INFLUENCE OF SEED ASPECTS AND PHOSPHORUS FERTILIZATION ON SEED QUALITY OF VELVET BEAN (*MUCUNA PRURIENS* L.) IN WESTERN KENYA

BY

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DEDICATION

To my husband Papa Amadou Mamour DIOP, my mother Maimouna FAYE for their moral support which kept me focused throughout this work. It is also dedicated to my daughter Fatima Zahra DIOP for her understanding, patience and encouragement. I dedicated this thesis to my uncle Sémou NDIAYE for his financial support and great interest in my studies since I was in secondary school.

ABSTRACT

Velvet bean (*Mucuna pruriens*) is known as a high yielding leguminous crop which is used as vegetable and fodder. However, seed morphological variability and seed coat dormancy has been reported, to affect seed germination and field emergence. Some studies have been conducted to explore the effect of phosphorus (P) on seed yields, but none have examined the effect of P on velvet bean seed quality. This study therefore assessed morphological characteristics of velvet bean seed, suitable methods of breaking seed dormancy, and the effect of phosphorus fertilization on germination potential of velvet bean seed. A total of 56 farmers were interviewed to document the agronomic practices used by farmers in the production of velvet bean. Data collection was done using a semi structured questionnaire. Four types of velvet bean seeds were collected from farmers during the survey in Bungoma County, Kenya. Morphological characteristics (seed coat color, hilum color, seed length, width and thickness) and seed quality (electrical conductivity (EC), germination test and imbibition rates) were determined for the 4 seed types. Field experiments (using RCBD with three replications) were established at Mabanga Agricultural and Training Center (ATC)and at the University of Eldoret (UoE) to evaluate the effect of four phosphorus rates (F0= 0Kg P/ha; F1= 15Kg P/ha; F2=30Kg P/ha; F3=45Kg P/ha) on seed quality of 4 types of velvet bean seed. The beans were harvested at five different stages. Germination percentage, percentage of normal and abnormal seedlings, fresh and dried seed weight and speed of germination index were then determined. Seeds harvested from the control experiment (F0= 0Kg/P/ha) at 70 DAF were treated with 6 different dormancy breaking treatments. Most farmers (65%) did not intercrop velvet bean with other crops. However, 30% of the farmers intercropped velvet bean with maize, 2% intercropped with groundnut and rotated with common bean**.** Seed quality assurance activities carried out in the field by farmers were weeding (98%), removing of diseased plants (25%) and planting plants to be for seed production separately (23%). There were significant differences ($P \leq 0.05$) among the four seed types in all seed traits measured except seed coat thickness. White seed type recorded a lower electrical conductivity (more vigorous), higher final germination percentage, speed of germination index and imbibition rate at 30°C than other seed types. Physiological maturity was reached at 14 DAF or 28 DAF depending on seed type and locality. Seed type collected at Mabanga (ATC) was dormant unlike seeds collected at the University of Eldoret (UoE). Phosphorus fertilizer affected FGP (Final Germination Percentage) and SGI (Speed of Germination index) (P<.001). At Mabanga ATC P0, P1 and P3 were given good values of FGP and SGI while at UoE P0, P1 and P2, depending on seed types. The most effective dormancy breaking treatment varied with locality and seed type. Velvet bean production can reduce fertilizer use in small scale farmers growing maize, harvesting should be done at harvest maturity and mechanical scarification can be used by farmers to break dormancy.

Keywords : Velvet Bean; Harvesting stage; Morphological Variability; Germination; Phosphorus rates; Dormancy.

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LIST OF ABREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
ARS	Agricultural Research Service
ATC	Agricultural and Training Center
ATP	Adenosine Triphosphate
CRD	Completely randomized design
CV	Coefficient of Variation
DAF	Days After Flowering
EC	Electrical Conductivity
FAO	Food And Agriculture Organization
FGP	Final Germination Percentage
F pr.	F probability
GENSTAT	General Statistics
GOK	Government of Kenya
IBPGR	International Board for Plant Genetic Resources
ILDIS	International Legume Database and Information Service
ISTA	International Seed Testing Association
LSD	Least Significant Difference
N	Nitrogen
NFSNP	National Food Security and Nutrition Policy
NRCS	Natural Resources Conservation Service
P	Phosphorus
RCBD	Randomized Complete Block Design
RHS	Royal Horticultural Society
SAGR	School of Agriculture
SE	Standard Error
SGI	Speed of Germination Index
UoE	University of Eldoret
USDA	United States Department of Agriculture

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CHAPTER ONE

INTRODUCTION

1.1 Background information

Mucuna pruriens Linn. (Family-Fabaceae), commonly known as velvet bean, is an annual climbing legume. This leguminous crop is endemic in India and other tropical regions, including South and Central America and native to tropical Asia and Africa. In order to increase velvet bean production, an average of 18,967 hectares were rehabilitated in Western Kenya (Wabwoba and Mutoro, 2019). Just like other legumes for example soybean, common bean, and mung bean velvet bean grows under moist and warm conditions in both cultivated and wild forms at altitudes below 1600m (Pugalenthi *et al*., 2005). The wild varieties of velvet bean are named itching bean while landraces are non-itching beans (Pugalenthi and Vadivel, 2007a, b). There is tremendous morphological and biochemical variability in velvet bean (Sathyanarayana et al., 2016).

Velvet bean is used a vegetable and fodder (Heuzé *et al*., 2015). Seeds are used as animal feeds for monogastric animals (Randrianantenaina, 2012). The seeds contain higher amounts (22 to 35%) of proteins compared toother legumes, hence are good sources of nitrogenous materials in feed production (Costa *et al*., 2006). Despite its nutritional advantages, it contains L-Dopa which is the major anti-nutritional factor in seeds. This molecule limits the digestibility of proteins and starch and can cause mental disorders such as acute mental confusion and hallucinations (Brandel, 2011). Different treatments have been tried to reduce L-Dopa concentration in velvet bean seeds in order to make them usable for animal and human nutrition (Diallo *et al*., 2002). Velvet bean has a high biomass production and compared to other legumes with over 90% of its nodules were active (Muinga, 2003). Velvet bean cultivation has been recommended to improve soil fertility in Africa.

In addition, to these uses it is known throughout the world as a medicinal plant (Sridhar and Rajeev, 2007). Powder seed of velvet bean contains a large amount of L-3,4 dihydroxy phenylalanine (L-DOPA), a neurotransmitter precursor and effective remedy for Parkinson's disease. The seeds also contain 5-HT (5-hydroxytryptamine), tryptamine, mucunin, mucunadine, prurieninin and prurienine used for various neurological disorders treatments (Misra and Wagner 2004, Misra and Wagner 2007). In the Ayurvedic system, as an anthelmintic and in order to treat diseases central nervous system, velvet bean seeds and roots are used (Sathiyanarayanan and Arulmozhi 2007). Its different seed preparations are used for aging management, diabetes, rheumatoid arthritis, nervous disorders and male infertility.

For seed propagated crop, a good crop establishment and yield, a systematic study on seed germination parameter is essential (Isha *et al*., 2018). Percentage of germination is an important characteristic of the seeds used for cultivation. It can be defined by the proportion of germinated seed when seeds are sown under the right conditions for growth. It is affected by seed viability, dormancy and environmental effects (Kumar *et al*., 2011). Vigorous seeds which germinate quickly and under favorable condition can produce vigorous seedlings in field conditions. Another important measurement of the quality of seed is seed vigour, which is expressed as, germination rate, or strength of seedlings produced among other parameters (Isha *et al*., 2018). This study will investigate percentage of germination as well as seed vigor.

Generally when seeds are subjected to favorable condition of temperature and moisture, it will germinate readily but some degree of dormancy is noted in many species. Dormancy is defined as the condition that prevents germination when ordinary requirement are met and maybe exogenous (seed coat dormancy) or endogenous. It is known that most species in the family Fabaceae are dormant due to it hard seed coat. Velvet Bean dormancy has been reported by Yogeesha and Shivananda (2003). Cold water treatment and scarification with sand paper and sulphuric acid have been investigated as facilitators for rapid and high germination in dormant seed coat (Munawar *et al*., 2015). This study investigated efficacy of concentrated sulphuric acid, cold water, hot water and mechanical scarification in breaking dormancy in velvet bean.

Seed with high quality increase agriculture production in any farming system (Sabry, 2018). However, production of velvet bean faces many constraints such as unavailability of quality seed and lack of standardized agronomic practices, seed management and utilization strategies. Therefore, it is important to investigate the agronomic practices, seed management and utilization strategies of velvet bean production.

Although many factors can affect the quality of seed, the management of fertilizer is especially important. Plant growth, seed yield and quality will be significantly affected by any deficiency of the macronutrients. Some studies have been conducted to determine phosphorus (P) effect on seed yields, but few have examined the effect on legume seed quality. Therefore, the influence of different phosphorus rates on velvet bean seed quality in Bungoma County is investigated in this study.

1.2 Statement of the problem

Velvet bean is a minor food crop, poorly adopted in agricultural systems (Eillitta *et al*., 2003) due to the presence of toxic compounds and anti-nutritional components that arise in plants from the secondary metabolism as well as poor field germination and emergence. However, farmers in Western Kenya are actively involved in velvet bean production in order to improve soil fertility and food production (Wabwoba and Mutoro, 2019). There is lack of knowledge on the agronomic practices, seed management and utilization which can improve farmers' seed quality. This lack of information has affected farmers' yields and incomes.

Limited information is also available with regard to morphological characteristics of different types of velvet bean (Ezeagu *et al*., 2003; Rich and Teixeira, 2011). It is important to determine these characteristic as they will serve as a guide to designers of velvet bean processing, storage and handling machinery (Eze *et al*., 2017).

Phosphorus fertilization is an important nutrient for legume cultivation (Klimek-Kopyra *et al*., 2019). Phosphorus has been shown to enhance seed quality of crops. Faster germination, larger leave and longer roots characterizes is noted for seeds with high P content (Zhu and Smith, 2001). Adequate phosphorus fertilizer application can promote faster root growth initiation and seedling establishment (Nadeem *et al*., 2011; Nadeem *et al*., 2012; White and Veneklaas, 2012). However there is a lack of knowledge on the effect of phosphorus fertilization on quality of velvet bean seed.

This research therefore assessed seed management practices and morphologically characterized the seed of velvet bean farmers from Bungoma County. It also looked at the suitable methods of breaking the dormancy of velvet bean seed and determined the effect of phosphorus fertilization on germination potential of velvet bean seed.

1.3 Justification of the study

Velvet bean is a highly nutritious crop for human and livestock and can play an important role in replenishing soil nutrients. In order to improve soil fertility, maximize grain and yields production, velvet bean can be intercropped with maize in the sub-humid regions. Velvet bean provides early season fodder, whether it is grown as a pure stand or in mixed cropping systems.

The use of velvet bean, particularly when incorporated into the soil in the flowering stage, appears to have a very beneficial effect on soil physical conditions (Shoko *et al*., 2015). Resource-poor farmers in rural areas who do not have access to sufficient fertilizer to apply the recommended rates, will greatly benefit from using velvet bean as a rotational crop because it will alleviate the deterioration of soil under continuous cropping conditions. It is therefore necessary to develop information about seed quality aspects in order to promote its production as well as their variability. This information is very important not only to nutritionist, medicine practitioners, soil scientists but also seed scientists and plant breeders for crop improvement.

