**	4.13	42.03	**10.17**	3.70	42.22	**11.42**
	Stem	1.81	40.16	**22.14**	1.71	40.81	**23.86**
CPI 81364	**Leaf**	3.76	42.16	**11.22**	3.92	41.86	**10.68**
	Stem	1.55	40.22	**25.98**	1.75	40.36	**23.08**
CV % (leaf)		6.9	2.4	**6.0**	4.4	0.8	**4.0**
CV % (stem)		9.1	0.7	**9.7**	7.6	1.7	**7.9**

20.13 (CPI 52508, fully irrigated) to 25.98 (CPI 81364, fully irrigated) (Table 10).

At the time of physiological maturity, stem biomass continued with highest C/N ratios among the distinct plant parts, which were even increased compared to the time of flowering.

Stem biomass was followed by leaf biomass and, smallest C/N ratios were obtained by seeds (Table 11). As C/N ratios in the stems ranged from 20.13 to 25.98 at the time of flowering, the ratios ranged between 19.32 (CPI 52535, rainfed) and 31.23 (CPI 60795, rainfed) at the time of

Table 11 Nitrogen and carbon allocation, and the C/N ratio of six *Lablab purpureus* accessions evaluated under two water treatments at the time of physiological maturity at KARI Katumani, Kenya

Accession ID	Plant part	Nitrogen and carbon allocation					
		Fully irrigated			Rainfed		
		N %	C %	C/N ratio	N %	C %	C/N ratio
Q6880B	Leaf	2.86	35.93	**12.55**	2.75	34.78	**12.64**
	Stem	1.44	40.78	**28.33**	1.34	39.27	**29.33**
	Seed	3.92	42.37	**10.81**	3.56	41.70	**11.72**
CPI 60795	Leaf	2.61	32.42	**12.42**	2.91	35.95	**12.34**
	Stem	1.68	42.56	**25.28**	1.32	41.15	**31.23**
	Seed	3.73	42.46	**11.38**	3.72	41.26	**11.09**
CPI 52508	Leaf	1.73	26.56	**15.32**	2.34	34.76	**14.88**
	Stem	1.74	40.49	**23.21**	1.60	40.30	**25.12**
	Seed	4.05	42.30	**10.44**	3.26	41.66	**12.78**
CPI 52513	Leaf	3.00	38.92	**12.99**	2.18	26.95	**12.37**
	Stem	1.51	41.23	**27.29**	2.00	38.63	**19.32**
	Seed	4.10	42.05	**10.25**	4.13	42.19	**10.21**
CPI 52535	Leaf	3.47	34.34	**9.89**	2.74	38.39	**14.04**
	Stem	1.69	39.31	**23.27**	1.50	40.96	**27.35**
	Seed	4.14	40.77	**9.86**	3.99	41.53	**10.40**
CPI 81364	Leaf	3.64	39.44	**10.85**	3.44	38.29	**11.14**
	Stem	1.49	41.11	**27.53**	1.45	40.34	**27.79**
	Seed	3.76	41.97	**11.17**	4.27	41.08	**9.63**
CV % (leaf)		23.6	13.8	**15.2**	16.4	12.0	**10.4**
CV % (stem)		8.0	2.6	**8.7**	16.3	2.4	**15.5**
CV % (seed)		4.5	1.5	**5.4**	9.9	0.9	**10.4**

physiological maturity (Table 11). Hence, C/N ratios of stems increased in most of the accessions between flowering and maturity. The ratio in the leaves ranged between 9.89 (CPI 52535, fully irrigated) and 14.04 (CPI 52535, rainfed) at maturity (Table 11). The closest C/N-ratio was found in the seeds of accession CPI 81364 under rainfed conditions being 9.63, the greatest ratio occurred under the same treatment in the seeds of accession CPI 52508 being 12.78 (Table 11).

4.3 Participatory research: *Lablab purpureus* acceptance study and blind taste paneling

4.3.1 Income structure and importance of agriculture

The income structure of smallholder farmers has changed over the last decades, leading to a greater diversity of income-generating activities as part of managing risks. Therefore, it is important to weight the importance of agricultural activities for the total household income as it may have a direct influence on interests towards agricultural innovations. Hence, the participant farmers were divided into two groups according their production orientation. Figure 14 shows the estimated distribution of (a) subsistent farmers, who depend primarily on on-farm production,

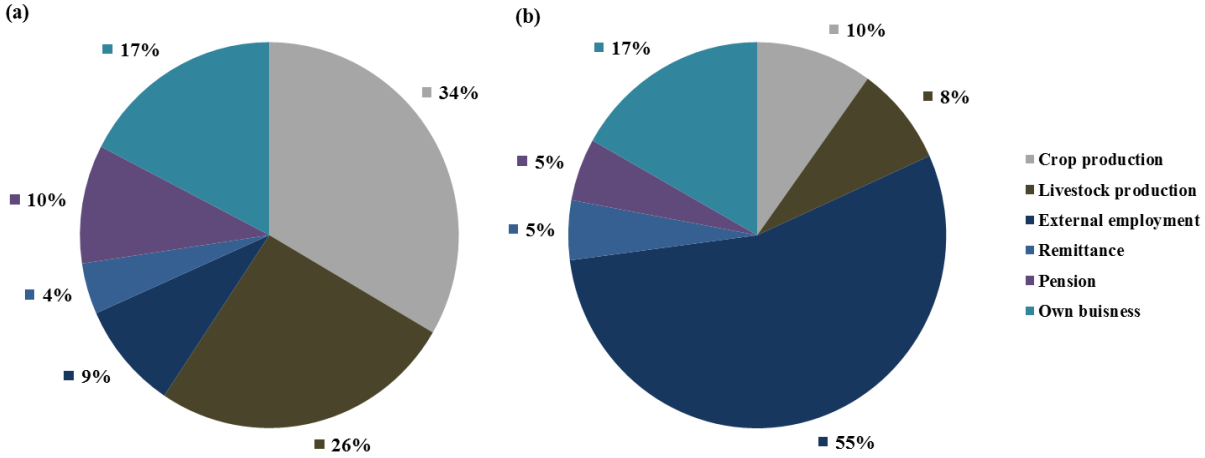

Figure 14 Estimated importance of agricultural activities on total household income; data from the 16 participant farmers across Machakos County; (a) Agricultural activities accounted for more than 50 % of total household income (n= 5), (b) non-agricultural activities accounted for more than 50% of total household income (n= 11)

whereas (b) part-time farmers obtain most of their income from external employment (Figure 14). Out of the total number of sixteen participating farmers, five household were assigned to (a) and eleven to (b). For the households were agriculture remains the main income source, crop production has the largest share, accounting for 34% of the total household income, followed by livestock production with 26% (Figure 14). The greatest share of non-agricultural income was by the revenues from own businesses, accounting for 17%. Own businesses may be selling purchased vegetables on the market or running a small kiosk. In case of (b), revenues from external employments accounted for the largest share to the total household income, summing up

to 55% (Figure 14). This was mostly generated by the husband from an employment in public services or private companies. Revenues from agricultural activities only accounted for 10 and 8% from crop and livestock production, respectively. As most of the farmers in (a) were already retired, the income from pension accounted for 10% and was supplemented by 4% of remittances (Figure 14).

4.3.2 Land size and agricultural use

When dividing the farmers into groups according to total agricultural land area available, six households were assigned to (a) having more than 10 acres and ten households were assigned (b) to having less than 10 acres[1] of agricultural land area (Figure 15). In case of (a), the total agricultural land area was divided into different shares of agricultural activities. Crop land

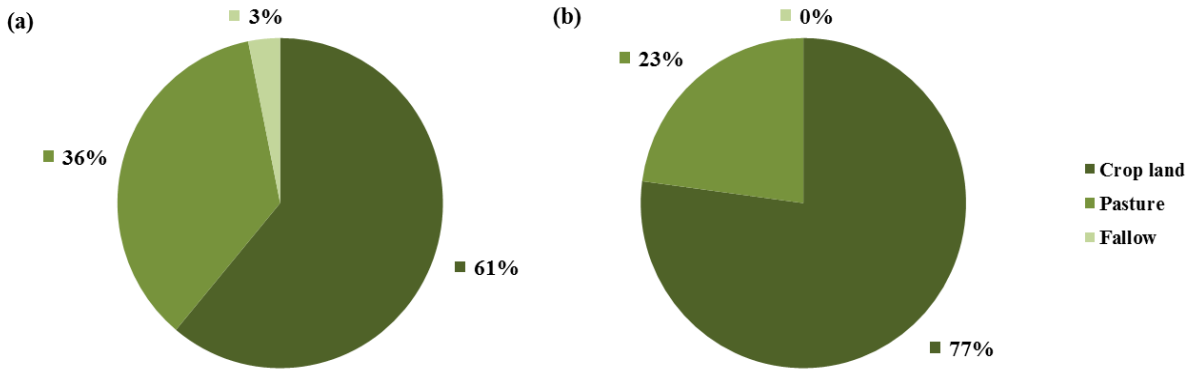

Figure 15 Shares of land use systems depending on total available agricultural area; data from the 16 participant farmers across Machakos County; (a) total agricultural land size is greater than 10 acres (n= 6), (b) total agricultural land size is smaller than 10 acres (n= 10)

accounted for 61%, pasture for 36% and fallow land for 3% of the total agricultural land area (Figure 15). In (b), the crop land took the largest share of the total land area with 77% followed by the pastures with 23%. In (b) there was no fallow land. This may indicate that the agricultural activities contributed the main share to household income in (b), and this was why the farmers did not allow for fallow land. Additionally the total agricultural land area, which may be very limited, may make year-round cropping necessary to sustain income.

[1] In Kenya, 1 acre is equivalent to 0.4 ha.

4.3.2.1 Diversity in legume cultivation

In total, a number of seven leguminous species was stated to be grown frequently by the participant farmers, common beans (*Phaseolus vulgaris* (L.)), pigeon peas (*Cajanus cajan* (L.) Millsp.), cowpeas (*Vigna unguiculata* (L.) Walp), lablab (*Lablab purpureus* (L.) Sweet), soybean (*Glycine max* (L.) Merr.), mung bean (*Vigna radiate* L. R. Wilczek), and black gram (*Lens culinaris* Medik.) (Figure 16). However, the shares on the land area which is used for legume cultivation varied greatly between those legume species.

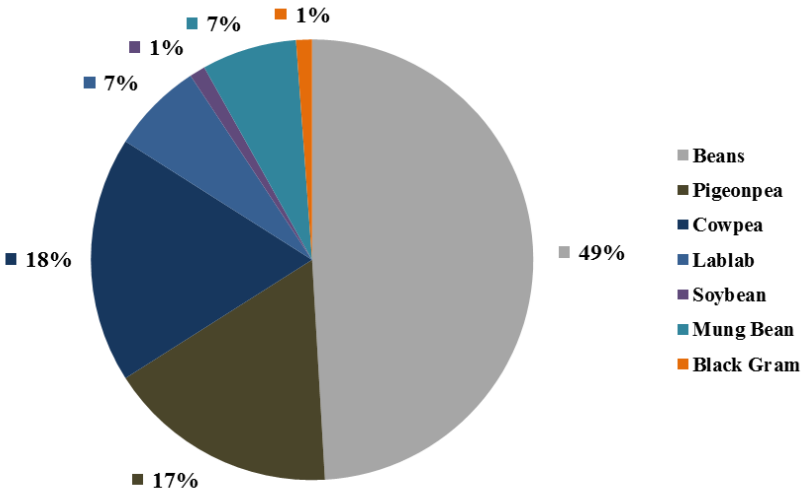

Figure 16 Crop legume diversity on 16 participant farms in Machakos County and their relative abundance on provided agricultural land area indicated in percentages; (n= 16)

Common beans accounted for the largest share of 49%, followed by cowpeas and pigeon peas with 18 and 17%, respectively. Minor leguminous species in terms of cultivation area are lablab, soybean, mung bean and black gram, accounting only for 7, 1, 7 and 1%, respectively (Figure 16).