Probably, due to its content of 3-4-dihydroxyphenylalanine (L-Dopa) and N,N-Dimethyltryptamine (DMT) in leaves and seeds, which provide a chemical barrier to the attack of insects and small mammals, velvet bean is resistant and tolerant to many pests and diseases, (Pugalenthi *et al*., 2005).

1.4 Objectives

1.4.1 Broad objective

To enhance cultivation of velvet bean through production of quality seed

1.4.2 Specific objectives

1. To investigate and document farmers agronomic and seed management practices in Velvet Bean cultivation in Bungoma County.
2. To morphologically characterize the velvet bean seeds types from Bungoma County.

3. To determine suitable methods of breaking seed dormancy in Velvet Bean.
4. To determine the influence of phosphorus fertilization on germination potential of Velvet Bean Seed.

1.4.3 Study hypothesis

Hypothesis 1:

H_0: Velvet bean farmers in Bungoma County have good seed management and agronomic practices.

H_1: Velvet bean farmers in Bungoma County have no good seed management and agronomic practices

Hypothesis 2:

H_0: Velvet bean seed types have no significant morphological difference from each other.

H_1: Velvet bean seed types have significant morphological difference from each other.

Hypothesis 3:

H_0: Various methods of breaking dormancy have no significant difference in their effectiveness in breaking dormant velvet bean seeds.

H_1: Various methods of breaking dormancy have a significant difference in their effectiveness in breaking dormant velvet bean seeds.

Hypothesis 4:

H_0: Phosphorus fertilization has no significant effect velvet bean seed quality.

H_1: Phosphorus fertilization has a significant effect velvet bean seed quality.

1.4.4 Thesis outline

The general introduction (chapter 1) outlined the importance of velvet bean and the factors that constrain it's production and seed quality. Description of the scientific problem, justification of the study, research objectives and hypotheses were expounded. A general review literature on velvet bean was done in chapter 2. Chapter

3 documents the survey on production, management, utilization and seed of velvet bean in Western Kenya. It also presents the morphological characterization of different seed types collected from Bungoma County during the survey. Chapter 4 investigated phosphorus fertilization effect on quality of velvet bean seed. Chapter 5 investigated the efficacy of various methods in breaking dormancy of velvet bean seeds sourced from the two field experiments. The general discussion summarizes the findings and outlines recommendations of this research study. It also suggests areas that require further research in chapter 6.

CHAPTER TWO

GENERAL LITERATURE REVIEW

2.1 Botanical description and ecological requirements

Mucuna genus have about one hundred tropical climbers species, some with decorative flowers in large pendant spikes. Many *Mucuna* species pods are extremely irritant hairs, including *Mucuna pruriens.*

Mucuna pruriens is derived from the vernacular name Brazilian Tupi-Guarani (Quattrocchi, 2012). 'Pruriens' refers to the itching sensation caused by stinging hairs of the plant. Velvet bean is an annual vine slightly woody, twining, its length is attaining 5-7 m and have pubescent stems. Velvet bean leaves are alternate and trifoliolate. Petioles are pubescent (10-30 cm long) and the inflorescences of axillary pseudoracemes (per node 1-3 flowers). Seeds are brown in colour with black spots and ellipsoid, with a hilium cream-colored (Acevedo-Rodriguez, 2005).

Mucuna pruriens var. utilis and var. pruriens have hairy fruits. The fruit of *var.* pruriens have brown or orange irritant bristles (wide 1 cm) and seeds are uniformly colored. Long pale silky hairs, are noted for *var.* utilis fruit (wide 2 mm) and seeds are often streaked in different colours (Flora of China Editorial Committee, 2014).

Velvet bean is known to be native to tropical Asia and possibly Africa (ILDIS, 2014; USDA-ARS, 2014). Despite conflicting sources on native versus introduced status, it is likely to have been introduced and naturalized to Puerto Rico (Acevedo-Rodriguez and Strong, 2012) as well as to parts of the USA (states of Florida, Alabama, and North and South Carolina) (USDA-NRCS, 2015).

Velvet bean is tropical or subtropical. It is well adapted to the humid and sub-humid tropics with a rainfall of between 1000 - 2500 mm and below 1600 m altitude (Vissoh *et al*., 2008). It tolerates temperatures from 19 to 27°C and grows on poor soils with pH between 5 and 7 (Heuzé *et al*., 2016). It can be found in a variety of habitats in the West Indies (Acevedo-Rodriguez, 2005). Velvet bean species is grown in forest, bush land, thickets, wooded grassland, and anthropic landscapes in Africa (USDA-ARS, 2014).

2.1.2 Use of velvet bean

Velvet bean is used as treating pain, diabetes, infertility, to calm nerves, to lower cholesterol and as blood purifier by different countries (Tropical plant database, 2014). Velvet bean contain both toxic-inducing principles as well as dopamine, nicotine, and serotonin (Bala *et al*., 2011).

In order to rebuild soils quickly, velvet bean is used as green manure. According to McGrath (2001) 150 kg of nitrogen and organic matter contribution (natural compost in the soil) of about 35 ton/ha is produced by velvet bean.

Velvet bean possess three main uses such as environmental service, food and feed (Feedipedia, 2014). As a source of protein supplement, it seeds nutritional importance has been well documented (Bressani, 2002).

2.2 Production of velvet bean

Seed is sown by using interrow spacing of 0.9-1m and within row spacing of 30-40 cm (Chakoma *et al*., 2016). Velvet bean seeds should be planted at a depth of 3-7 cm. Velvet Bean is relatively drought tolerant and often produces a significant amount of seed yielding between 2.9 to 6.9 tonnes /ha (Pugalenthi *et al*., 2007).

Velvet bean is a leguminous climber and therefore, depending on annual rainfall, it should be planted 3 - 4 weeks after emergence in between the cereals (Chakoma *et al*., 2016). Cereal yield can be reduced when velvet bean is planted too early and densely.

In order to facilitates weeding and spraying, velvet bean can be planted within same row as maize and in between maize plants (Chakoma *et al*., 2016). Shading by cereal crop, planting delay and infestation of aphids (*Aphis craccivora*) can cause high yield reduction (Oudhia 2001a). It is advised for farmers to keep velvet bean free from weed by weeding as soon as weeds start appearing which will also reduce pest infestation. Plant support reduces pest infestation and increases yield by 25%. Between 45–50 DAS (days after sowing), flowering can start (Oudhia and Tripathi, 2001).

2.3 Seed variability

According to Oudhia (2001b), cultivar names are not available for velvet bean and good viability and higher germination were noted in local seed available in Chhattisgarh (India).

Many accessions and varieties of velvet bean have great demand in food and pharmaceutical industries. In some countries, several other velvet bean varieties are being used for weed control, soil cover and both animal and human consumption (Acevedo-Rodriguez, 2005).

The genotypes commonly cited in the literature are: *Mucuna pruriens var. cochinchinensis*, *Mucuna pruriens var. utilis*, *Mucuna sp. var. Georgia* ,*Mucuna sp. var. ghana*, *Mucuna sp. var. jaspadea*, *Mucuna sp. var. preta*, *Mucuna sp. var. rajada*, *Mucuna sp. var. veracruz, Mucuna sp. var deeringiana*, *Mucuna sp. var. nagaland* etc. (Kantiono, 2012). Morphological differences are associated with presence of pubescent hairs on the pods, color of the seed coat and length of the production cycle (Eilitta *et al*., 2003). Regarding the color of integument, some seven varieties are listed in Madagascar as follow:

Plate 2.1: The seeds of the varieties of velvet bean existing in Madagascar. Source: Rakotomalala (2013)

2.4 Seed quality

According to Banu et al (2004), seed quality can be defined standard of excellence in certain characteristics or attributes that will determine the performance of the seed when sown or stored. Genetic purity, physical aspects and physiological parameters (such as viability, germination and vigour), seed physical purity, moisture content, and seed health, all together contribute to seed quality (Nigussu *et al*., 2019; Alemu, 2019). In seed quality, seed source play an important role since location influences seed nutrient content.

Seed quality plays an important role in obtaining optimum growth and yield production in farm (Akbar *et al*.,2004). Many factors such as moisture content, germination percent, viability, vigour, survival ability, seed health, genetic characteristics and storage conditions, influence performance of the crop in the field (Molnar *et al*., 2005). A high quality seed is important to ensure maximum seed germination and seedling vigour, which leads to maximum yield. The quality of seed is also reflected in the final growth, maturity of plants, their uniformity and stability of yield. Seed germinability and vigour are essential in order to estimate seedling rate production (Matos, 2009). Adequate imbibition capacity is also important because it determines the success of seed germination and plant growth (Ribeiro *et al*., 2015). Germination test is used to determine seed viability and it starts with dry seed water absorption and ends with radicle elongation (Wolny *et al*., 2018). Rapid seed imbibition leads to the leaching of more electrolytes before the cell membranes have time to reorganize (Pereira & Masetto, 2021). Electrical conductivity test is used to estimate seed vigour and it is a good indicator of the seedling emergence in field for different plant species (Silva *et al*., 2012).

2.5 Seed dormancy

Seed dormancy is defined as the inability of a viable seed to germinate under conditions which are favorable for germination (Sanchez *et al*., 2004). Physical/external dormancy is exhibited by hard seed coat and has been reported in velvet bean (Yogeesha and Shivananda, 2003). In adverse environmental conditions, a hard seed coat improves seed survival in the soil and helps to avoid species extinction in nature (Tiryaki and Topu, 2014). However seed coat dormancy prevents oxygen and/or water from permeating into the seed thus inhibiting germination.

Pigmentation of the seed coat has been shown to play an important role in seed dormancy and germination (Ochuodho and Modi, 2008). Important characteristics for distinguishing between hard seeded and soft seeded varieties of *Vicia sativa*, is seed size and color (Büyükkartal *et al*., 2013). Seed size of hard seeded lines is smaller than that of the soft seeded lines.

Some studies have been conducted on the development of a convenient method of seed quality improvement for several crop species like common bean (Possobom *et al*., 2015), cowpea (Marwanto, 2004) and Arabidopsis (Debeaujon, 2000) by using seed size and coat colour. In agricultural systems, seed quality is very important with early seedling growth and establishment especially dependent on seed reserves, before photosynthetic capacity is developed. Seed quality is closely linked with the seed size and weight (Sousa *et al*., 2016; Snider *et al*., 2016).

There are many methods used to break seed dormancy. These include scarification by notching the seed coat with a sharp knife, scarifying the seed coat with sand paper, soaking the seed in hot/cold water or sulphuric acid as well as stratification (subjecting the seeds to high or cold temperatures) (Sanchez *et al*., 2004). Once the dormancy is broken water is absorbed by the cell wall and macromolecules in the process of imbibition. The cell wall enlarges and seed coat becomes softened allowing oxygen diffusion for seed respiration leading to germination (Mwami *et al*., 2017). This study seeks to determine the effectiveness of soaking seed, scarification and stratification in breaking dormancy in velvet bean.

2.6 Effect of phosphorus on seed quality and germination

In the tropics, other than soil moisture deficiency, plant nutrient deficiency is the other major factor limiting crop productivity. Any one of macronutrients deficiency will significantly hamper plant growth, seed yield and quality. Most tropical soils are deficient in phosphorus (Hanyabui *et al*., 2020) and the domination by kaolinitic clay results in phosphorus fixation rendering it unavailable for plant uptake.