4.3.3 Plant biomass development and yield

4.3.3.1 Biomass yield at flowering and maturity

The 16 farm sites across Machakos County were assigned to two different soil types according to their texture and were classified rather as sandy clay or sandy loam. Nine farm sites were assigned to the sandy loam soil type and four to the sandy clay one. In general, plant biomass

yields were much lower on the on-farm experimental sites than on the on-station site, independent of the applied water treatment. At the time of flowering, neither the biomass production among accessions on sandy clay, nor on sandy loam soil type showed significant differences ($p \leq 0.05$) (Table 12). Plant biomass yields at flowering ranged from 1008.5 kg DM ha^{-1} (CPI 52508, sandy clay) to 1806 kg DM ha^{-1} (Q6880B, sandy clay) (Table 9). The coefficient of variance (CV) was 22.2% for the sandy clay soil type, and 6.2% for the sandy loam soil type. At the time of physiological maturity, no significant differences among accessions

Table 12 Above ground dry matter production of six *Lablab purpureus* accessions according to soil types at the time of flowering and physiological maturity evaluated on 13-farms (n= 4 for sandy clay; n= 9 for sandy loam), in Machakos County; different letters indicate significant differences ($p \leq 0.05$) among accessions and between plant development stages by soil type, respectively, according to Tukey test

Plant development stage	Accession ID	Dry matter production [kg DM ha^{-1}]					
		Sandy clay	Confidence interval		Sandy loam	Confidence interval	
			lower	upper		lower	upper
90% flowering	**Q6880B**	1806.0 **ab**	1189.8	2624.2	1251.0 **bc**	893.8	1700.9
	CPI 60795	1791.5 **ab**	1179.0	2605.2	1149.5 **bc**	814.4	1574.0
	CPI 52508	1008.5 **b**	613.7	1559.6	1157.5 **bc**	820.7	1584.0
	CPI 52513	1170.7 **b**	728.1	1780.3	1208.0 **bc**	860.2	1647.2
	CPI 52535	1505.7 **ab**	969.2	2228.1	1038.4 **c**	728.1	1434.3
	CPI 81364	1628.1 **ab**	1058.6	2390.5	1186.9 **bc**	843.6	1620.8
	CV %	**22.2**			**6.2**		
physiological matruity*	**Q6880B**	3157.6 **a**	2256.6	4292.5	1890.5 **a-c**	1463.9	2400.0
	CPI 60795	2161.8 **ab**	1484.8	3036.7	1782.3 **a-c**	1374.1	2271.4
	CPI 52508	2073.7 **ab**	1417.8	2924.1	1379.8 **bc**	1042.6	1789.3
	CPI 52513	2730.9 **ab**	1923.2	3758.0	2349.4 **ab**	1847.9	2942.2
	CPI 52535	2747.6 **ab**	1936.2	3778.9	2692.5 **a**	2104.1	3391.0
	CPI 81364	3207.7 **a**	2296.0	4355.1	2746.5 **a**	2183.3	3407.5
	CV %	**17.9**			**25.5**		

* when 90% of the pods have turned brownish

in the sandy clay soil type existed, but, in the sandy loam soil type (Table 12). Here, accessions CPI 52535 and CPI 81364 differed significantly from accession CPI 52508 (Table 12). Plant biomass yield at the time of physiological maturity ranged from 1379.8 kg DM ha^{-1} (CPI 52508, sandy loam) to 3207.7 kg DM ha^{-1} (CPI 81364, sandy clay). Additionally, accession CPI 81364 obtained highest biomass yields on the sandy loam soil type as well, being 2746.5 kg ha^{-1} (Table 12). Whereas accession CPI 52508 obtained poorest biomass yields on both soil types (Table 12). The coefficient of variance increased towards the time of physiological maturity and was, 17.9 among the accessions on the sandy clay soil type, and 25.5 among the accessions on the sandy loam soil type (Table 12).

4.3.3.2 Accession and soil type effect on biomass production at maturity

In contrast to the plant biomass yield at flowering, there were significant differences detected for biomass yields among the accessions at the time of physiological maturity (Figure 17). When analyzing mean plant biomass across soil types, the highest average biomass yield was achieved by accession CPI 81364, with 3000 kg DM ha^{-1} (Figure 17). The lowest biomass yield was obtained by accession CPI 52508 with only 1800 kg DM ha^{-1} (Figure 17). However, the standard deviation (SD) was high across all lablab accessions, reflecting the great variance of biomass production across the farm sites (Figure 17).

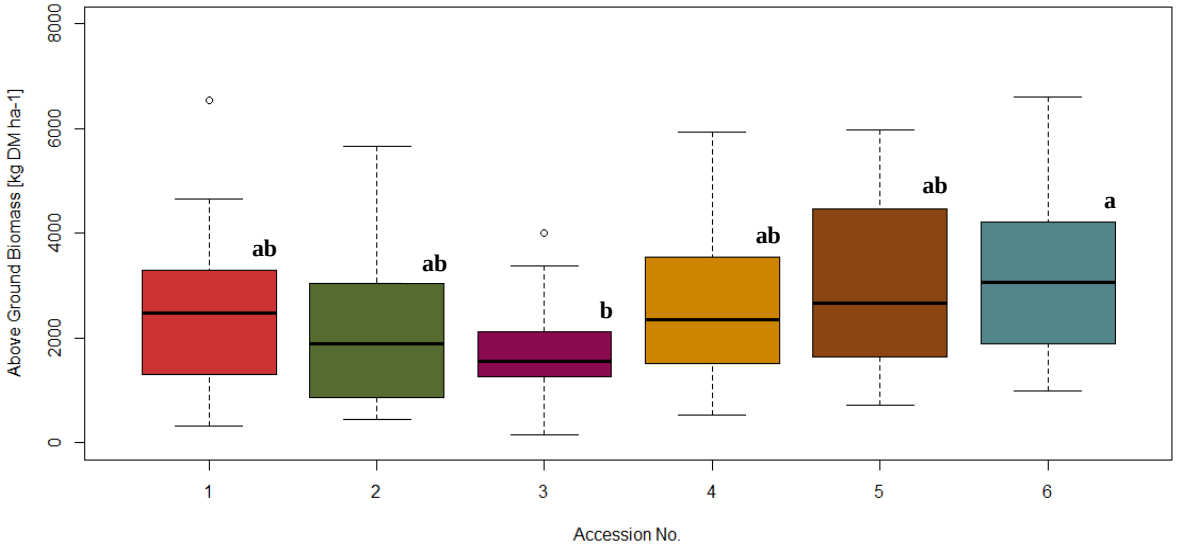

Figure 17 Differences in biomass production at the time of physiological maturity between the six *Lablab purpureus* accessions evaluated on 13-farms, in Machakos County; 1 (Q6880B), 2 (CPI 60795), 3 (CPI 52508), 4 (CPI 52513), 5 (CPI 52535), 6 (CPI 81364); different letters indicate significant differences ($p \leq 0.05$) among accessions according to Tukey test

In addition, plant performances on the two soil type groups were significantly different at the time of physiological maturity in terms of biomass production (Figure 18). When assessing biomass yields of the accessions according to soil type, biomass yield on the sandy clay was significantly higher compared to the sandy loam soil type (Figure 18).

While, on average, biomass yields of 2500 kg DM ha^{-1} were produced on the sandy clay soil, the average biomass yield on the sandy loam was 2000 kg DM ha^{-1} (Figure 18).

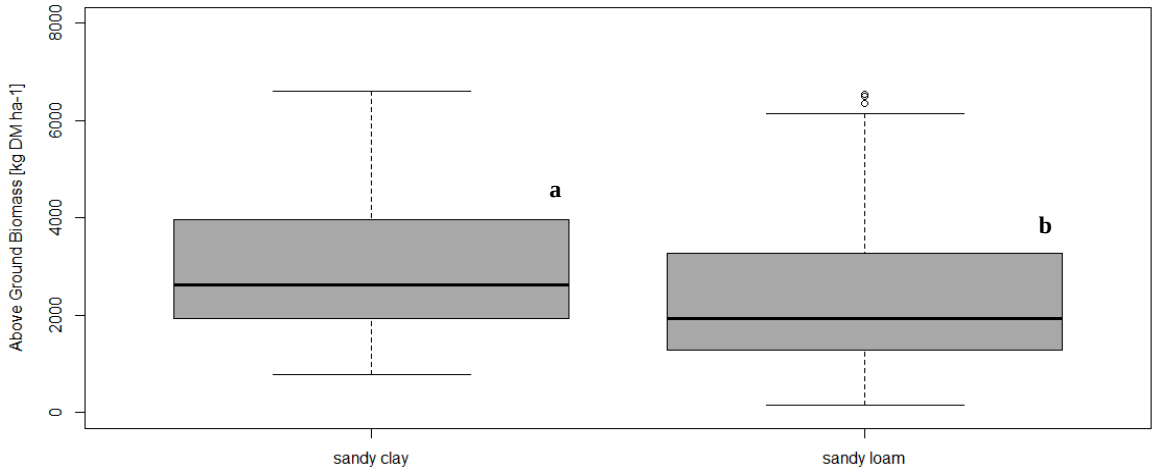

Figure 18 Differences in biomass production of six *Lablab purpureus* accessions evaluated at the time of physiological maturity between two different soil types on 13-farms (n= 4 for sandy clay; n= 9 for sandy loam), in Machakos County; different letters indicate significant differences ($p \leq 0.05$) between the soil types according to Tukey test

4.3.4 Grain yield production

For the sandy clay soil type, accession Q6880B was significantly different from accessions CPI 52508 and CPI 52535, whereas on the sandy loam soil type no significant differences existed (Table 13). However, accessions CPI 52508 and CPI 52535 from the sandy clay soil type were significantly different from accession Q6880B on the sandy loam soil type (Table 13).

Table 13 Grain yield of six *Lablab purpureus* accessions according to soil types evaluated on 13-farm sites (n= 4 for sandy clay; n= 9 for sandy loam), in Machakos County; different letters indicate significant differences ($p \leq 0.05$) among accessions and between soil types according to Tukey test

Accession ID	Grain yield [kg ha^{-1}]					
	Sandy clay	Confidence interval		Sandy loam	Confidence interval	
		lower	upper		lower	upper
Q6880B	739.7 **a**	455.6	1102.2	705.5 **a**	513.2	932.6
CPI 60795	298.1 **a-c**	138.2	528.7	426.7 **a-c**	284.6	601.6
CPI 52508	153.0 **bc**	50.6	320.6	311.6 **a-c**	194.3	460.4
CPI 52513	288.7 **a-c**	132.1	515.7	534.0 **a-c**	371.3	730.4
CPI 52535	118.0 **c**	32.6	266.7	372.1 **a-c**	233.1	548.1
CPI 81364	444.2 **a-c**	237.7	724.8	552.1 **ab**	386.0	751.8
CV %	**66.9**			**29.5**		

Coefficients of variance were high with 66.9 on the sandy clay soil, and 29.5 on the sandy loam soil (Table 13). On the sandy clay and on the sandy loam soils, maximum grain yields were achieved by accession Q6880B with 739.7 and 705.5 kg ha^{-1}, respectively (Table 13). The lowest grain yields were achieved by accession CPI 52535 with only 139 kg ha^{-1} on the sandy clay and by accession CPI 52508 with only 133.4 kg ha^{-1} on the sandy loam (Table 13).

4.3.4.1 Accession and soil type effect on grain yield

When assessing grain yields across the two soil types, accessions Q6880B and CPI 81364 were significantly different from accessions CPI 52508 and CPI 52535 (Figure 19). Additionally, grain yields from accessions Q6880B and CPI 60795 were significantly different. The highest average

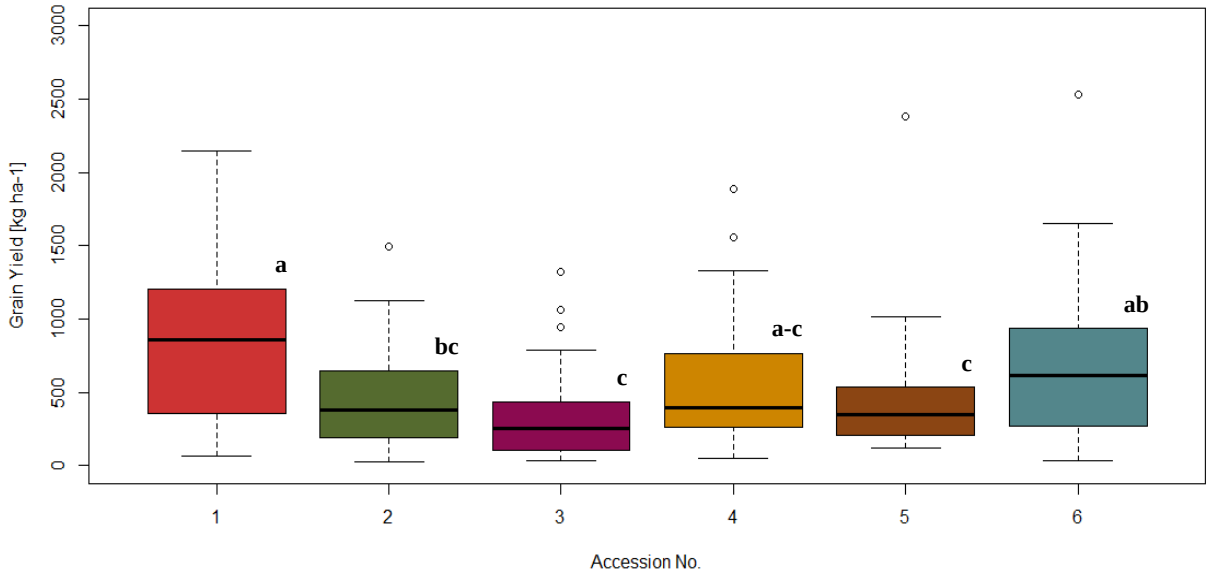

Figure 19 Differences in grain yield among six *Lablab purpureus* accessions evaluated on 13-farms, in Machakos County; 1 (Q6880B), 2 (CPI 60795), 3 (CPI 52508), 4 (CPI 52513), 5 (CPI 52535), 6 (CPI 81364); different letters indicate significant differences ($p \leq 0.05$) among accessions according to Tukey test

grain yields across all farm sites were achieved by accession Q6880B with about 800 kg ha^{-1} followed by accession CPI 81364 with an average yield of about 600 kg ha^{-1} (Figure 19).