Phosphorus (P) forms the skeleton of cellular membrane and DNA and is essential component of ATP (adenosine triphosphate). Total P content in seeds can be significantly influenced by phosphorus application to mother plant (Modi, 2002). Total P content in seeds is related to metabolic functions in seeds and highly correlated with phytic acid, main form of storage phosphorus (Raboy, 2009). During germination water is translocated to emerging root and shoot tissues, seed phosphorus reserves were rapidly mobilized (White and Veneklaas, 2012). Faster germination, larger first leave and longer roots in legume crop such as common and lupin beans is noted for seeds with high P content showed (Zhu and Smith, 2001). However, other studies reported that with increasing phosphorus fertilization, no effect on root growth or root to shoot ration was noted (Ristvey *et al*., 2007), or root growth increased but root to shoot ratio decreased (ration Kim *et al*., 2008).

Little is known about whether velvet bean seed quality is affected by phosphorus fertilization. Therefore, this study was conducted to explore the impact of P application on seed germination in an attempt to improve germinability and longevity through fertilization management.

CHAPTER THREE

PRODUCTION, MANAGEMENT, UTILIZATION AND SEED QUALITY OF VELVET BEAN (*Mucuna pruriens* L. DC) IN WESTERN KENYA

Abstract

Farmers' are increasingly interested in velvet bean nutritive capacities as food and animal feed. However, production of velvet bean faces many constraints such as unavailability of quality seed and lack of standardized agronomic practices, seed management and utilization strategies. The purpose of this research was to investigate the agronomic practices, seed management and utilization strategies of velvet bean production in Bungoma County, Kenya. A total of 56 farmers, from 10 farmers groups were interviewed. A semi structured questionnaire was used for data collection while the Epi info 7 computer software program was used to analyze the data. Four types of velvet bean seeds were collected from farmers during the survey. Morphological variability in seed characteristics like seed coat color, hilum color, seed length, width and thickness (IBPGR descriptor) was evaluated in four replications of 50 seeds each. Fifty seeds replicated 3 times were used to determine the electrical conductivity (EC) for each seed type. Germination test of these seeds was done using CRD. To investigate the dynamics and rates of imbibition, thirty seeds replicated 3 times for each seed type were subjected to temperatures of 20, 25, 30, 30/20°C and in ambient condition during a germination test. Data were subjected to analysis of variance (ANOVA) using GENSTAT software release 14.1 and the mean separations was done using least significant difference (LSD) at 5% level of significance. Pearson correlation coefficient was used to analyze seed traits of the morphotypes. Germination percentage data was analyzed using Microsoft Office (Excel) V.2013. Most farmers surveyed had less than 0.5 acre under velvet bean cultivation and had been planting velvet bean seed for one year. Majority of velvet bean farmers did not deploy seed selection criteria in the field. The reasons cited for crop popularity include: soil fertility restoration, human and animal nutrition, drought tolerance, pest and disease tolerance, food security and medicinal value. Most farmers (65%) did not intercrop velvet bean with other crops. However, 30% of the farmers intercropped velvet bean with maize, 2% intercropped with groundnut and rotated with common bean**.** Seed quality assurance activities carried out in the field by farmers were weeding (98%), removing diseased or off types (25%) and planting separately (23%). Forty eight percent of the farmers indicated that they sold seed to other farmers and 16% to Agriculture Office. Among seed types in all seed traits measured, significant differences ($p \leq 0.05$) were noted except seed coat thickness. White seed type recorded a lower electrical conductivity (more vigorous), higher final germination percentage, speed of germination index and imbibition rate at 30°C for both substratum (sand and filter paper) than others seed types. This study therefore recommends that agronomic and seed management practices need to be standardized to improve seed quality at farm level hence increase the production of velvet bean.

Keywords: Agronomic practices, seed management, utilization, seed morphology, seed quality, velvet bean

3.1 Introduction

Velvet bean has the ability to both restore soil fertility and provide food (FAO, 2011). Velvet bean has multiple functions that could help smallholder farmers boost their livelihoods by increasing livestock and crop production. Compared to other legumes, velvet bean rhizobia fixes more nitrogen, which helps improve soil fertility (Muoni *et al.*, 2019). In order facilitates weeding and spraying, velvet bean can be planted with maize in between maize plants and within the same row. Velvet bean also has medicinal values and is used to treat Parkinson's disease, impotency and snake bites (Natarajan *et al.*, 2012). According to Jonathan et al (2015), velvet bean is an emerging multiple use crop with a lot of potential for enhancing biodiversity and soil fertility. It has nutritional value like soybean which is better than any other legumes such as common bean. Despite its potential, velvet bean remains a minor food crop. It is poorly adopted in agricultural systems. This is due to the presence of toxic and anti-nutritional compounds that arise from secondary metabolism in plants as well as poor field germination and emergence (Eillitta *et al*., 2003).

According to Kenya Vision 2030 and National Food Security and Nutrition Policy (NFSNP), local food production is one of the means of alleviating household food insecurity (GOK, 2008a,b). However, food insecurity continues to persist with about 53% of the people in the rural areas being overall poor while 51% are food insecure (GOK, 2008c). In addition, 53% of Kenyan children have inadequate protein intakes (Manary, 2013).

Farmers in Western Kenya face a number of food production constraints (land degradation, low soil fertility, poor rainfall, climate variability), resulting in high food insecurity. Adoption of legumes with high protein content such as velvet bean can reduce food insecurity in Kenya.

Cropping systems are impacted by several factors that include: climate change, limited access to adequate inputs, unpredicted and insufficient rainfall, increased drought frequencies, compromised soil quality and fertility and inadequate knowledge on crop production (Muoni *et al*., 2019). A fifty percent increase in grain yield was recorded at demonstration farms in Bungoma, Siaya and Kakamega counties that used velvet bean as a rotation crop or intercrop in maize grown under conservation agriculture systems (Ministry of Agriculture Annual report, 2018). Domestication of velvet bean is increasing as well as area under cultivation and the markets. Therefore, adequate knowledge on velvet bean seed production is important for farmers in these areas.

The purpose of the present research was to investigate farmer's agronomic practices, seed management and utilization strategies in Western Kenya and discuss their influence on seed quality at farm level in an effort to increase the production of velvet bean in this region.

3.2 Material and methods

3.3.1 Survey

The research was carried out in Bungoma County between 10th to 15thJune 2019 and targeted farmer groups growing velvet beans. Bungoma County is located on the southern slopes of Mount Elgon in western Kenya covering an area of about 3,032 km^2. It borders the Republic of Uganda to the northwest, Busia to the west and southwest, Kakamega County to the east and southeast and Trans-Nzoia County to the northeast, (Ralph *et al*., 2005). The County is divided into 9 sub counties namely

Bumula, Kimilili, Mt.Elgon, Webuye East and West, Bungoma Central, Bungoma North, Bungoma South and Bungoma west. The county receives between 400 and 1800 mm of annual rainfall, with annual temperatures varying between 10 and 32 ºC (ASDSP, 2014). Agriculture is the primary source of income and employment with maize, finger millet, Irish and sweet potato, banana, beans and various vegetables being the main food crops grown in the County.

Farmers interviewed were selected using purposive sampling from a list of farmers groups growing velvet bean. Fifty six farmers, from 10 groups in Bungoma County were interviewed (**Table 3.1**). A structured questionnaire was used for data collection on farmers' characteristics, agronomic practices, seed management and utilization strategies in Bungoma County. Interview sessions were conducted during visits to respondents 'homes. Responses were filled in the questionnaires and observations on the agronomic practices, seed management, farmlands sizes, food type cultivated etc., were done after the interview sessions.

Table 3.1: Number of farmers growing velvet bean for each group in Bungoma County

Farmers group	Number of velvet bean farmers	Total number of farmers	Percentage of velvet bean farmers (%)
Nambuyakhaka	7	22	32
Yetanabukokholo	8	30	27
Mulomandala	6	6	100
Ngarisha	5	25	20
Namasa star	6	18	33
Subila FFS	7	15	47
Tabuti lima	1	15	7
Integrated community health organization	4	18	22
Musangafu help group	8	30	27
Wakipu	4	15	27
Total	**56**	**194**	**29**

Epi info 7 software was used to analyze data. Data collected, was grouped into categories, coded, entered and analyzed. To determine the adequacy, credibility and usefulness of the data according to the study's objectives, further evaluation and analysis were done. Qualitative and quantitative data were described and organized using descriptive statistics (percentages). The results were presented using bar graphs and pie charts.

3.3.2 Laboratory experiment

Seeds obtained from the survey were taken to the Seed Physiology Laboratory, Department of Seed, Crop and Horticultural Sciences, University of Eldoret and experiments set up to determine the quality of farmers' seeds in Bungoma County. This experiments was carried out between 17th to 30th June 2019.

3.3.2.1 Morphological characterization of velvet bean seed types from Bungoma County

Seeds were categorized into different types. Morphological variability in seed characteristics like seed coat color, and hilum color, was evaluated in four replications of 50 seeds each type using the IBPGR descriptor. To determine seed variability (length, width and thickness) a seed caliper was used. Seed length was measured over the seed coat along the longest axis of the seed. The seed width measurement was taken on one of the widest faces at the middle of the seed. Then seed coat thickness was measured on one of the smallest faces at the middle of the seed without removal of seed coat.

3.3.2.2 Electrical conductivity of velvet bean seed types from Bungoma County

For each seed type fifty seeds were weighed and this was replicated 3 times. The clean seeds were then immersed in 100ml of distilled water at 25°C temperature for 24 hours. The conductivity meter was warmed for about 30 minutes before testing.

Conductance of distilled water in a beaker was measured. The electrode was then cleaned with a tissue paper. It was inserted into leachate and conductance of the leachate was read. The electrode was thoroughly washed using a wash bottle and wiped with a clean tissue paper before reusing. To get the electrical conductivity (EC) of leachate the reading of distilled water was subtracted from the sample reading then divided by the weight of the seed in grams:

$$\textbf{Electrical conductivity} = \frac{\textbf{EC Reading} - \textbf{Control}}{\textbf{Weight}}$$

Results represent the mean of 3 measurements ± standard error (SE) and are expressed as mS g^{-1}.

3.3.2.3 Germination test of velvet bean seed types from Bungoma County

Three replications of 50 seeds each from each types of velvet bean were used for preconditioning stage and germination tests. In order to reduce the chances of contamination, petri dishes and plastic containers were sterilized with 1% sodium hypochlorite. The seeds were chipped at the hilium, then placed into petri dishes and put into the incubator. A container filled with distilled water was placed below the petri dishes. This setup was incubated at 25°C for 2 days.

Sand was obtained from University of Eldoret farm, washed and dried at the greenhouse and then sterilized in an oven set at 150°C. Three replications of fifty seeds from the 4 types of velvet bean was counted and placed into their respective plastic containers containing the sand. The plastic containers (covered with lids) were placed into the incubator at altering temperature 30/20°C in the light/dark (8h/16h a day) (ISTA, 2015). Seeds were incubated for 14 days while monitoring germination count daily, according to ISTA (2011). Seeds were considered germinated if their radicle had protruded at least 2 mm. Final germination percentage (FGP) and Speed of germination index (SGI) were calculated according to ISTA (2011) as follows:

$$\mathbf{F}\boldsymbol{G}\mathbf{P} = \frac{\mathrm{NT}\ \boldsymbol{x}\ \mathbf{100}}{N}$$

Where:
FGP = Final Germination Percentage
NT = Total Number of Seeds Germinated
N = Number of Seeds Sown.

$$\mathbf{SGI} = \sum \frac{\mathrm{n}}{d}$$

Where:

n = number of seedlings emerging o day ‘d’

d = number of day

3.3.2.4 Imbibition rate of velvet bean seed types from Bungoma County

In order to know the optimum media for water uptake of velvet bean seeds, two media were used: sand and filter paper. Three replications of thirty seeds were subjected to temperatures of 20, 25, 30, 30/20°C in the light/dark (8h/16h a day) and in ambient condition at the following times 2, 4, 6, 8, 24 and 48 h. Water imbibing capacity of the seeds (ws) was calculated the formula by Hidayati *et al*. (2001).

$$\%\mathbf{Ws} = \frac{(\boldsymbol{Wi}-\boldsymbol{Wd})}{\boldsymbol{Wd}}\mathbf{X100}$$

Where Ws: water imbibing capacity of the seeds, Wi: seed wet weight after each imbibition time and Wd: initial weight of dry seeds (g).

3.3.2.5 Data Analysis

Seed morphological data, germination percentage, speed of germination index were subjected to one way analysis of variance (ANOVA) using GENSTAT software release 14.1. Mean separation was done using least significant difference (LSD) at 5% probability. Pearson correlation coefficient was used to relate the seed traits with germination percentage using Microsoft Office (Excel) V.2013. For the electrical conductivity (EC) and imbibition rates, data was subjected to descriptive analysis and presented as line graph using Microsoft Office (Excel) V.2013.

3.3 Results

3.3.1 Survey

3.3.1.1 Farmers' characteristics

The farmer's characteristics captured in this study included: Sub-county surveyed, education levels of the respondents, reason for joining farmers group and sources of income.

Five Sub-Counties were surveyed (Figure 3.1) according to the number of farmer groups. Sixty five percent of the respondents were located in Bumula. Bulondo and Sangalo sub county had less percentage of farmers surveyed (2% each).

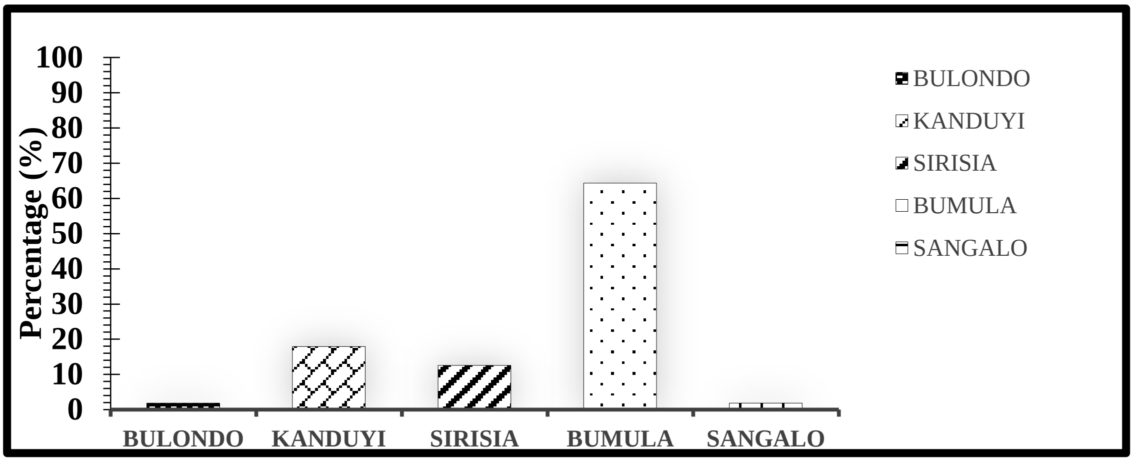


Figure 3.1: Areas surveyed in Bungoma County

About 84% of the farmers had attained upper primary and secondary school education; only 5% had not attained a formal education (Figure 3.2).

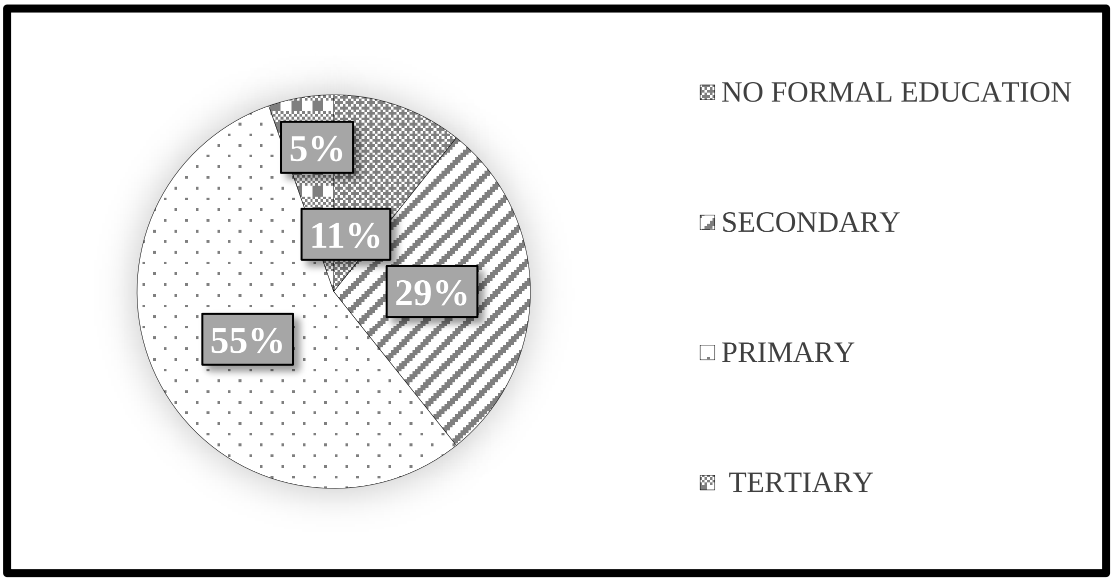


Figure 3.2: Education levels of velvet bean farmers in Bungoma County

Majority of the respondents have joined a farmers group for seed production (86%), commodity marketing (71%) and social support (68%) and 41% for savings and credit services (Figure 3.3).

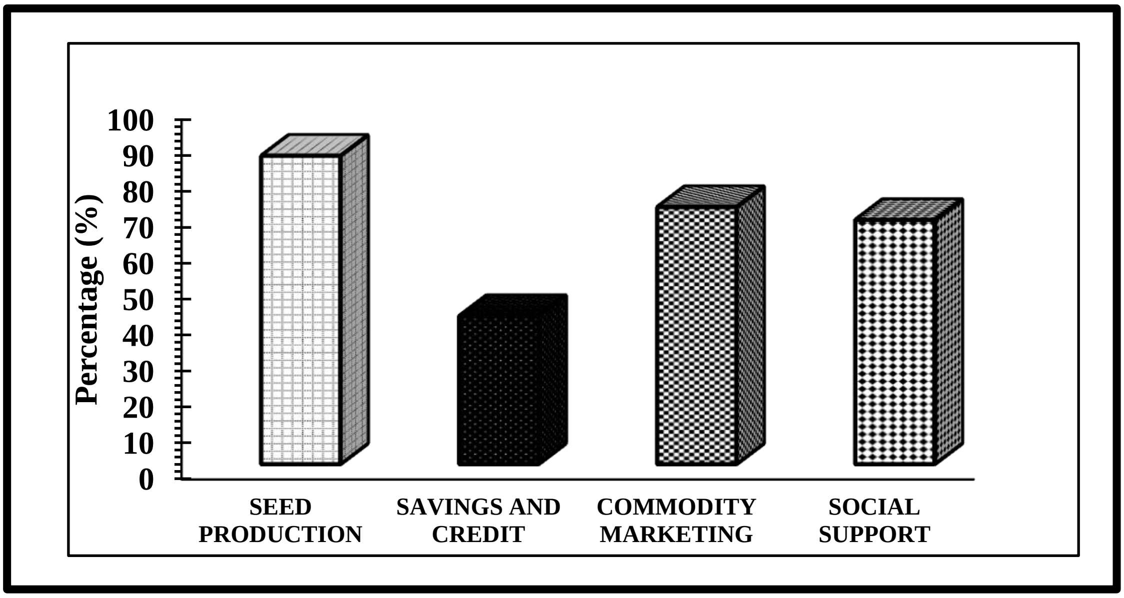


Figure 3.3: Reasons for joining farmers group involved in velvet bean cultivation in Bungoma County

Most of the farmers groups had food crop farming (98%) as their main activity, followed by livestock farming (23%), business (23%) and cash crop farming (18%). Some farmers (2%) had casual labor as their main activity (Figure 3.4).

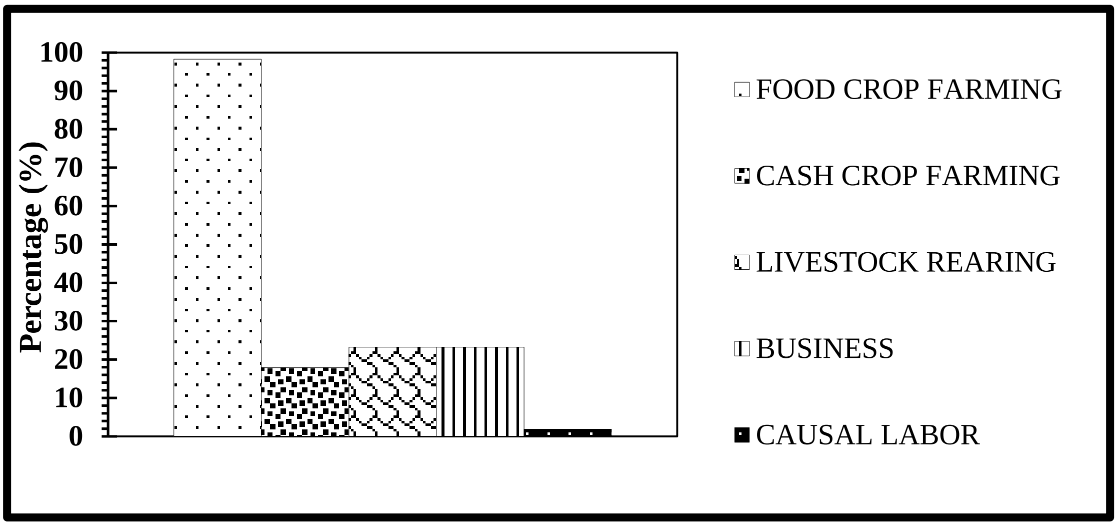


Figure 3.4: Source of income of farmers involved in velvet bean cultivation in Bungoma County

3.3.1.2 Agronomy of velvet bean

Majority of the respondents (80%) surveyed had less than 0.5 acre under velvet bean cultivation (Figure 3.5).