The lowest mean grain yields were achieved by accession CPI 52508 with only about 250 kg ha^{-1} followed by accession CPI 52535 with only about 300 kg ha^{-1} (Figure 19). Overall, four out of six accessions yielded below 500 kg ha^{-1} grain on average.

Results indicate that the soil type had a significant impact on grain yield (Figure 20). Grain yields from all evaluated accessions were, on average, higher on the sandy loam soil type with about 450 kg ha^{-1}, than on sandy clay soil type with about 400 kg ha^{-1}. However, the variance was high in general and even higher on the sandy loam soil type (Figure 20).

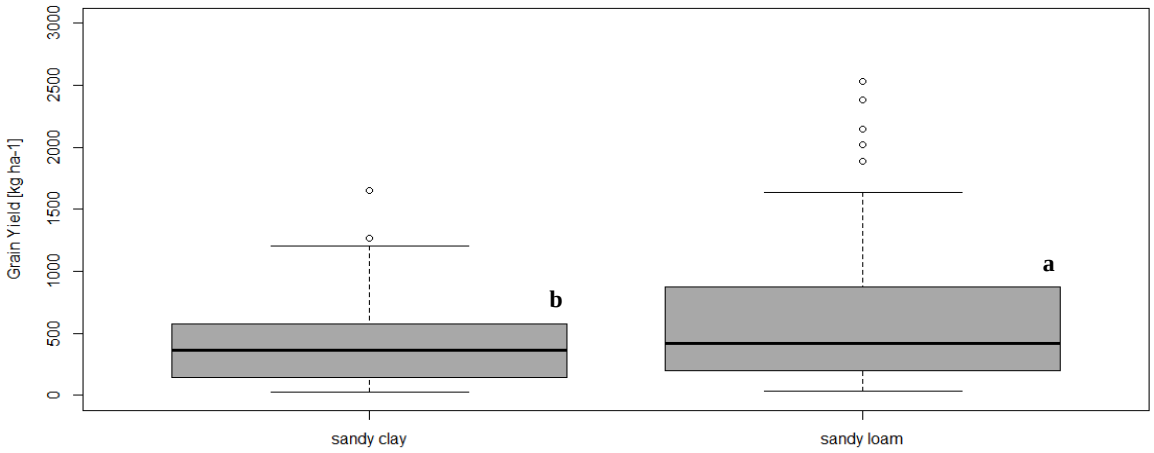

Figure 20 Differences in grain yield of six *Lablab purpureus* accessions evaluated between two different soil types on 13-farms (n= 4 for sandy clay; n= 9 for sandy loam), in Machakos County; different letters indicate significant differences ($p \leq 0.05$) between the soil types according to Tukey test

4.3.5 Taste paneling

4.3.5.1 Hedonic scores of selected lablab accessions

The performance of a blind organoleptic taste assessment with lablab accessions was carried out separately from the evaluation of the agronomic performance. In addition to the six lablab accessions tested on farmers' fields, a commercially available lablab variety from KARI, (DL 1002), was included in the tasting. In terms of taste, accession CPI 81364 and KARI cultivar DL 1002 obtained the highest scores in the grain dish, accessions Q6880B and CPI 52535 in the pod dish, and accessions CPI 52513 and CPI 52535 in the leaf dish (Table 14).

The significant differences showed that accession CPI 81364 and cultivar DL 1002 were evaluated best in terms of grain tasting, whereas cultivar DL 1002 scored significantly lower in the pod tasting compared to most accessions (Table 14). Significant differences were found between the low rated cultivar DL 1002 and the accessions CPI 81364, Q6880B, CPI 52535, and CPI 52513which obtained higher scores (Table 14).

The overall acceptability, the mean of the individual evaluated eating characteristics, follows the same tendencies as indicated in Table 14.

Table 14 Hedonic scores of individual characteristics of selected *Lablab purpureus* accessions from a blind taste paneling at KARI Katumani (n = 14); different letters indicate significant differences ($p \leq 0.05$) among accessions by characteristic and dish type, respectively, according to Tukey test

	Appearance			Odor			Texture			Taste		
Type of dish	**Grain**	**Pod**	**Leaf**	**Grain**	**Pod**	**Leaf**	**Grain**	**Pod**	**Leaf**	**Grain**	**Pod**	**Leaf**
Accession ID												
Q 6880B	2.92 **bc**	4.85 **a**	4.83 **a**	2.71 **b**	4.71 **a**	4.50 **a**	3.64 **ab**	4.00 **a**	2.50 **b**	3.28 **bc**	4.85 **a**	3.16 **a**
CPI 60795	1.57 **c**	3.35 **b-d**	4.50 **a**	2.64 **b**	3.71 **ab**	3.83 **a**	3.14 **a-c**	2.07 **bc**	2.58 **b**	2.21 **c**	2.71 **b-d**	3.25 **a**
CPI 52508	2.92 **bc**	2.92 **cd**	4.83 **a**	2.42 **b**	3.50 **a**	4.16 **a**	2.50 **bc**	2.14 **bc**	3.83 **ab**	2.35 **c**	2.07 **cd**	3.66 **a**
CPI 52513	3.85 **ab**	3.85 **a-d**	4.41 **a**	3.14 **ab**	4.21 **ab**	4.16 **a**	2.00 **c**	3.14 **ab**	4.50 **a**	2.57 **c**	3.42 **a-c**	3.75 **a**
CPI 52535	4.28 **ab**	4.28 **ab**	4.83 **a**	3.00 **ab**	4.14 **ab**	4.00 **a**	2.92 **a-c**	4.14 **a**	3.33 **ab**	2.50 **c**	4.28 **a**	3.75 **a**
CPI 81364	4.78 **a**	4.07 **a-c**	4.50 **a**	4.35 **a**	4.21 **ab**	3.66 **a**	4.42 **a**	3.14 **ab**	2.41 **b**	4.92 **a**	4.00 **ab**	3.50 **a**
DL 1002	2.92 **bc**	2.57 **d**	4.00 **a**	3.78 **ab**	3.14 **b**	3.75 **a**	4.35 **a**	1.21 **c**	2.58 **b**	4.42 **ab**	1.35 **d**	2.50 **a**
Mean	3.32	3.70	4.56	3.15	3.95	4.01	3.28	2.83	3.10	3.18	3.24	3.37
CV %	**32.25**	**21.59**	**6.72**	**21.87**	**13.35**	**7.26**	**27.74**	**37.99**	**26.05**	**34.08**	**38.85**	**13.31**

Accessions CPI 81364 and DL 1002 scored highest in the grain dish assessment with a score of 4.62 and 3.87, respectively (Table 15), being significantly different from accessions CPI 60795, CPI 52508 and, CPI 52535 (Table 15). Additionally, accession CPI 81364 was scored significantly different from accession Q6880B and CPI 52535.

Regarding the pod dish, accessions Q6880B and CPI 52535 scored best with 4.60 and 4.21, respectively (Table 15). Therefore, those two accessions have been scored significantly different

Table 15 Mean hedonic scores of selected *Lablab purpureus* accessions from a blind taste paneling at KARI Katumani (n = 14); different letters indicate significant differences ($p \leq 0.05$) among accessions by dish type, respectively, according to Tukey test

	Overall acceptability		
Type of dish	**Grain**	**Pod**	**Leaf**
Accession ID			
Q 6880B	3.14 **bc**	4.60 **a**	3.75 **a**
CPI 60795	2.39 **c**	2.96 **b-d**	3.54 **a**
CPI 52508	2.55 **c**	2.66 **cd**	4.12 **a**
CPI 52513	2.89 **c**	3.66 **a-c**	4.21 **a**
CPI 52535	3.18 **bc**	4.21 **a**	3.96 **a**
CPI 81364	4.62 **a**	3.86 **ab**	3.52 **a**
DL 1002	3.87 **ab**	2.07 **d**	3.21 **a**
Mean	3.23	3.43	3.76
CV %	**24.05**	**26.32**	**9.60**

from accessions CPI 60795, CPI 52508 and DL 1002 (Table 15). Hence, the least scored DL 1002 with only 2.07, showed significant differences to the accessions Q6880B, CPI 52513, CPI 52535 and CPI 81364 (Table 15). There were no significant differences in the overall assessment of the leaf dish.

4.3.5.2 Assessment of overall acceptability of selected lablab accessions

In addition to the individual scoring of the dishes and the individual evaluation of appearance, odor, texture and taste; the panelists were asked to finally select their most liked and disliked lablab accession. In Figure 21 (a) the individual shares for the best liked lablab accessions are shown, whereas in (b) the shares for the least liked lablab accession are presented (Figure 21). This should then, in general, correspond to the scores of the overall acceptability in Table 15. The most liked lablab accessions included Q6880B, CPI 81364 and CPI 52513, which 26, 25 and 18% of the panelists chose as the overall best tasting lablab accession (Figure 21). The least liked

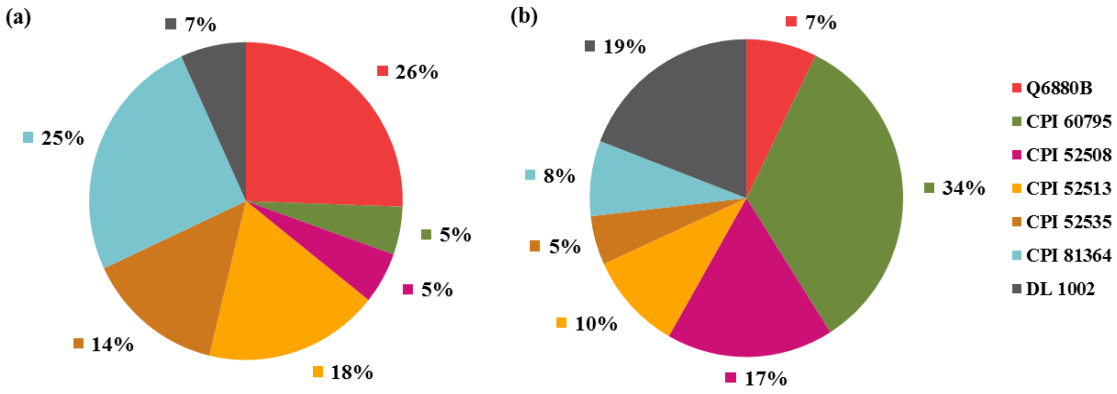

Figure 21 Assessment of the overall acceptability of the evaluated *Lablab purpureus* accessions by 14 panelists; in percentages; (a) Frequency of most liked accession, (b) Frequency of least liked accession

lablab accessions were CPI 60795, KARI variety DL 1002 and CPI 52508 selected by 34, 19 and 17% of the panelists, respectively (Figure 21).

In general, these results correspond to the results from the hedonic scoring. However, especially KARI variety DL 1002 has been evaluated better within the hedonic scoring than in the overall assessment. Otherwise, both evaluation methods identified clearly accessions CPI 81364 and Q6880B as the panelists-favorites.

5 Discussion

The following discussion examines whether the six *Lablab purpureus* accessions evaluated have proven to serve multiple uses and suit farmers' preferences and might thus be successfully integrated in smallholder mixed crop-livestock farming systems in the semi-arid regions of Eastern Kenya.

Lablab purpureus (L.) Sweet: A drought resistant legume?

Short-season potential and phenological plasticity

Aside from the lack of good germplasm, a major restriction to the wider use of *Lablab purpureus* in smallholder farming systems is their relatively long growing period which can lead to failure of flowering under limited and highly variable rainfall conditions, and consequently seed production (Whitbread et al. 2011). This in reverse would increase the dependency of farmers on external seed sources (Whitbread et al. 2011). The identification of short-season varieties with adequate biomass and grain yield under water-limited conditions could be, therefore, a way of largely solving this problem.

Comparing times to physiological maturity among the lablab accessions with recorded data from field trials conducted by Ayisi et al. (2004) and Whitbread et al. (2011) in the Limpopo Province, South Africa, great differences in time to maturity have been detected for the same lablab accessions between those two locations. Whereas the lablab accessions reached maturity between 99 and 102 DAP under environmental conditions in the Limpopo Province, South Africa (Ayisi et al. 2004; Whitbread et al. 2011), physiological maturity was only reached between 112 and 122 DAP under the environmental conditions in Machakos County, Kenya. The evaluation identified accessions CPI 81364 and Q6880B to be the earliest among all accessions in Kenya. The delay of almost two weeks in plant development between both locations indicates the existence of physiological differences among the accessions (Karachi 1987; Hall and Naidu 2004). Shehu et al. (2001) noticed lablab's sensitivity to photoperiod and temperature and, concluded photoperiods exceeding 13h per day are likely to result in an indeterminate growth pattern (Kim and Okubo 1995, 1996; Shehu et al. 2001). Consequently, this may have contributed to a difference in development pattern and growth durations between both locations.