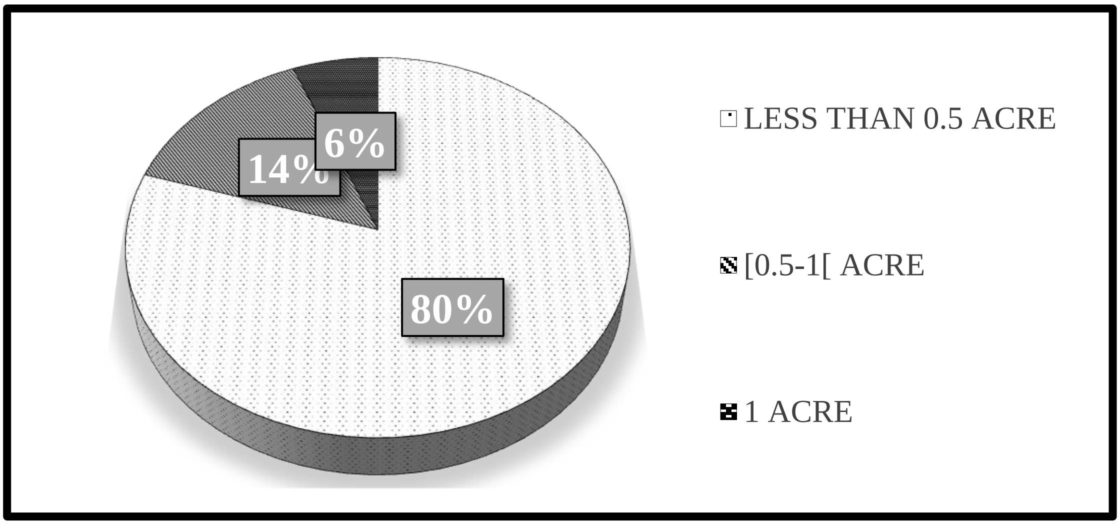


Figure 3.5: Proportion of farm under velvet bean cultivation

In Bungoma County, the reasons cited for crop popularity included: restoration of soil fertility (100% of farmers surveyed), provision of both human and animal nutrition (96%), drought tolerance of the crop (89%), thus ensured production, pest and disease tolerance (73%), food security (54%) and medicinal value (21%) (Figure 3.6).

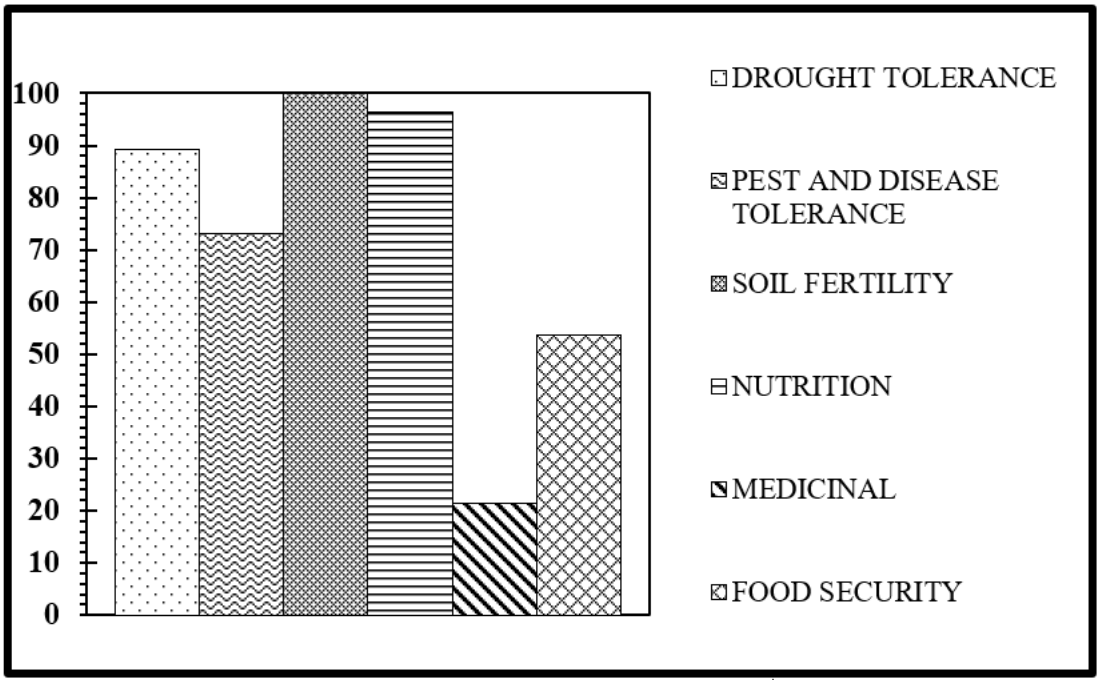


Figure 3.6: Reasons for crop popularity cited by velvet bean farmers in Bungoma County

On average 80% of the farmers indicated that the main reason for low popularity of velvet bean seed was difficulty in cooking (Figure 3.7). Also 64%, 54% and 45% of the farmers respectively indicated velvet beans take long to germinate and establish, have long maturity period and there is difficulty in accessing the seed.

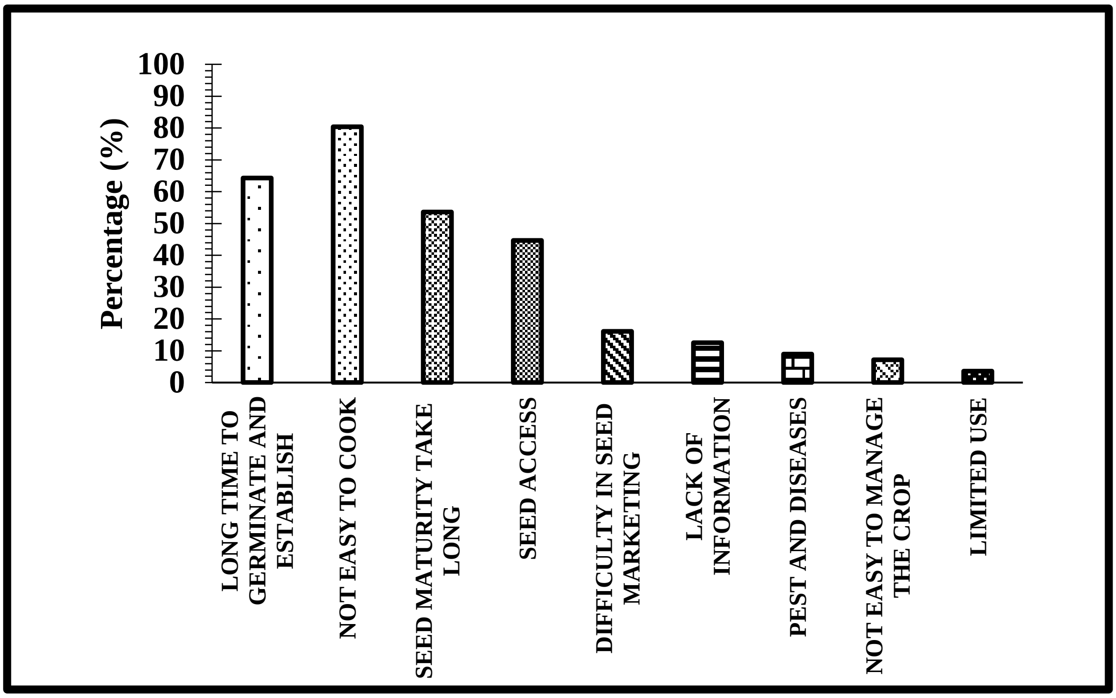


Figure 3.7: Reasons for low popularity of velvet bean farmers in Bungoma County

3.3.1.3 Seed management practices

Most of the farmers (66%) did not intercrop velvet bean with other crops (Figure 3.8). However, 30% of the farmers intercropped velvet bean with maize, 2% intercropped with groundnut, banana and in rotation with beans.

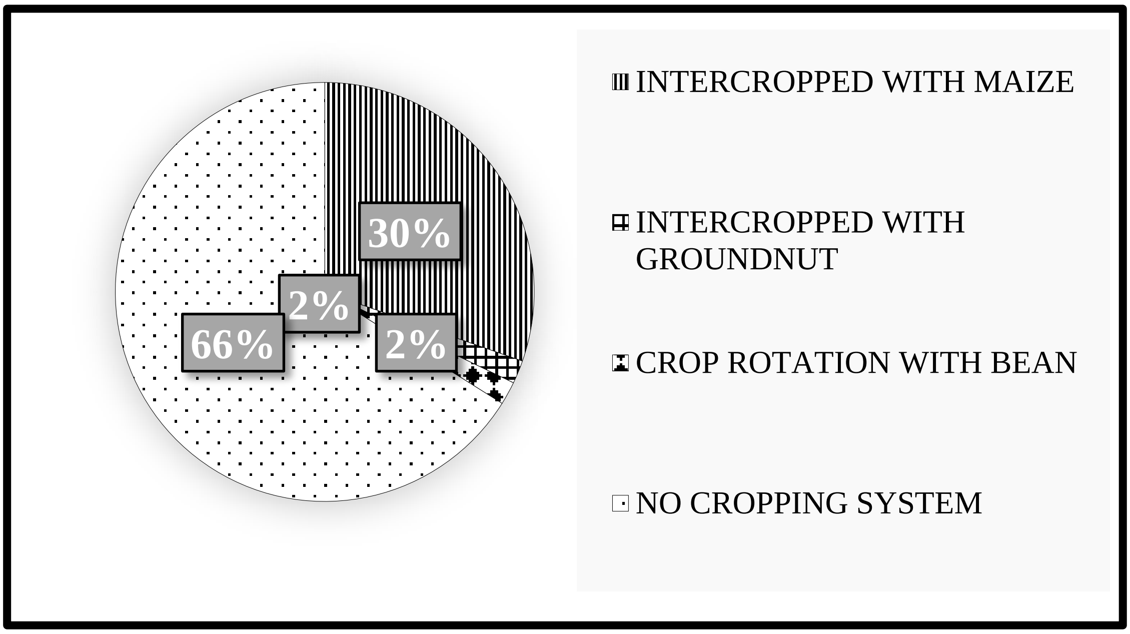


Figure 3.8: Cropping system used by farmers in Bungoma County

Most of the farmers (43%) weeded velvet bean thrice and others weeded once (16%) or twice (41%) (Figure 3.9).