Additionally, literature has evidenced that the growth habit in many leguminous species is rather morphologically unstable than genetically controlled (Kim und Okubo 1995). Therefore, phenological plasticity as a function of sensitivity to temperature and photoperiod reflected in growth pattern (Kim and Okubo 1995; Subbarao et al. 1995). However, growing periods in all lablab accessions were much longer compared to more commonly grown legumes such as common beans (*Phaseolus vulgaris* L.) and cowpeas (*Vigna unguiculata* L. Walp). These legumes have shown to mature between 90 and 100 DAP under equal environmental conditions and are, therefore, currently favored by farmers (Njarui et al. 2004b).

Whether a variety that has a potentially short or long growth cycle is more beneficial under drought-conditions is likely to depend on the extent to which they can adapt to current moisture conditions, i.e. the level of developmental and phenological plasticity. In general, short growing periods may help to escape drought stress during the reproductive stage (Blum 2009). However, the presence of a high level of developmental and phenological plasticity may additionally ensure production success as it exhibits the ability to be more capable in adapting to soil moisture availability and rainfall events since several onsets of flowering can be produced (Subbarao et al. 1995; Turner et al. 2001). Since the presence of high levels of plasticity enables the production of new leaves and/or extension of vegetative growth upon relief of drought stress, this presence is considered to exhibit greater recovery potential (Subbarao et al. 1995; Snapp and Silim 2002; Vadez et al. 2010). In more favorable seasons, the plant may adjust from a rather short growing period to a rather long growing period, thereby making use of additional moisture. Under field conditions in Kenya, repeated flowering and shooting of new leaves under more favorable moisture conditions could be observed in accessions CPI 81364 and Q6880B, indicating their developmental and phenological plasticity is high. However, data to support this is absent from this study since only one harvest at maturity was conducted. On the other hand, high levels of developmental and phenological plasticity are associated with late maturity, moderate yield potential and a high labor demand for most legumes, all of which generally fall outside a farmer's set of preferences when choosing varieties (Subbarao et al. 1995; Snapp and Silim 2002). In reality, farmers usually prefer early-maturing varieties that exhibit synchronous flowering and high yield potential while requiring low labor input, even if it means they forfeit benefits in more favorable seasons (Snapp and Silim 2002; Turner et al. 2001).

Development of traditional growth parameters under drought stress

Traditional measures for screening plants' tolerance to drought include the investigation of biomass and grain yield production under certain water regimes. This is so because the magnitude in reduction indicates plants' potential to persist and tolerate drought. Biomass dry weight is, therefore, likely to be reduced in stressed plants (Muchow 1985a; Guretzki and Papenbrock 2013). Reduced growth is a function of limited water availability leading to reduced turgor and restricted mitosis resulting in a lower rate of cell division and elongation (Guretzki and Papenbrock 2013). Additionally, the HI is a useful measure to determine crop productivity in terms of grain production as it reflects the ratio by which assimilates are used for biomass or grain yield production (Subbarao et al. 1995; Turner et al. 2001).

The evaluation of biomass and grain yields of the evaluated lablab accessions has shown that both were greatly reduced at the on-farm experimental sites compared to the on-station experimental site. Biomass yields of the six lablab accessions evaluated ranged between 2600 and 4800 kg DM ha^{-1} in the on-station rainfed experiment, while the yields of their counterparts in the on-farm experiments were comparatively reduced by 20 to 50%. On-station, the greatest reduction in biomass production across the water treatments was observed in accessions CPI 52535 and CPI 52513, where biomass yields were reduced by 30 to 40% between the fully irrigated and rainfed water treatments. Accession CPI 81364 obtained equally high amounts of biomass among all the water treatments on-station, but also comparable high mean biomass yields across the farm sites, with an average reduction of just 25%. The study by Ayisi et al. (2004) confirms a great biomass potential of this accession, exceeding 5000 kg DM ha^{-1} in a semi-arid region of South Africa. This indicates that the critical drought threshold level after which biomass production is severely affected has not yet been reached and suggests a great capability to produce high biomass yields under water-limited conditions. Generally poor biomass yields were obtained by accession CPI 52508, which fell on average below 2000 kg ha^{-1} across the farm sites.

In terms of grain production, only accession CPI 52535 yielded <500 kg ha^{-1} for the on-station experimental setting, whereas only accession Q6880B obtained mean grain yields >500 kg ha^{-1} across the farm sites. As grain yields reached up to 2000 kg ha^{-1} for the on-station experimental setting, grain yield from the on-farm experiments were severely reduced, attaining a reduction by

up to 75%. However, accessions Q6880B, CPI 60795 and CPI 81364 were able to achieve grain yields >1000 kg ha^{-1} while obtaining biomass yields of around 3000 to 4000 kg DM ha^{-1} with an in-season rainfall of only 340 mm on-station. Therefore, those accessions may be especially suitable in these semi-arid regions of Eastern Kenya. In comparison, the same lablab accessions obtained grain yields ranging only between 99 and 731 kg ha^{-1} across three evaluation periods in South Africa with a water supply between 450 mm and 550 mm per season (Ayisi et al. 2004; Whitbread et al. 2011). Some lablab accessions may even exceed the grain yields of more commonly grown legumes. Under comparable environmental conditions, grain yields of cowpea have been reported to only range between 200 and 900 kg ha^{-1} (Uarrota 2010). The common bean is reported to yield between 979 and 1459 kg grain ha^{-1} in a study conducted in the semi-arid region of Eastern Kenya as well (Maingi et al. 2001).

The severe reduction of biomass and grain yield on the farm sites compared to the on-station experiment may be attributed to a number of factors. Generally, agronomic management such as repeated weeding and sufficient pest management are crucial to obtain high yields in lablab (Mullen et al. 2003; Njarui et al. 2004a). Especially pod boring insects have been identified as a major threat in this region, a situation which is exacerbated by the limited use of pesticides in general (Njarui et al. 2004a). Poor pest and weed management may result in reduced plant vigor and capability to produce well and recover after stress periods on-farm. Additionally, the rainfall patterns were expected to vary greatly across farm sites, with some likely to receive even less than the recorded rainfall of 340 mm.

Furthermore, soil fertility was highly variable across farm sites. Both rainfall and soil fertility variation across farm sites make comparisons for biomass and grain yields difficult. Even the heterogeneity in soil fertility within each farm might be high. Here, a study has proven that soil fertility is decreasing with greater distance from the homestead (Titonell et al. 2005). This phenomenon may be attributed to farmers' preference to rather fertilize fields that have shown to be relatively more fertile and, therefore, more reliable in terms of production compared to other fields, a management decision that leads to increased nutrient mining of certain fields (Titonell et al. 2005). Additionally, smallholders keep their livestock generally close to the homestead overnight to avoid theft. Since costs to transfer the stored manure from homesteads to more distant fields are high - in terms of money, time and labor - fields close to the homestead are,

therefore, more likely to receive higher amounts of fertilizer leading to pronounced gradients in terms of soil fertility across farms.

To assess the productivity of the lablab accessions evaluated in terms of grain yield, the harvest index (HI) was used. The HI varies as a result of differences in the ability of genotypes to partition current assimilates towards grain-filling and, to reallocate stored or structural assimilates to the grains (Turner et al. 2001; Tesfaye et al. 2006). The HI is, therefore, largely related to the temporal pattern of dry matter (DM) production and partitioning which is closely connected to timing of stresses (Fischer 1981).

The HI was expected to be relatively low under the given environmental conditions which were fairly harsh. However, the HI varied greatly between accessions but was not consistently lower under rainfed conditions. Here, higher values compared to the fully irrigated water treatment might prove a more efficient resource allocation and utilization, seen in accession Q6880B, CPI 60795 and CPI 52508, or might prove that the fully irrigated accessions produced relatively more biomass than grains with additional water. Furthermore, low HI values under rainfed conditions might be a result of poor dry matter allocation available to be translocated to the reproductive organs in the later stages of growth and/or indicate the absence of sink organs because of early flower dropping (Tesfaye et al. 2006). In contrast, the lack of significant differences among accessions and between water treatments might indicate that plants under rainfed conditions experienced a fast remobilization of dry matter to the reproductive organs, which accumulated before stress occurred and their leaves were shed (Tesfaye et al. 2006). However, with maximum HI values of 0.401 under fully irrigated and with 0.429 under rainfed conditions, the lablab accessions performed moderately compared to other leguminous species. A shelter experiment with the common bean conducted by Ramirez-Vallejo et al. (1998) resulted in HI ranges between 0.42 and 0.53 for stressed plants and between 0.58 and 0.60 for non-stressed plants. Chapman et al. (1985) reported HI value ranges between 0.33 and 0.42 in cowpea, between 0.31 and 0.40 in pigeon pea, between 0.19 and 0.36 in black gram and between 0.42 and 0.47 in green gram, depending on the water regime. Tesfaye et al. (2006) reported HI values ranging between 0.13 and 0.54 for common bean, and values between 0.22 and 0.40 for cowpea, depending on the water treatment and timing of water stress.

Morphological and physiological traits to cope with water stress

Morphological and physiological adaptation mechanisms to drought conditions in legumes include moderate plant sizes, reduced leaf area and the early closure of stomata to minimize water losses through transpiration (Subbarao et al. 1995; Turner et al. 2001; Guretzki and Papenbrock 2013).

At the time of flowering, usually the peak of leaf area index (LAI) in legumes is reached. Subsequently, the vegetative phase merges into the reproductive phase, where assimilates are used rather for pod development and grain filling than for the production of new leaves (Tesfaye et al. 2006). Therefore, the LAI was considerably reduced towards the end of the growth cycle, a phenomenon observed across all accessions and water treatments. Reasons include leaf senescence, leaf drop and shedding of leaves in the latter growth period (Tesfaye et al. 2006). Generally, the LAI was reduced among the accessions under rainfed conditions compared to the fully irrigated water treatment. This indicates the sensitivity of canopy development to water deficits, which leads to a reduction in LAI resulting from decreased leaf initiation or expansion, an increase in leaf senescence and shedding, or a combination of these processes (Muchow 1985a). Additionally, a higher LAI under irrigated conditions may indicate the presence of a greater developmental plasticity leading to enhanced ability to adjust canopy development according to moisture availability (Tesfaye et al. 2006). Maximum LAI among the accessions at flowering did not exceed 2.5 but ranged usually between 1 and 2. The greatest difference in LAI between water treatments at flowering was attained by accessions CPI 81364 and CPI 52513 where the LAI was reduced by 25 and 50%, respectively, under rainfed conditions. This may indicate that plants have been stressed severely during the flowering and pod setting period (Tesfaye et al. 2006). Furthermore, the reduction in LAI under rainfed conditions might be attributed to the adjustment towards more erect leaves or spatial distribution of leaves (Muchow 1985a; Tesfaye et al. 2006). The ability of lablab to adjust leaf orientation has been proven by Muchow (1985a), and is a reversible process. More erect leaves allow plants to decrease the leaf surface area that is intercepting the radiation used for photosynthesis. Under water-limited conditions plants' ability to change leaf orientation allows the minimization of water losses through transpiration especially when radiation intensity is high. Under more favorable moisture conditions leaves become less erect, which enables increased radiation interception (Muchow

1985a). This enables the plants to adjust the leaf area that is intercepting light according to radiation intensity, which can be observed on a recurrent daily basis. Plants that are able to change leaf orientation might also be able to maintain a high leaf area while simultaneously moderating water losses through transpiration - possibly a good strategy for coping with drought (Muchow 1985a). Therefore, the ability of legumes to adjust leaf orientation has a major effect on transpiration efficiency as well.

Water movement is known to be dependent on gradients along the soil-plant-atmosphere continuum, with transpiration being driven by radiation and evaporative demand and, thereby largely by the vapor pressure deficit of the air (Fischer 1981; Vadez et al. 2010). Transpiration efficiency (TE) is determined by the water loss through transpiration in relation to the carbon gain through photosynthesis. Rates are controlled via the stomatal conductance which plays an important role in adjusting plant physiological processes to moisture availability while maintaining productivity (Subbarao et al. 1995; Turner et al. 2001). Consequently, early closure of stomata compromises the rate of photosynthesis leading to a reduction in production of assimilates and reducing growth and yield (Subbarao et al. 1995; Turner et al. 2001; Medrano 2002; Vadez et al. 2010; Guretzki and Papenbrock 2013). Where canopy development is decreased and, therefore, water loss is reduced (Vadez et al. 2010), the plant water status is likely to be sufficient to allow the stomata to remain partially open and allow photosynthesis to continue (Muchow 1985b). During water-deficit periods, this may explain the greater TE among the lablab accessions found under rainfed conditions compared to the lower TE found under irrigated conditions. Significant differences were found only in accession CPI 52508 between both water treatments, indicating substantial adaptation to drought conditions either by leaf orientation adjustment or efficient control of stomatal conductance.

However, to further investigate physiological differences in stomatal conductance, which affect the TE of a crop, alternative measures might deliver more reliable data while being less time consuming. In general, the reliability of the presented data might be compromised as such sensitive measurements under field conditions are greatly influenced by the predominant environmental conditions. Environmental conditions might vary greatly from day to day. Since accessions were measured according to a fixed schedule, some accessions were always measured

in the morning whereas others rather at noon when temperatures and radiation were highest. Furthermore, measurements were restricted to a certain number of measurements per plant due to limitations in battery capacity of the measurement device. Additionally, selection of only one leaf per plant does not always accurately represent the physiological processes of the whole plant. Therefore, more advanced methods such as infrared thermography and chlorophyll fluorescence possibly offer the opportunity for timely investigating physiological changes under drought stress at the plant or plant stand level (Roháček et al. 2008; Guretzki and Papenbrock 2014).

To additionally evaluate the efficiency of the existing biomass in producing new biomass, the relative growth rate (RGR) is a valuable parameter. The RGR is usually reduced towards the end of a plant's growth because less leafy biomass is produced, assimilates are transferred towards grain production and ripening, and because net carbon losses occur through respiration of shaded leaf layers (Poorter and Remkes 1990). However, a high RGR at the beginning of plants' growth may be especially beneficial under water-limited conditions as high leaf shading of the ground allows the plant to use water that has been evaporated from the soil and reaches the underside of leaves (Poorter and Remkes 1990; Subbarao et al. 1995; Turner et al. 2001; Hall and Naidu 2004). Early vigor and fast growing rates might also be related to enhanced root growth to cope with nutrient deficiencies (Poorter and Remkes 1990). It is assumed that strategies increasing the rate of canopy closure and interception early in a plant's life increase the proportion of transpiration relative to evapotranspiration and, thereby yield per unit water (Turner et al. 2001). A fast closure of the canopy additionally creates advantages for the plant in terms of weed competiveness (Poorter and Remkes 1990). Moreover, it has been discussed whether small-seeded plant species such as lablab genotypes have an inherently greater RGR especially in the beginning of plant growth compared to larger-seeded plant species like common bean (Maranon and Grubb 1993). The basis of this assumption is the theory of smaller-seeded species having smaller cells, which contain a smaller amount of DNA per cell leading to a shorter minimum time for cell division (Maranon and Grubb 1993). Whether having small or large seeds is beneficial under deficit conditions is strongly debated (Maranon and Grubb 1993). Initial RGR of the lablab accessions ranged between 0.08 and 0.14 g g^{-1} day^{-1}, resulting in an RGR reduced by 50 to 70% at flowering.

Lablab purpureus (L.) Sweet: A multipurpose legume?

Potential as supplementary livestock feed and soil amendment

Useful measures to evaluate the suitability of lablab as a livestock supplementary feed and/or soil amendment include leaf/stem and C/N ratio, among others. It is assumed that rapid senescence and abscission of leaves in legumes is a reaction to the reallocation of carbon (C) and nitrogen (N) from senescing leaves to sustain yield under water deficit conditions, which is expressed via the leaf/stem ratio (Turner et al. 2001). The leaf/stem ratio in legumes is usually reduced towards the end of the life cycle (Tesfaye et al. 2006). And, as leafy biomass generally exhibits greater palatability and digestibility, the remaining share of leaves at the end of a plant's life cycle is an important indicator in estimating its value for livestock nutrition (Aganga and Tshwenyane 2003).

The highest leaf/stem ratios at maturity were maintained by accession CPI 81364 followed by accession Q6880B, suggesting they might be especially suitable as supplementary livestock feed since a large share of leafy biomass was maintained. However, in the case of accession CPI 52535 which was thought to be a good forage-type, leaf/stem ratio was comparably low at maturity. This may indicate that the amount of stem was substantially higher than the amount of leaves. However, further research regarding palatability, digestibility and nutritional composition is needed to draw a comprehensive picture of the feeding value offered by the evaluated accessions.

Furthermore, the C/N ratio is an important value to evaluate the quality as a soil amendment. Here, the mineralization of N is an important factor in determining the rate of mineralization, immobilization and nitrification during decomposition in the soil (Bengtsson et al. 2003). In general, the smaller the C/N ratio, the higher the N content in relation to the C content and the faster it may be decomposed by soil microorganisms (Hadas et al. 2004). However, decomposition rate is not only a function of the C/N ratio, but a complex interaction of N content, lignin content, water soluble N and cellulose content (Bengtsson et al. 2003; Hadas et al. 2004). Additionally, the prevalent environmental conditions have a great impact on decomposition rate as well. The C/N ratio among accessions at maturity was greatest in stems and generally lowest in seeds, followed by leaf parts. The ratio among accessions was in general higher in the rainfed

water treatment compared to the fully irrigated water treatment. This may indicate a relatively greater stem utilization of mobile compounds such as N for grain filling processes, a phenomenon commonly found in stressed plants, e.g. under drought stress (Blum 2005). It is widely known that cereals such as maize or wheat have greater C/N ratios compared to legumes. For maize, a C/N ratio of 32.4 is reported and for wheat a ratio of 136 (Hadas et al. 2004). This indicates lablab residues may have a high decomposition rate leading to fast benefits in terms of N supply for subsequent crops. However, more research is needed in this area to prove the quality of lablab accessions as a soil amendment.

What is a legume "must have" to gain farmers' favor?

Apart from agronomic characteristics, cooking and eating qualities of lablab are considered to be the main reasons for its decreasing cultivation and low acceptance across smallholder farmers in Kenya (Shivachi et al. 2012).

Farmers claim the long cooking time of most lablab varieties is leading to increased energy costs, and they complain about lablab's bitter taste, which is mostly found in the black-seeded cultivars (Shivachi et al. 2012). Understanding farmers' perceptions and priorities, therefore, is crucial to facilitate adoption of new crops or genotypes (Sperling et al. 1993; Snapp and Silim 2002). However, apart from cooking time, sensory characteristics such as appearance, texture, and taste contribute a great share to subsistence farmers' choice for a particular bean variety (Shivachi et al. 2012). Incorporation of sensory characteristics in breeding programs is crucial to adoption, though a great challenge since these programs mainly focus on yield, maturity time, and resistance to diseases (Shivachi et al. 2012).

The most promising accession, which has scored well in terms of sensory characteristics, was accession CPI 81364, a tan-seeded genotype. This accession scored significantly higher in terms of grain taste assessment but also obtained a significantly higher score in the overall acceptability among all evaluated accessions. Additionally, the commercially available lablab cultivar DL 1002 obtained similar scores. Moderate to high eating qualities were also found for accession Q6880B. These two accessions, CPI 81364 and Q6880B, have also achieved high biomass and grain yields, under rainfed conditions on-station as well as across farm sites. Of interest was also the seed color since commercially available lablab cultivars are predominantly black

(Muhammad et al. 2003). However, the seeds of the accession that scored best was tan-colored, indicating farmers do not automatically favor black-seeded lablab cultivars. Accessions CPI 60795, CPI 52508 and CPI 52513 were poorly scored, indicating low eating qualities. Further research is needed to estimate the anti-nutritional factors such as trypsin inhibitors and hydrogen cyanide contained by the evaluated accessions. While these factors do not pose a problem for human consumption under correct pre-treatment (Deka and Sarkar 1990), pre-treatments might be uneconomical when residues are intended as a livestock feed (Guretzki and Papenbrock 2014).

However, farmers' preferences consist of a complex range of criteria including adaptation to local conditions, yield security, grain quality, cash returns, marketability, the provision of multipurpose uses and low labor requirements (Sperling et al. 1993; Snapp and Silim 2002; Graham and Vance 2003; Kamanga et al. 2010). Aspects such as yield and taste may compete the anti-nutritional factors in terms of acceptability by farmers since pre-treatments are comparably simple (Guretzki and Papenbrock 2014). Attributes leading to reduced acceptability by farmers were shown to include lack of markets for grains, difficulties in cooking due to toxicity, difficulties to intercrop with maize, high labor demand, low yield expectations, as well as susceptibility to pests and diseases (Kamanga et al. 2010). A participatory study conducted in a smallholder community in Malawi found that a limited access to seed, an absence of markets for seeds, a lack of interest among farmers, insufficient benefits and labor restrictions were major reasons for a limited adoption of legume-integrated farming systems (Pircher et al. 2012).

In general, participatory research plays a crucial role in developing strategies that suit farmers' expectations and reflect a better agronomic performance compared to currently used strategies. It has been noticed that farmers have an intimate knowledge of their local environment, production problems, crop priorities and criteria for evaluation (Sumberg et al. 2003; Kamanga et al. 2010), but their voices have mainly been neglected by researchers and, therefore, have had little impact on their projects (Bellon 2001; Kamanga et al. 2010). Additionally, most formal research outcomes are often not accessible to and are inappropriate for resource-poor farmers. It is thus an urgent need to increasingly address farmers, to include their knowledge, and to share outcomes so that farmers and researchers may mutually benefit (Quansah et al. 2001; Sumberg et al. 2003;

Kamanga et al. 2010). Research results may increasingly reach developing regions and the people for which it is intended to help.

Lablab's genetic diversity offers great possibilities to select germplasm suitable to a particular area while focusing on drought resistance along with high yield potentials (Karachi 1987; Hall and Naidu 2004). Additionally, lablab's ability to adjust leaf orientation in response to water deficits at different stages of growth may be an especially beneficial attribute for drought-prone areas and an advantage over more commonly grown legumes that lack this ability. But the actual benefits of this ability require further research to quantify the magnitude to which transpiration losses are reduced. In addition, the stability of the lablab accession's agronomic performance under typical environmental conditions needs to be assessed. To this end, experiments that are conducted throughout more than one growing season are needed for a more comprehensive picture. Furthermore, broad adoption by farmers might only be achieved when management packages are developed that simplify the harvesting process and offer guidance for the efficient control of pests and diseases without the use of expensive inputs. Further, seeds need to be widely available and prices should be competitive to those of more commonly traded legume species (Tefera 2006).

6 Conclusion

Lablab purpureus (L.) Sweet exhibits a number of attributes making it a possible alternative to today's more commonly grown legumes under the environmental conditions of the semi-arid regions in Eastern Kenya. Its genetic diversity makes lablab a valuable source in identifying germplasm that is suiting proposed regions and farmers' needs. The maintenance of *Lablab purpureus* in today's smallholder farming systems would then, additionally, aid to the conservation of lablab as a traditional crop for food and fodder in Africa and may help in diminishing its threat of genetic erosion.

The results of this study indicate greatest potential for the black-seeded accession Q6880B and the tan-seeded accession CPI 81364 to be successfully integrated into today's smallholder mixed crop-livestock farming systems of the semi-arid regions in Eastern Kenya. Both these accessions have proven to supply comparable high amounts of biomass and grain yields, while being potentially short-season varieties. Additionally, both are suggested to exhibit a high level of developmental and phenological plasticity, which might be especially beneficial during more favorable seasons. Moreover, both these accessions may be promising in terms of human consumption since high scores were attained during the organoleptic taste assessment. Thereby, they would serve for multiple uses.

However, further research is proposed, especially on accession Q6880B and CPI 81364 so that a more comprehensive picture can be drawn including several regions and seasons. Additionally, an effective but reasonable package to treat pests and diseases needs to be developed.

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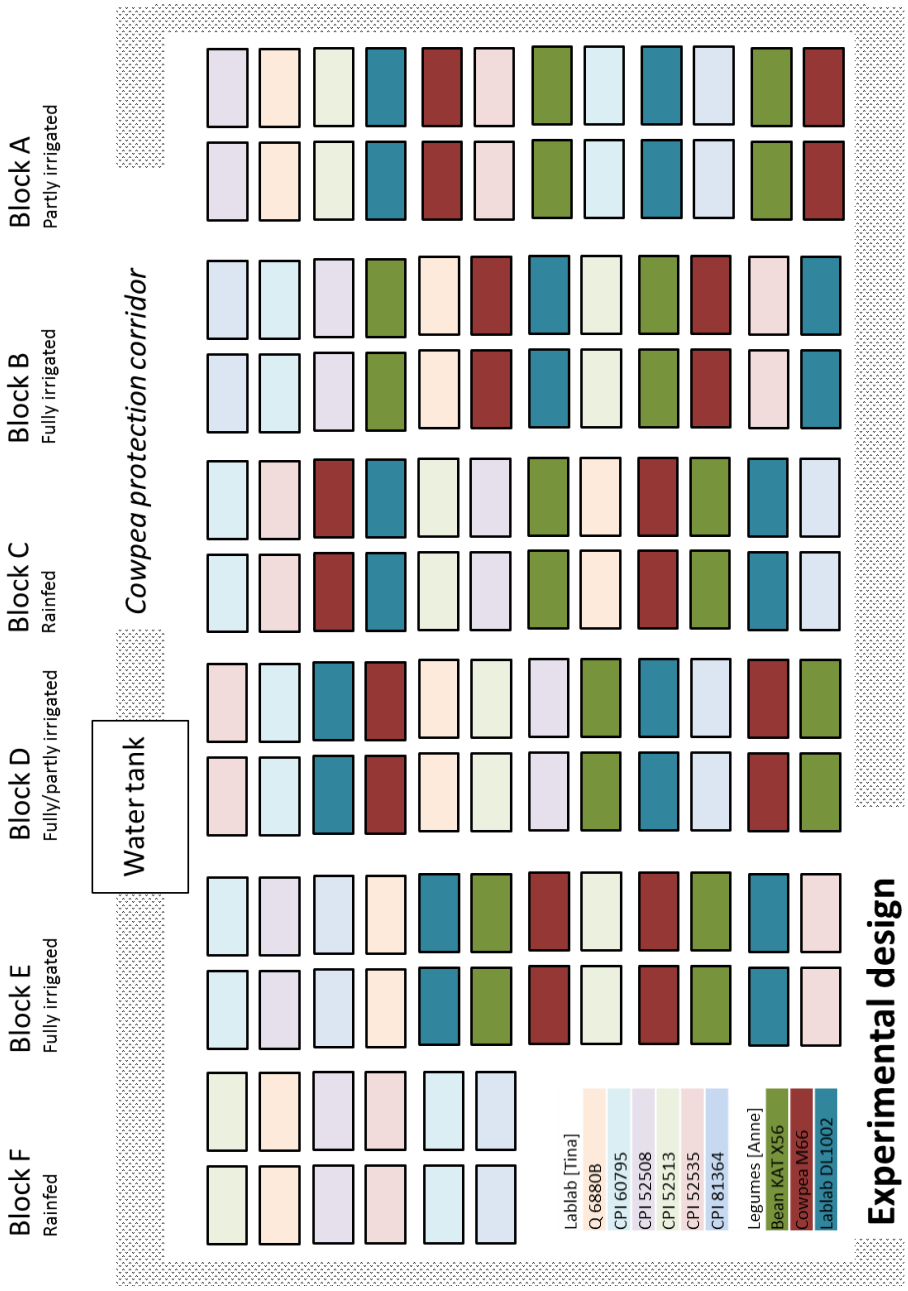
8 Annex

Annex 1

Experimental plot design of the on-station water-deficit trial at KARI, Katumani, Machakos County, in Kenya.