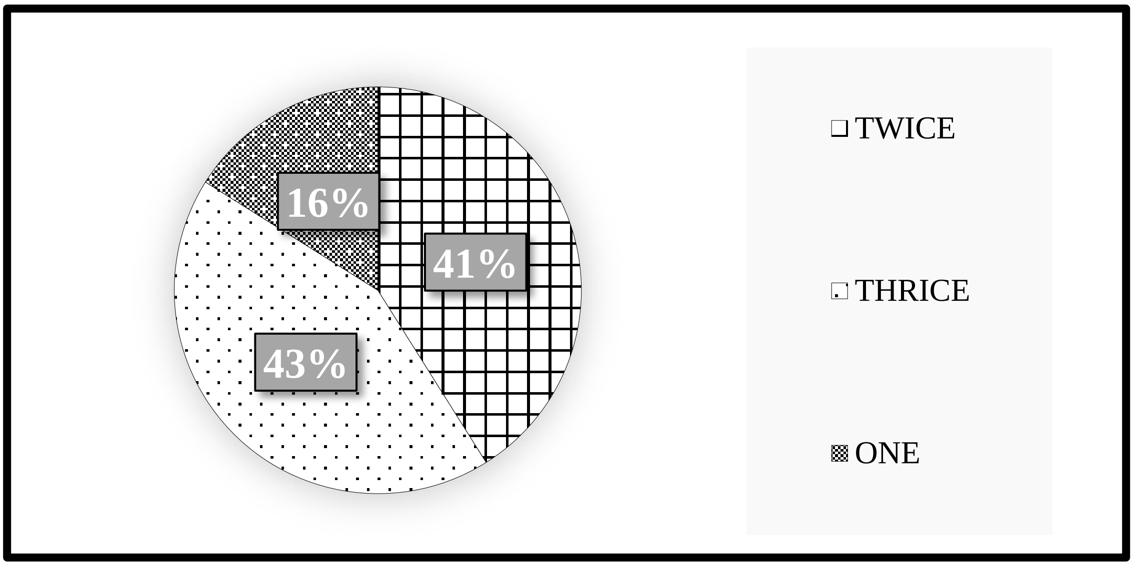


Figure 3.9: Frequency of weeding of velvet bean by farmers in Bungoma County

On average 52% of the sampled farmers have been planting velvet bean seed for one year, 30% for two years and few (7%) more than three years and 11% are not planting it yet (Figure 3.10).

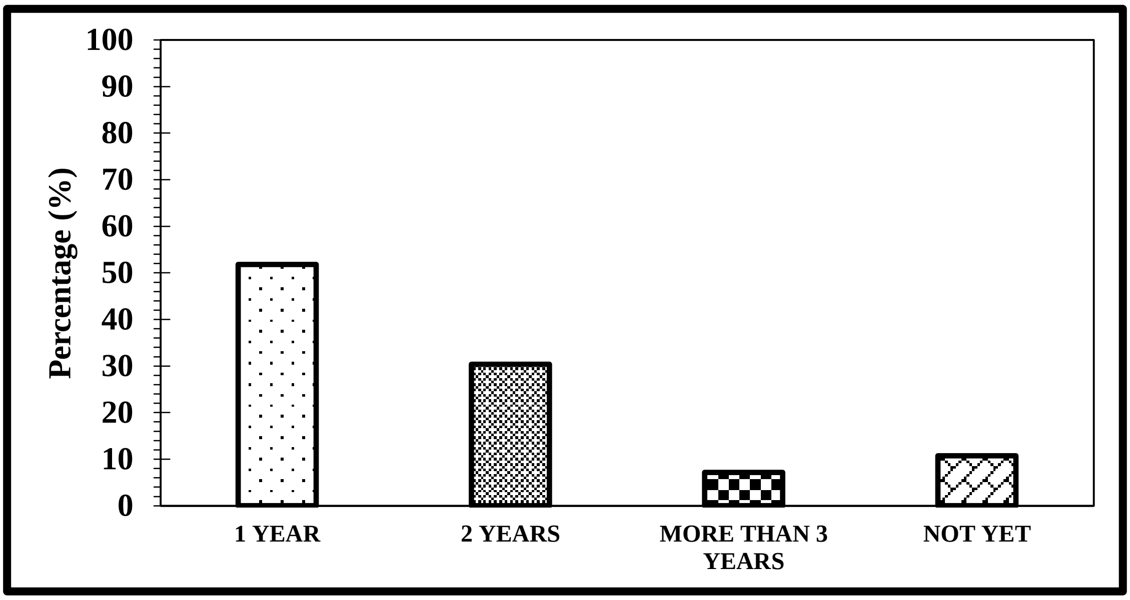


Figure 3.10: Duration of growing velvet bean by farmers in Bungoma County

Most of the farmers (61%) did not use any seed selection criteria in the field. However, 29% harvested seeds from healthy looking plants and pods, 20% harvested from high yielding plant (Figure 3.11).

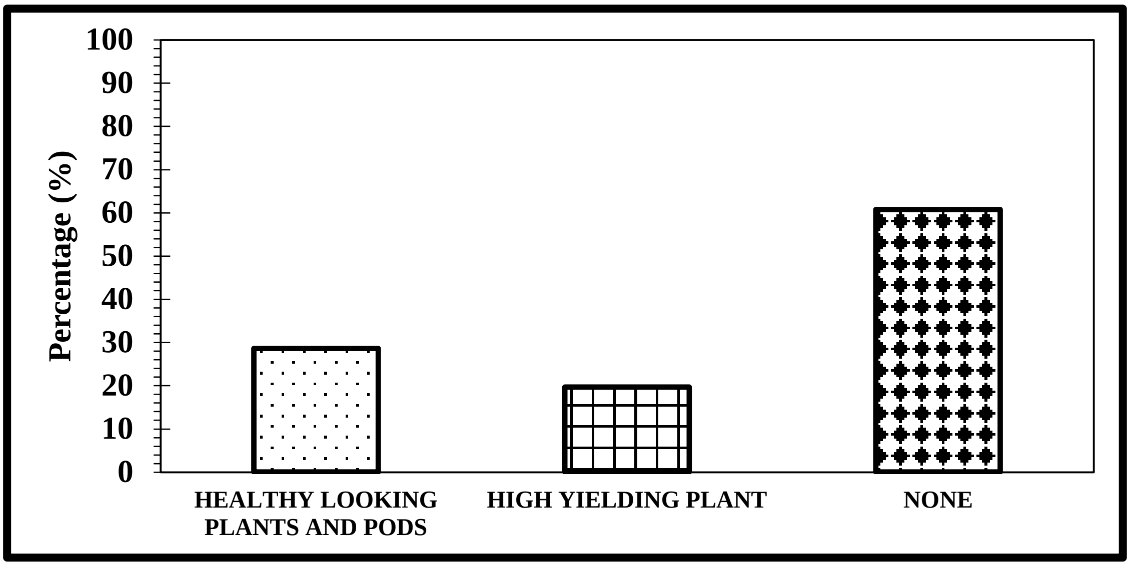


Figure 3.11: Seed selection criteria used by velvet bean farmers in Bungoma County

In the field, the seed quality assurance activities carried out by farmers were weeding (98%), removing diseased or off types (25%) and planting separately (23%) (Figure 3.12).

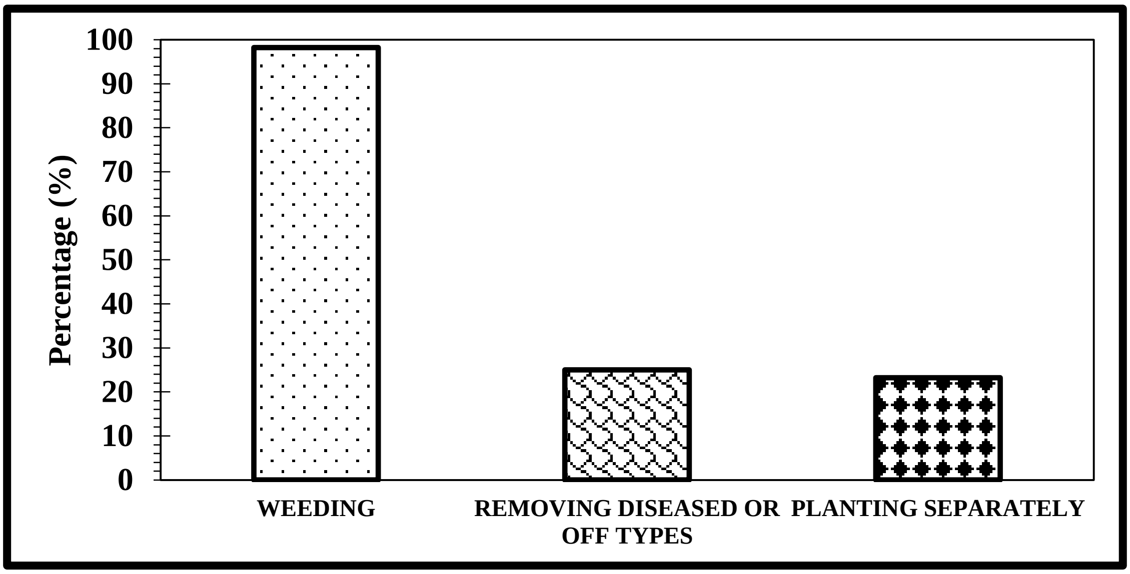


Figure 3.12: Seed quality assurance activities carried out in the field by velvet bean farmers in Bungoma County

3.3.1.4 Utilization

Seventy three percent of the farmers indicated that velvet bean seed can be used as food (e.g. for making chapati, mandazi, as cooked beans, porridge, tea), 48 % as medicine (e.g. for treatment of asthma, blood pressure, improve sexual function), 36 % as beverage, 25% for improving soil fertility and only 4 % for oil extraction used for soap making (Figure 3.13).

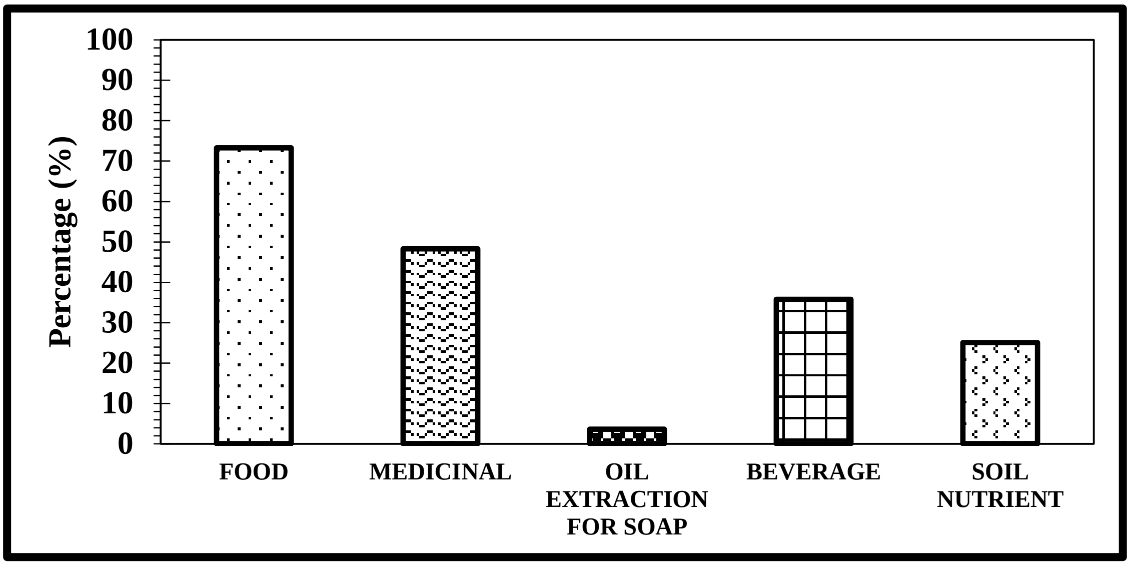


Figure 3.13: Use of velvet bean seed by farmers in Bungoma County

Farmers mentioned that the main uses of velvet bean leaves were improving soil fertility (95 %), used as animal feed (34%) and as a cover crop (32%) (Figure 3.14). Few farmers indicated that they used velvet bean leaf to inhibit *Striga* weed and 4 % consumed the leaf as vegetable (boiled or boiled and fried).