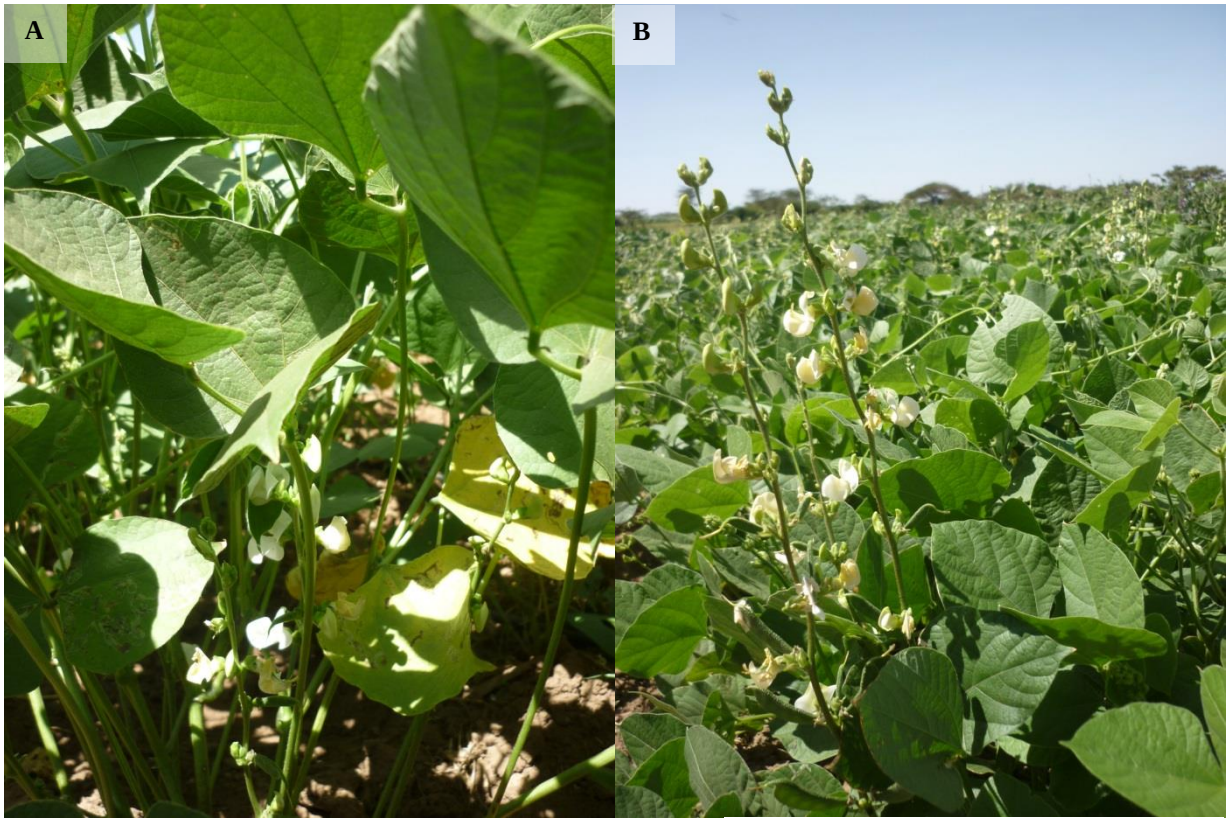


Annex 2

Differences among the six *Lablab purpureus* accessions evaluated regarding their inflorescence position, pictures taken from the on-station water-deficit trial 63 days after planting (DAP) at KARI, Katumani, Machakos County, in Kenya.

A: inflorescence on short peduncles, close to ground surface in the plants center; in accession CPI 52513

B: inflorescence on long peduncles, above canopy layer; in accession CPI 81364



Photos: © Kristina Grotelüschen 2013/14

Annex 3

First household questionnaire, conducted before sowing of the six *Lablab purpureus* accessions evaluated on 16-farms across Machakos County, in Kenya.

Household Questionaire #1

The first questionnaire will be handed out before sowing the *Lablab purpureus* accessions. The questions are related to numbers of family members, farms size and farming system as well as to the importance of legumes.

A-1 Household Identification

A11 Farm Number: _____

A12 GPS Reading: Latitude-(N/S) _____ Longitude-(E/W) _____ Altitude _____ masl

A13 Agro-ecological Zone (AEZ): _____

A14 Country: _____ A15 Place/Village name: _____

A16 Description of Location of Household [e.g. near primary school]: _____

_____

A-2 General Information

A21 Name of respondent: _____ A22 Age (yrs.): _____

A23 Respondent(s) position in household: ____ [1: Husband; 2: Wife; 3: Farm manager/Worker; 4:Son; 5: Daughter]

A24 Phone: _____

A25 Details of household head

(i) Name: _____ ii) Sex _____ [1= Male; 2= Female]

(iii) Age (yrs.): _____ (iv) Years of crop farming experience: _____

(v) Phone: _____

B Household Roster

B1 How many people stay in this farm-household and what is their main occupation [none, farming, Employed (public/private, own business), etc.]?

B11 No.	B12 Name	B13 Position in HH	B14 Age	B15 Gender	B16 Main occupation	B17 % of time devoted to farm activities				
						0	0-25	25-50	50-75	75-100
1										
2										

3										
4										
5										
6										
7										
8										
9										
10										

1: Husband; 2: Wife; 3: Farm manager/ Worker; 4: Son; 5: Daughter; 6: Grandparent(s); 7: Relative; 8: Non relative

Notes: _____

C Agriculture – General

C1 How much land in area do you currently have ownership of or cultivation rights over [incl. land rented out, but excl. land rented from others]?

Land-use	Land parcel #1	Land parcel #2	Land parcel #3
Crop land			
Pasture			
Land rented out			
Size of land			
Total			

Notes: _____

C2 How much land area do you currently rent from others? [Amount/Unit of Area] _____

C3 What percentage [%] of household income does each of these sources contribute per year?

Crop Production	_____	Livestock Production	_____
External employment	_____	Remittance	_____
Pension	_____	Own business	_____
Other (specify)	_____	**Total**	**100%**

C4 What kind of livestock do you own, in what quantity and what are the feed sources?

		Feed Source[%]					
Livestock	**Quantity**	Purchased feed	Saved residues	Saved hay	Grazing	HH leftover	Other (specify)
Dairy cattle							
Zebu cattle							
Ox/Bullock							
Donkey							
Goat							
Sheep							

Chicken							
Rabbit							
Guineapig							
Other (specify)							

Notes: _____

C5 What type of fertilizer do you use for the current rainy season and in what quantity?

	Amount of component [kg/ha] [kg/acre]				
Type of fertilizer	Amount of FYM	Amount of Compost	Amount of inorg. fertilizer	None	**Total amount [kg/ha] [kg/acre]**
FYM					
Compost					
inorg. fertilizer					
FYM + Compost					
FYM + inorg. fertilizer					
Compost + inorg. fertilizer					
None					

Notes: _____

C6 What kind of crops do you usually cultivate during the long rains [reporting last 2 years]?

Maize	☐	Millet	☐	Sorghum	☐	Herbs	☐
Potatoes	☐	Vegetables	☐	Fruits	☐	Any Legume	☐
Trees (wood)	☐	Trees (fruit)	☐	Fodder plants	☐	Pigeon pea	☐

Notes: _____

C7 What kind of crops do you usually cultivate during the short rains [reporting last 2 years]?

Maize	☐	Millet	☐	Sorghum	☐	Herbs	☐
Potatoes	☐	Vegetables	☐	Fruits	☐	Any Legume	☐
Trees (wood)	☐	Trees (fruit)	☐	Fodder plants	☐	Pigeon pea	☐

Notes: _____

D Agriculture – Legume cultivation

D1 Which legumes do you usually cultivate for own consumption and/or for other purposes [reporting the last 2 years]?

Legume	**Yes**	**No**	**Food**		**Fodder**	**To Sell**	**Other (specify)**
			Grain	**Leaves**			

Bean							
Pigeon pea							
Chickpea							
Cowpea							
Lablab							
Soybean							
Mung bean							
Black gram							
Other (specify)							

**** Main use; * Use**

Notes: _____

D2 Considering the land proportion you do legume cultivation on, to what extend do you usually include each legumes, respectively [reporting the last 2 years]?

Legume	**Long rainy season [Mar.- Jun.]**				**Short rainy season [Nov.- Febr.]**			
	>75% legume area	**>50% legume area**	**<50% legume area**	**<25% legume area**	**>75% legume area**	**>50% legume area**	**<50% legume area**	**<25% legume area**
Bean								
Pigeon pea								
Chickpea								
Cowpea								
Lablab								
Soybean								
Mung bean								
Black gram								
Other (specify)								

Notes: _____

D3 Who is mostly responsible for the agricultural activities considering legume cultivation?

Agricultural activity	**Responsible Person**	**Supervised by**
Crop selection (species)		
Seed selection (variety)		
Field-use planning		
Field preparation		
Planting		
Weeding		
Spraying against pests & diseases		

Fertilizing		
Harvesting		
Thrashing		

1: Husband; 2: Wife; 3: Farm manager/ Worker; 4: Son; 5: Daughter; 6: Grandparent(s); 7: Relative; 8: Non relative

Notes: _____

D4 How do you usually include the legumes into your production system?

Sole stand ☐ Intercropped ☐ Both ☐

Notes: _____

D5 How would you characterize each of the legumes and how do you rank them within the legumes you are using?

Legume	**Drought resistant**		**Susceptible to pests & diseases**		**Weed competiveness**		**High storage losses**	**Low yielding**	**Bad fodder quality**	**Other (specify)**
		Rank		**Rank**		**Rank**				
Bean										
Pigeon pea										
Chickpea										
Cowpea										
Lablab										
Soybean										
Mung bean										
Black gram										
Other										

1: does apply; 2: does not apply; 3: no experience/idea

Notes: _____

D6 What is your usual seed-source for the grain legumes you are cultivating?

Government ministry ☐ Neighbor ☐
Donated by a project ☐ Own saved ☐
Relatives ☐ Buy from open market ☐
Buy from agro-vet ☐ Other (specify) ☐

Notes: _____

D7 Which of the stated features would you refer to lablab?

Nutritious/healthy	☐	Good for soil fertility	☐
Great biomass production	☐	Cultural importance	☐
Drought-tolerant	☐	Multipurpose use	☐
Good marketable	☐	Other (specify)	☐

Notes: _____

D8 If you do not cultivate lablab, what are the reasons?

Lack of seeds	☐	Not good for food/taste	☐
Not aware about lablab	☐	Land is too small	☐
No suitable variety	☐	Labor intensive	☐
Other (specify)	☐		

Notes:_____

Annex 4

Second household questionnaire, conducted at the time of flowering of the six *Lablab purpureus* accessions evaluated on 16-farms across Machakos County, in Kenya.

Household Questionaire #2

Name of the respondent:

_____

E Agriculture – Legume Maintenance

E1 Do you usually spray any pesticides or herbicides for your legume cultivation? If yes, what do you usually use and how often/at what plant stages?