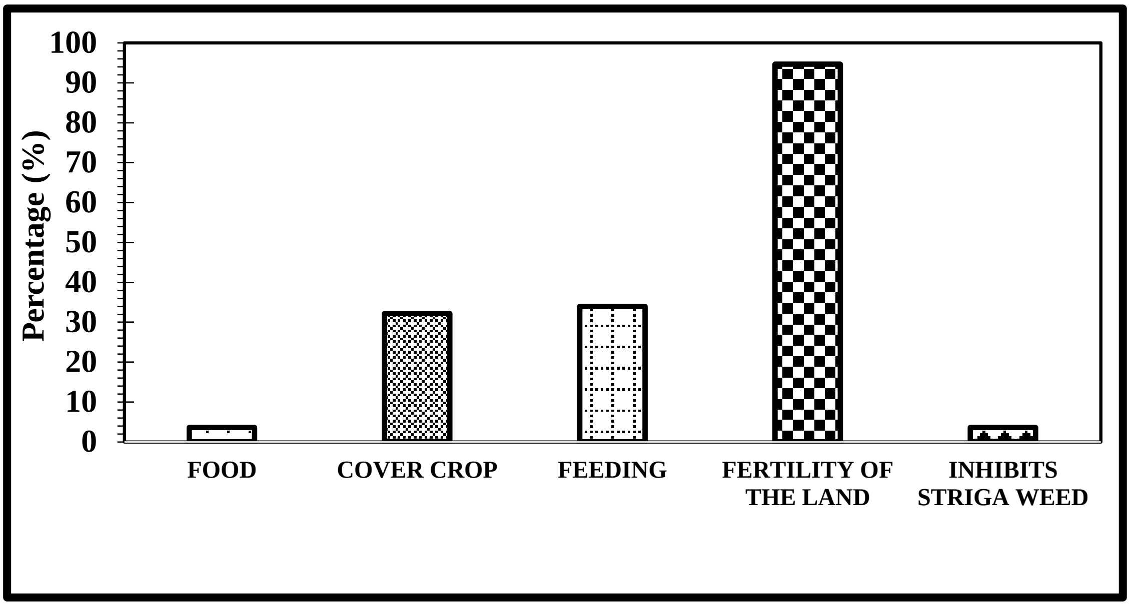


Figure 3.14: Use of leaf by velvet bean farmers in Bungoma County

Small percentage of the respondents (2 %) indicated that velvet bean flower can be used as medicinal tonic (e.g. ulcer: flowers added in boiling water) and a beverage (Figure 3.15). Majority of the farmers (96 %) did not know the use of the flower.

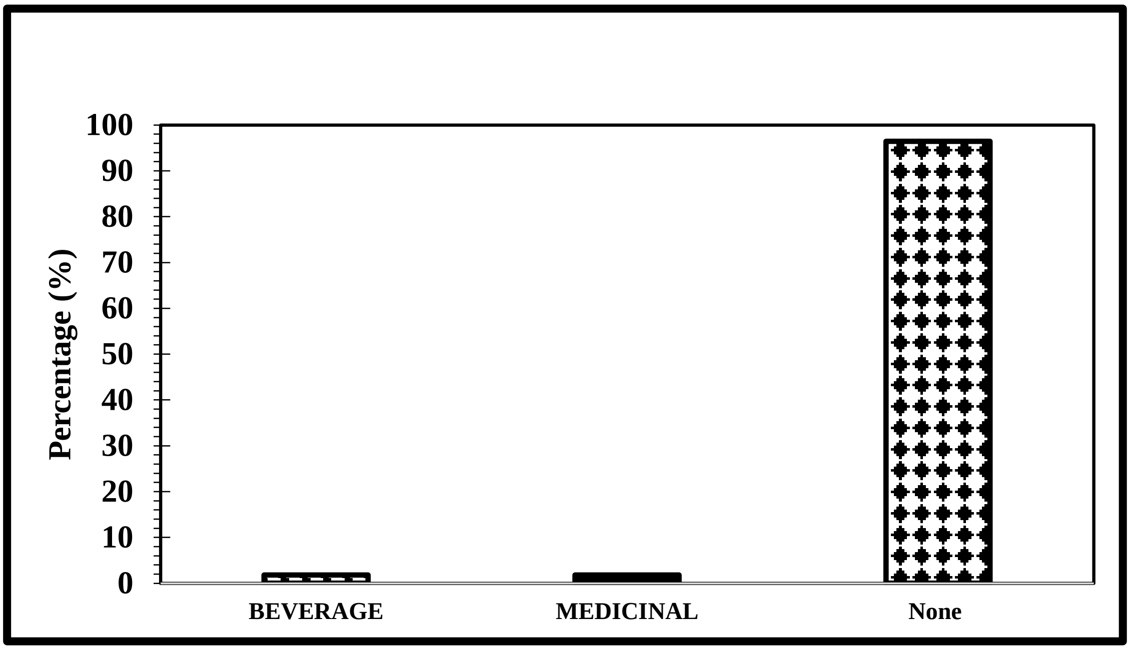


Figure 3.15: Uses of velvet bean flowers as indicated by farmers in Bungoma County

Majority of the respondents (52%) said that velvet bean root can be used to improve soil structure (Figure 3.16). Others said it can be used to break hard pan (23%), prevent soil borne diseases (11%) and prevent soil erosion (9%), as medicine (e.g. treatment of teeth) (7%) and 4% to control animal attack on field crops.

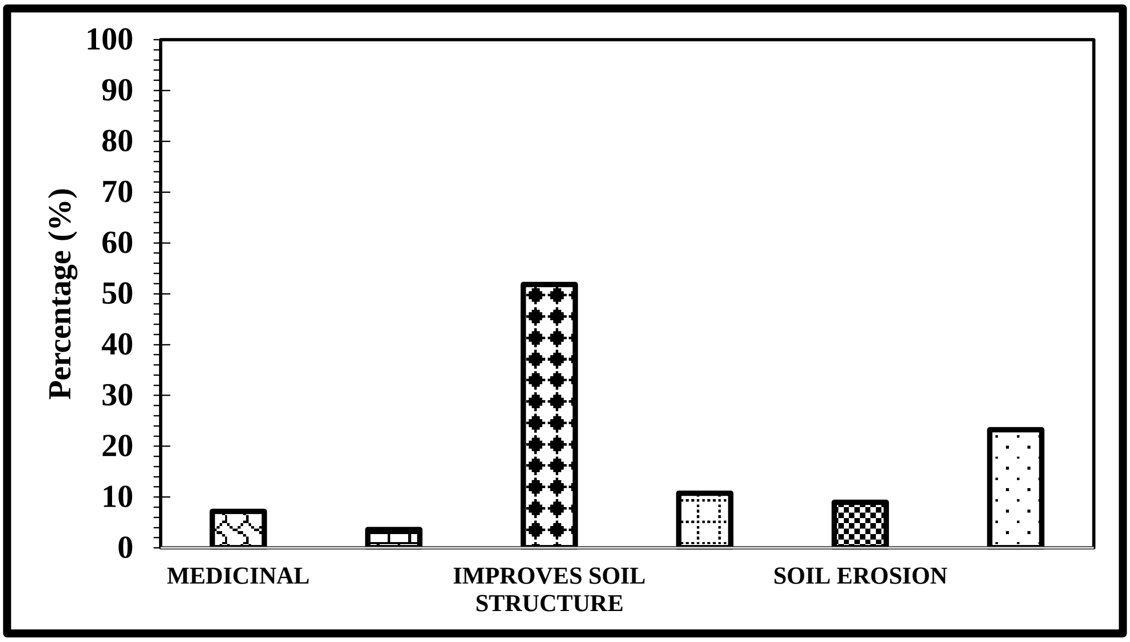


Figure 3.16: Uses of velvet bean roots indicated by farmers in Bungoma County

Over half (61%) of the respondents did not know any use of the pod but 25% said the pod can be decomposed for fertilizer, 7% said it can be used as animal feeding, 5% as firewood and 2% as medicine (e.g. asthma, blood pressure) (Figure 3.17).

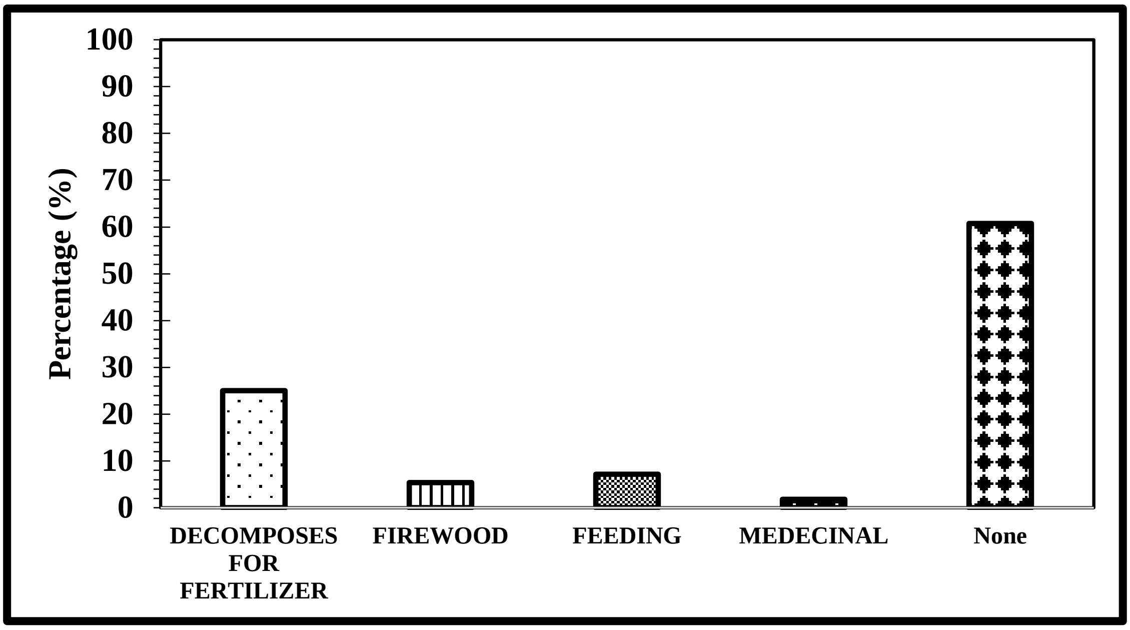


Figure 3.17: Uses of velvet pod as indicated by farmers in Bungoma County

3.3.2 Laboratory experiments

3.3.2.1 Morphological variability

Among seed types, there were significant differences (p≤0.05) in all seed traits measured except seed coat thickness (Table 3.2). White and Brown white seed types had significantly longer and wider seed than other seed types.

Table 3.2: Morphological variation in seed length, width and thickness among four seed type of velvet bean in a laboratory experiment conducted between 17th to 30th June 2019 at the University of Eldoret

Seed type	Seed length (mm)	Seed width (mm)	Thickness (mm)
Black	13.10 **a**	9.27 **a**	9.101
Dark brown black	13.18 **a**	9.59 **a**	9.455
Brown white	15.30 **b**	11.73 **b**	9.484
White	15.55 **b**	11.82 **b**	9.491
LSD	1.8579	1.8916	0.3470
CV (%)	8.4	11.6	NS
F pr.	0.020	0.019	0.086- >0.05

LSD: LSD: Fischer's Least significant differences, CV: coefficient of variation, F pr.: F probability. Mean followed by a different letter within a column are significant different at p≤0.,05, NS- treatment effects not significant.