Frequency / Agent	No	Yes	Once Plant Stage [WAP]:	Twice Plant Stage [WAP]:	Other [specify] Plant Stage [WAP]:
Duduthrin					
Marshall					
Thunder					
Biological [specify]					
Other [specify]					

_____

F Agriculture – *Lablab purpureus* cultivation

F1 What did you cultivate last season on the plot the lablab accessions are cultivated currently?

Beans ☐ Cowpea ☐ Maize ☐ Pigeon Pea ☐ Lablab ☐ Mung Bean ☐
Vegetables ☐ Other [specify] ☐

F2 After planting till now, how often did you weed the plot and in what time interval?

.....Weeding Interval Times of Weeding	Every two weeks	Every three weeks	Other [specify]

Once			
Twice			
Three Times			
Other [specify]			

F3 How would you assess the weed occurrence in the entire lablab plot?

Very high **Fair** **Very little**

F4 How would you assess the pest and disease occurrence in the entire lablab plot?

Very high **Fair** **Very little**

F5 How would you evaluate the lablab accessions considering their overall performance compared to the legumes you are usually cultivating [germination and establishment success, weed competiveness, pest & disease occurrence, drought resistance]? ☐

Compared to: Beans ☐ **Cowpea** ☐ **Pigeon Pea** **Mung Bean** ☐

Very poor **Fair** **Very good**

F6.1 How would you evaluate each lablab accession considering their weed competiveness compared to the legumes you are usually cultivating?

Compared to: Beans ☐ **Cowpea** ☐ **Pigeon Pea** ☐ **Mung Bean** ☐

[1] Q 6880B: Very poor **Fair** **Very good**

[2] CPI 60795: Very poor **Fair** **Very good**

[3] CPI 52508: Very poor **Fair** **Very good**

[4] CPI 52513: Very poor **Fair** **Very good**

[5] CPI 52535: Very poor **Fair** **Very good**

[6] CPI 81364: Very poor **Fair** **Very good**

F6.2 How would you rank the weed competiveness within the lablab accessions?

	[1]	[2]	[3]	[4]	[5]	[6]
[1]	----------					
[2]		----------				
[3]			----------			
[4]				----------		
[5]					----------	
[6]						----------

F7.1 How would you evaluate each lablab accession considering their pests and disease occurrence compared to the legumes you are usually cultivating?

Compared to: Beans ☐ Cowpea ☐ Pigeon Pea ☐ Mung Bean ☐

[1] Q 6880B: Very poor Fair Very good

[2] CPI 60795: Very poor Fair Very good

[3] CPI 52508: Very poor Fair Very good

[4] CPI 52513: Very poor Fair Very good

[5] CPI 52535: Very poor Fair Very good

[6] CPI 81364: Very poor Fair Very good

F7.2 How would you rank the pests and disease occurrence within the lablab accessions?

	[1]	[2]	[3]	[4]	[5]	[6]
[1]	----------					

[2]		----------				
[3]			----------			
[4]				----------		
[5]					----------	
[6]						----------

F8.1 How would you evaluate each lablab accession considering their drought resistance compared to the legumes you are usually cultivating [observation of plant/ leaf death, leaf wilting etc.]?

Compared to: Beans ☐ Cowpea ☐ Pigeon Pea ☐ Mung Bean ☐

[1] Q 6880B: Very poor Fair Very good

[2] CPI 60795: Very poor Fair Very good

[3] CPI 52508: Very poor Fair Very good

[4] CPI 52513: Very poor Fair Very good

[5] CPI 52535: Very poor Fair Very good

[6] CPI 81364: Very poor Fair Very good

F8.2 How would you rank the drought resistance within the lablab accessions?

	[1]	[2]	[3]	[4]	[5]	[6]
[1]	----------					
[2]		----------				
[3]			----------			
[4]				----------		
[5]					----------	

[6]						----------

F9 How would you assess the overall production losses by weeds, pests and diseases compared to the legumes you are usually cultivating?

Compared to: Beans ☐ Cowpea ☐ Pigeon Pea ☐ Mung Bean ☐

[1] Q 6880B: Very poor Fair Very good

[2] CPI 60795: Very poor Fair Very good

[3] CPI 52508: Very poor Fair Very good

[4] CPI 52513: Very poor Fair Very good

[5] CPI 52535: Very poor Fair Very good

[6] CPI 81364: Very poor Fair Very good

F10 So far, which lablab accession seems most desirable to you?

[1] ☐ [2] ☐ [3] ☐ [4] ☐ [5] ☐ [6] ☐

F11 So far, which lablab accession seems least desirable to you?

[1] ☐ [2] ☐ [3] ☐ [4] ☐ [5] ☐ [6] ☐

Annex 5

Third household questionnaire, conducted at the time of physiological maturity of the six *Lablab purpureus* accessions evaluated on 16-farms across Machakos County, in Kenya.

Household Questionaire #3

Name of the respondent:

G Agriculture – Risks for agriculture in Machakos County

G1 In review of the short-rainy season 2013/14, how would you assess it in regards to rainfall and rainfall distribution?

Above average ☐ Average ☐ Below average ☐

G2 In your opinion, what are the main limitations for agriculture in this area? [*Note: Please let the farmers rank the three most important constraints for agriculture with 1, 2, 3***]**

Water scarcity	☐	Lack of good germplasm	☐
Unreliable rainfall	☐	Lack of extension work	☐
Soil erosion	☐	Labour shortage	☐
Low soil fertility	☐	High pest and diesease occurence	☐
Lack of inputs [fertilizer, pesticides etc.]	☐	Other [specify]	☐

G3 Can you think of any changes in current agricultural systems to improve the overall situation and ensure food production?

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

H Agriculture – *Lablab purpureus* cultivation evaluation

H1 **In review, how do you assess the overall performance of the lablab accessions? [***Note: this includes the occurrence of pests and diseases, weeds, drought tolerance and high yield potential***]**

[1] Q 6880B: **Very poor** **Fair** **Very good**

[2] CPI 60795: **Very poor** **Fair** **Very good**

[3] CPI 52508: **Very poor** **Fair** **Very good**

[4] CPI 52513: **Very poor** **Fair** **Very good**

[5] CPI 52535: **Very poor** **Fair** **Very good**

[6] CPI 81364: **Very poor** **Fair** **Very good**

H2 **How do you finally assess the agronomic performance separately for every lablab accessions?**

Accession No.	Affected by pests and diseases			Drought resistance potential			High yield potential			Labour requirements		
	high	fair	low	high	fair	low	high	fair	low	high	fair	low
[1] Q6880B												
[2] CPI 60795												
[3] CPI 52508												
[4] CPI 52513												
[5] CPI 52535												
[6] CPI 81364												

H3 **Overall, how did you like the lablab accessions compared to the legumes you are usually cultivating? [***Note: As in the second questionnaire, you mark with what kind of legume you are comparing the lablab accessions***]**

Compared to: Beans ☐ Cowpea ☐ Pigeon pea ☐

[1] Q 6880B: **Dislike extremely** **Fair** **Like extremely**

[2] CPI 60795: Dislike extremely Fair Like extremely

[3] CPI 52508: Dislike extremely Fair Like extremely

[4] CPI 52513: Dislike extremely Fair Like extremely

[5] CPI 52535: Dislike extremely Fair Like extremely

[6] CPI 81364: Dislike extremely Fair Like extremely

H4 Will you consider any of the lablab accessions for future cropping's and if so, for what purpose?

Accession No.	Yes	No	Production Intension			Fodder	Fallow	Market	Why?
			Grain	Food Pod	Leaf				
[1] Q 6880B									
[2] CPI 60795									
[3] CPI 52508									
[4] CPI 52513									
[5] CPI 52535									
[6] CPI 81364									

H5 Regarding the harvest of the lablab, is there any disadvantage you can think of ? [*Note: This could include for example the position of the pods; but please try to let the farmers think before you hand the hint***]**

_____

_____

H6 Which advantageous features would you now state when describing the lablab accessions?
[*Note: Agronomic features including high yield, short growing period, drought and pest tolerance, great biomass production; if more than one are stated they need to be ranked***]**

[1] Q6880B_____
[2] CPI60795_____
[3] CPI 52508_____
[4] CPI 52513_____
[5] CPI 52535_____
[6] CPI 81364_____

H7 **What kind of disadvantages would you now state when describing the lablab accessions?** **[***Note: Agronomic features including low yield, long growing period, drought tolerance and pest susceptibility, little fodder usability; if more than one are stated they need to be ranked***]**

[1] Q6880B

_____

[2] CPI 60795

_____

[3] CPI 52508

_____

[4] CPI 52513

_____

[5] CPI 52535

_____

[6] CPI 81364

_____

H8 **Regarding to their overall performance, which lablab accession you like the most? [***Note: Please let the farmers rank the three most promising accessions with 1, 2, 3***]**

[1] ☐ **[2]** ☐ **[3]** ☐ **[4]** ☐ **[5]** ☐ **[6]** ☐

Why? _____

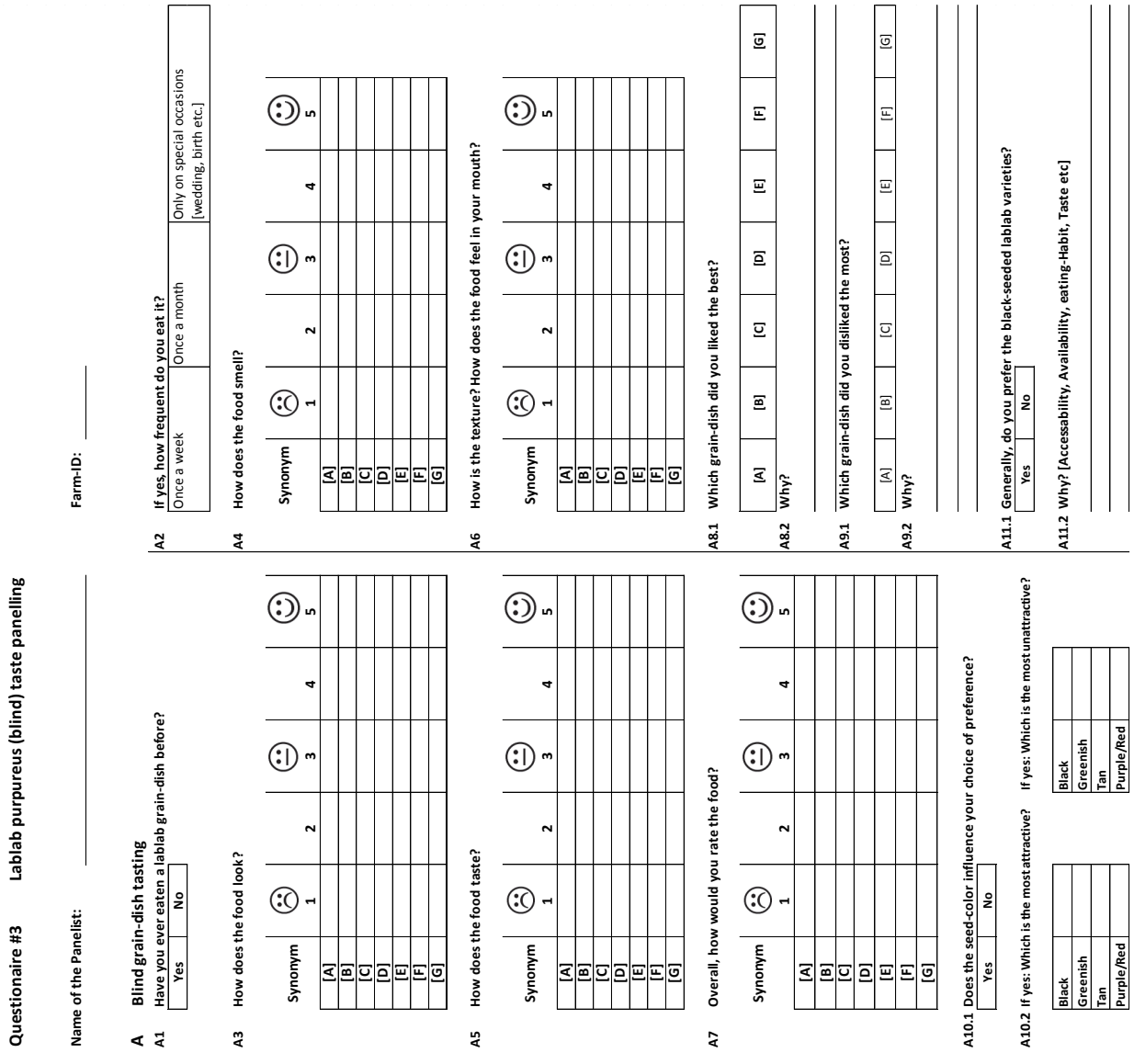
H9 **Regarding to their overall performance, which lablab accession you disliked the most? [***Note: Please let the farmers rank the three least promising accessions with 1, 2, 3***]**

[1] ☐ **[2]** ☐ **[3]** ☐ **[4]** ☐ **[5]** ☐ **[6]** ☐

Why? _____

Annex 6

Scoring questionnaire for the blind taste paneling of the grain dish of the six *Lablab purpureus* accessions evaluated and the KARI cultivar DL 1002, conducted with 14 panelists at KARI, Katumani, Machakos County, in Kenya.



Questionaire #3 **Lablab purpureus (blind) taste panelling**

Name of the Panelist: _____ **Farm-ID:** _____

A **Blind grain-dish tasting**

A1 Have you ever eaten a lablab grain-dish before?

Yes	No

A2 If yes, how frequent do you eat it?

Once a week	Once a month	Only on special occasions [wedding, birth etc.]

A3 How does the food look?

Synonym	1	2	3	4	5
[A]					
[B]					
[C]					
[D]					
[E]					
[F]					
[G]					

A4 How does the food smell?

Synonym	1	2	3	4	5
[A]					
[B]					
[C]					
[D]					
[E]					
[F]					
[G]					

A5 How does the food taste?

Synonym	1	2	3	4	5
[A]					
[B]					
[C]					
[D]					
[E]					
[F]					
[G]					

A6 How is the texture? How does the food feel in your mouth?

Synonym	1	2	3	4	5
[A]					
[B]					
[C]					
[D]					
[E]					
[F]					
[G]					

A7 Overall, how would you rate the food?

Synonym	1	2	3	4	5
[A]					
[B]					
[C]					
[D]					
[E]					
[F]					
[G]					

A8.1 Which grain-dish did you liked the best?

[A]	[B]	[C]	[D]	[E]	[F]	[G]

A8.2 Why?

A9.1 Which grain-dish did you disliked the most?

[A]	[B]	[C]	[D]	[E]	[F]	[G]

A9.2 Why?

A10.1 Does the seed-color influence your choice of preference?

Yes	No

A10.2 If yes: Which is the most attractive?

Black	
Greenish	
Tan	
Purple/Red	

If yes: Which is the most unattractive?

Black	
Greenish	
Tan	
Purple/Red	

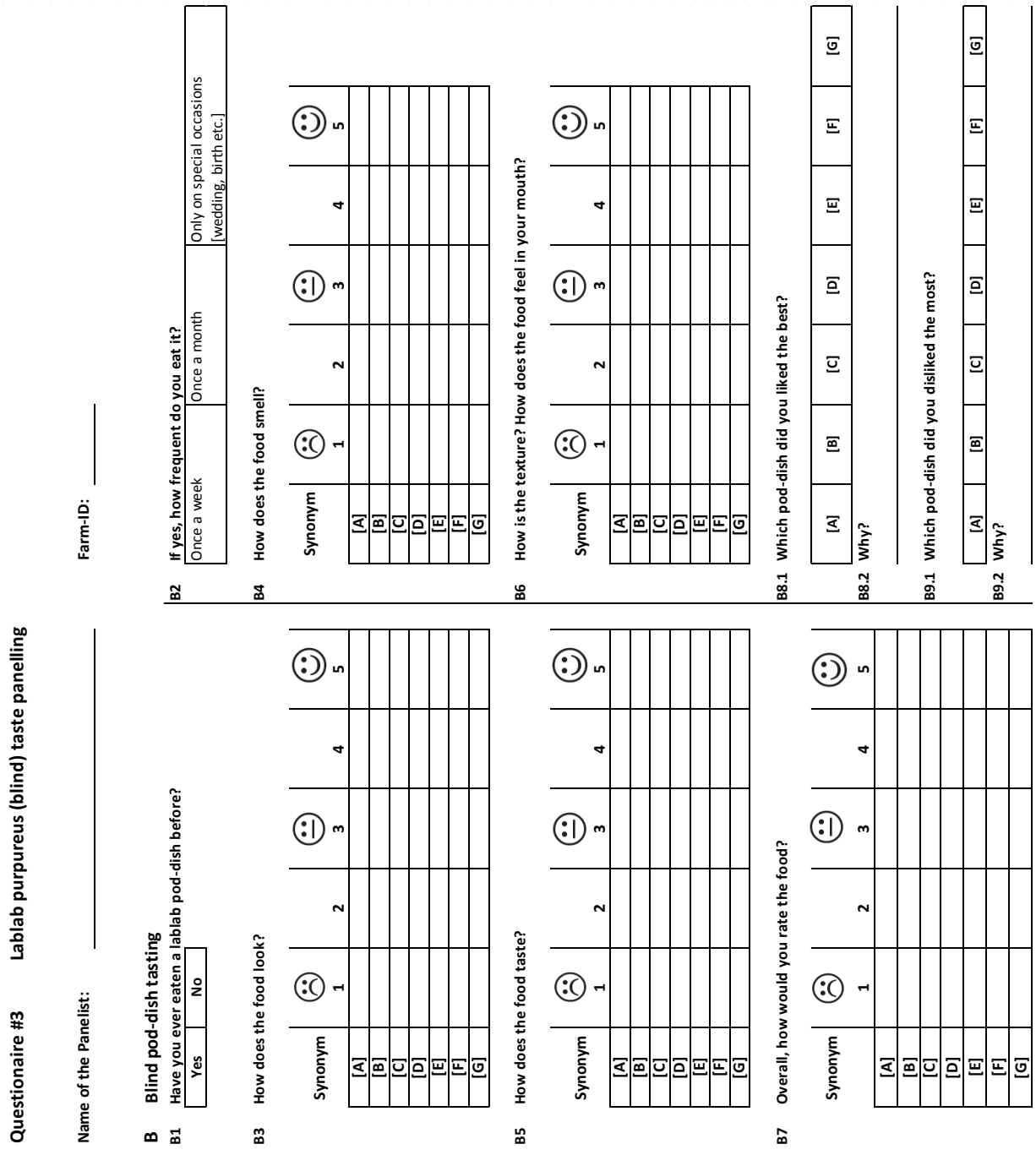
A11.1 Generally, do you prefer the black-seeded lablab varieties?

Yes	No

A11.2 Why? [Accessability, Availability, eating-Habit, Taste etc]

Annex 7

Scoring questionnaire for the blind taste paneling of the pod dish of the six *Lablab purpureus* accessions evaluated and the KARI cultivar DL 1002, conducted with 14 panelists at KARI, Katumani, Machakos County, in Kenya.



Questionaire #3 **Lablab purpureus (blind) taste panelling**

Name of the Panelist: _____ **Farm-ID:** _____

B **Blind pod-dish tasting**

B1 Have you ever eaten a lablab pod-dish before?

Yes	No

B2 If yes, how frequent do you eat it?

Once a week	Once a month	Only on special occasions [wedding, birth etc.]

B3 How does the food look?

Synonym	1	2	3	4	5
[A]					
[B]					
[C]					
[D]					
[E]					
[F]					
[G]					

B4 How does the food smell?

Synonym	1	2	3	4	5
[A]					
[B]					
[C]					
[D]					
[E]					
[F]					
[G]					

B5 How does the food taste?

Synonym	1	2	3	4	5
[A]					
[B]					
[C]					
[D]					
[E]					
[F]					
[G]					

B6 How is the texture? How does the food feel in your mouth?

Synonym	1	2	3	4	5
[A]					
[B]					
[C]					
[D]					
[E]					
[F]					
[G]					

B7 Overall, how would you rate the food?

Synonym	1	2	3	4	5
[A]					
[B]					
[C]					
[D]					
[E]					
[F]					
[G]					

B8.1 Which pod-dish did you liked the best?

[A]	[B]	[C]	[D]	[E]	[F]	[G]

B8.2 Why?

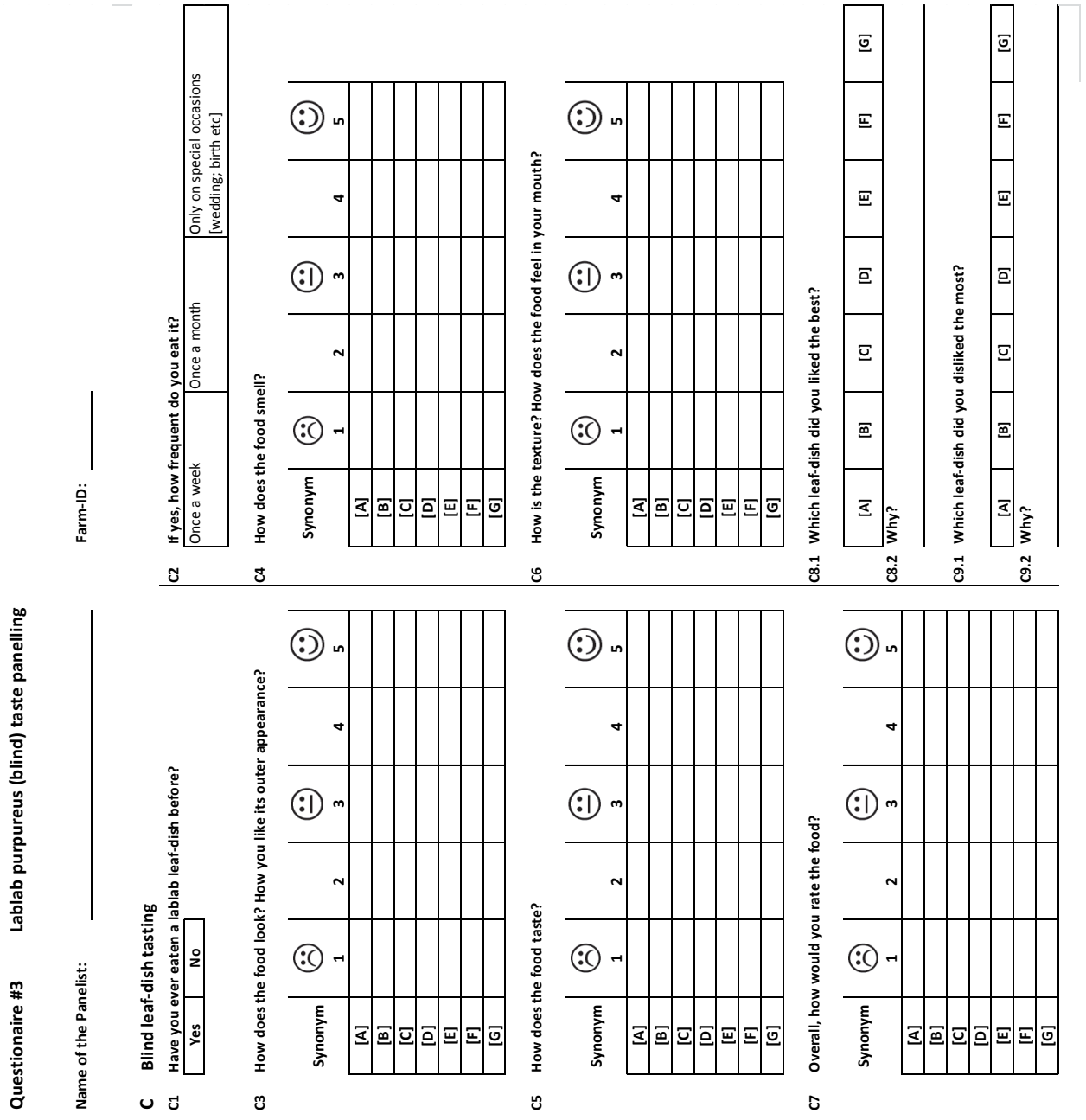
B9.1 Which pod-dish did you disliked the most?

[A]	[B]	[C]	[D]	[E]	[F]	[G]

B9.2 Why?

Annex 8

Scoring questionnaire for the blind taste paneling of the leaf dish of the six *Lablab purpureus* accessions evaluated and the KARI cultivar DL 1002, conducted with 14 panelists at KARI, Katumani, Machakos County, in Kenya.



Questionaire #3 **Lablab purpureus (blind) taste panelling**

Name of the Panelist: _____ **Farm-ID:** _____

C **Blind leaf-dish tasting**

C1 **Have you ever eaten a lablab leaf-dish before?**

Yes	No

C2 **If yes, how frequent do you eat it?**

Once a week	Once a month	Only on special occasions [wedding; birth etc]

C3 **How does the food look? How you like its outer appearance?**

Synonym	1	2	3	4	5
[A]					
[B]					
[C]					
[D]					
[E]					
[F]					
[G]					

C4 **How does the food smell?**

Synonym	1	2	3	4	5
[A]					
[B]					
[C]					
[D]					
[E]					
[F]					
[G]					

C5 **How does the food taste?**

Synonym	1	2	3	4	5
[A]					
[B]					
[C]					
[D]					
[E]					
[F]					
[G]					

C6 **How is the texture? How does the food feel in your mouth?**

Synonym	1	2	3	4	5
[A]					
[B]					
[C]					
[D]					
[E]					
[F]					
[G]					

C7 **Overall, how would you rate the food?**

Synonym	1	2	3	4	5
[A]					
[B]					
[C]					
[D]					
[E]					
[F]					
[G]					

C8.1 **Which leaf-dish did you liked the best?**

[A]	[B]	[C]	[D]	[E]	[F]	[G]

C8.2 **Why?**

C9.1 **Which leaf-dish did you disliked the most?**

[A]	[B]	[C]	[D]	[E]	[F]	[G]

C9.2 **Why?**

STATUTORY DECLARATION

I herewith declare that I composed my thesis submitted independently without having used any other sources or means than stated therein.

Date: **Signature:**