Correlation of seed traits showed that seed length correlated with seed width (r= 0.996, p≤0.05) and seed thickness (r=0.660, p≤0.05) (Table 3.3). Seed width and seed thickness also showed a significant positive correlation (r=0.713, p≤0.05). Seed length and width positively correlated with germination percentage (p≤0.05).

Table 3.3: Mean correlation coefficient (r) between seed traits and germination percentage of velvet bean seed type in a laboratory experiment conducted between 17th to 30th June 2019 at the University of Eldoret

Seed type	Seed length (mm)	Seed width (mm)	Thickness (mm)
Seed length (mm)			
Seed width (mm)	0.996*		
Thickness (mm)	0.660*	0.713*	
FGP (%)	0.929*	0.935*	0.829*

FGP = Final germination percentage
* correlations were significant

Using the RHS colour chart 4 seed, types were identified (Plate 3.1 and Table 3.4). Velvet bean seed coats ranged from black to dark greyish ,yellowish brown to yellowish grey, dark greyish yellowish brown (dark brown black) and yellowish grey (brown white seed type) Spot were observed respectively on the seed coat. Pinkish grey pattern colour was observed on the seed coat of the white seed type.

All seed type had a yellowish white hilium colour but the group differed from yellow white to white (Table 3.5).

Plate 3.1: Different seed types collected from farmers during the survey in Bungoma County

Table 3.4: Seed Colour (RHS Chart) in a laboratory experiment conducted between 17th to 30th June 2019 at the University of Eldoret

Type	Seed colour	*Code*	*Group*	Spot colour	*Code*	*Goup*	Pattern colour	*Code*	*Group*
Black	Black	203 B	Black group						
Dark brown black	Black	203 B	Black group	Dark Greyish Yellowish Brown	N200 A	Brown group			
Brown white	Dark Greyish Yellowish Brown	N199 B	Grey Brown group	Yellowish Grey	156 A	Greyed-white groupe			
White	Yellowish Grey	156 A	Greyed-white group				Pinkish Grey	201 D	Grey group

Table 3.5: Hilium Colour (RHS Chart) in a laboratory experiment conducted between 17th to 30th June 2019 at the University of Eldoret

Type	HiliumColour	*Code*	*Group*
Black	Yellowish white	158D	Yellow white group
Darkbrown black	Yellowish white	158D	Yellow white group
Brown white	Yellowish white	155B	White group
White	Yellowish white	155B	White group

3.3.2.2 Electrical conductivity (EC)

Among the seed types, no significant difference in the average EC was noted. White seed type with average electrical 0.0012mSg^{-1} was more vigorous than dark brown black, followed by black and brown white seed type (Table 3.6). Lower the EC value greater is the vigor of the seed.

Table 3.6: Electrical conductivity of velvet bean seed in a laboratory experiment conducted between 17th to 30th June 2019 at the University of Eldoret

Seed Type	Average EC (mSg-1)
Black	0.0016**a**
Dark brown black	0.0019**a**
Brown white	0.0014**a**
White	0.0012 **a**
LSD	0.00084
CV (%)	36.0
F pr.	0.427

LSD: Least significant differences, CV: coefficient of variation, F pr.: F probability. Mean followed by the same letter within a column are not significantly different at $p \leq 0.05$

3.3.2.3 Germination test

Final germination percentage (FGP) and speed of germination index (SGI) significantly ($p \leq 0.05$) differed with seed type. White seed type had significantly ($p \leq 0.05$) higher FGP (76.67%) and SGI (5.31) than the others seed types, followed by brown white (57.33% ; 4.02). FGP and SGI were low for dark brown black and black seed type (Figure 3.18 and Figure 3.19).

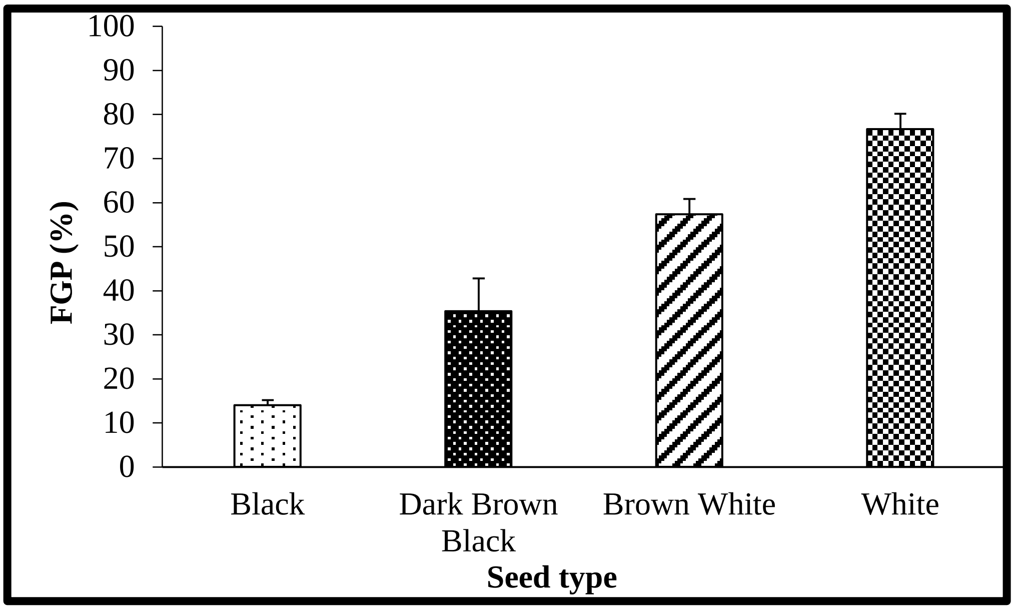


Figure 3.18: Germination percentage of four velvet bean seed types in a laboratory experiment conducted between 17th to 30th June 2019 at the University of Eldoret

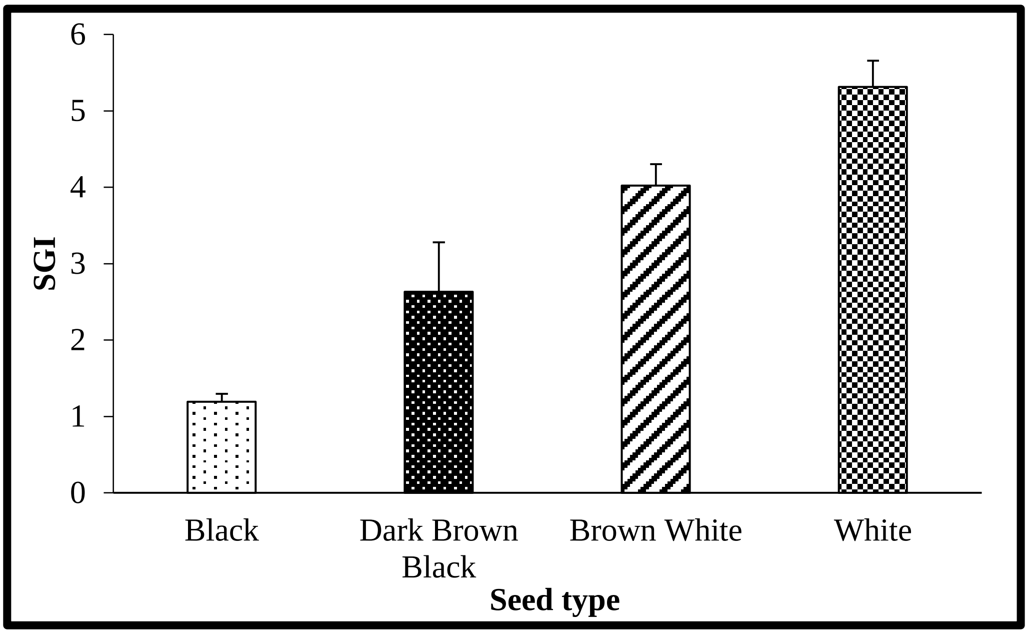


Figure 3.19: Speed of germination index of four velvet bean seed type in a laboratory experiment conducted between 17th to 30th June 2019 at the University of Eldoret

3.3.2.4 Imbibition

Water imbibing capacity of the seeds significantly ($p \leq 0.05$) differed among seed types. As temperature increased, the water imbibing capacity also increased but the alternative temperature 30/20°C resulted in completely interruption of the water uptake for both media. In all two cases, the seeds revealed the lowest water imbibing capacity at ambient condition. The maximum imbibition was reached at 25°C (black, dark brown black seed types) and 30°C (white, brown white seed types) using filter paper as media (Figure 3.20). In contrast, dark brown black seed type reached maximum imbibition capacity at 30°C using sand as media (Figure 3.21).

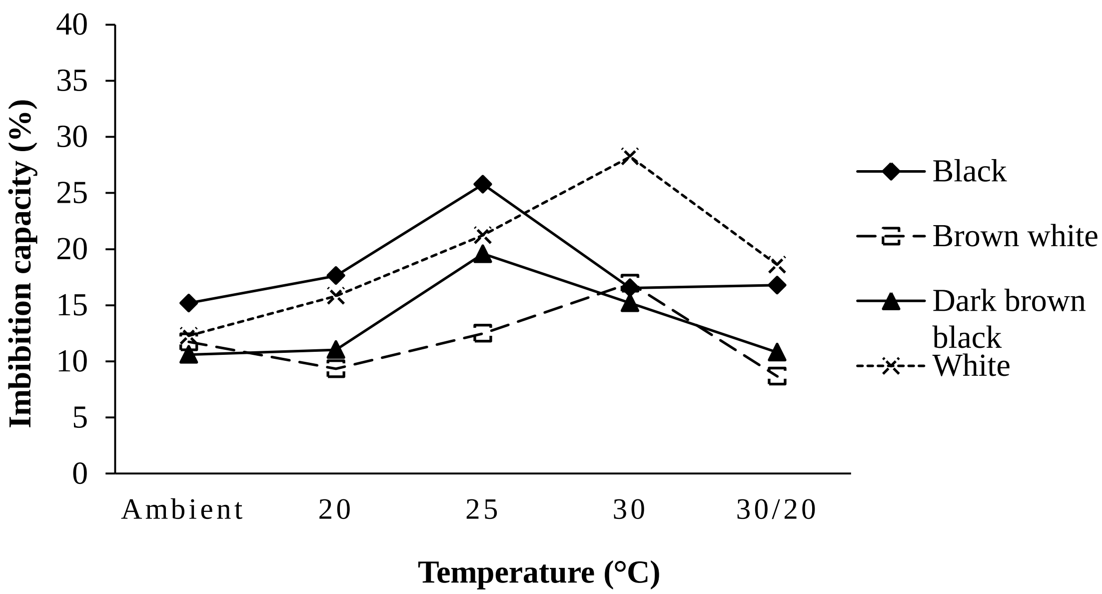


Figure 3.20: Imbibition capacity of velvet bean seed type using filter paper as media in a laboratory experiment conducted between 17th to 30th June 2019 at the University of Eldoret

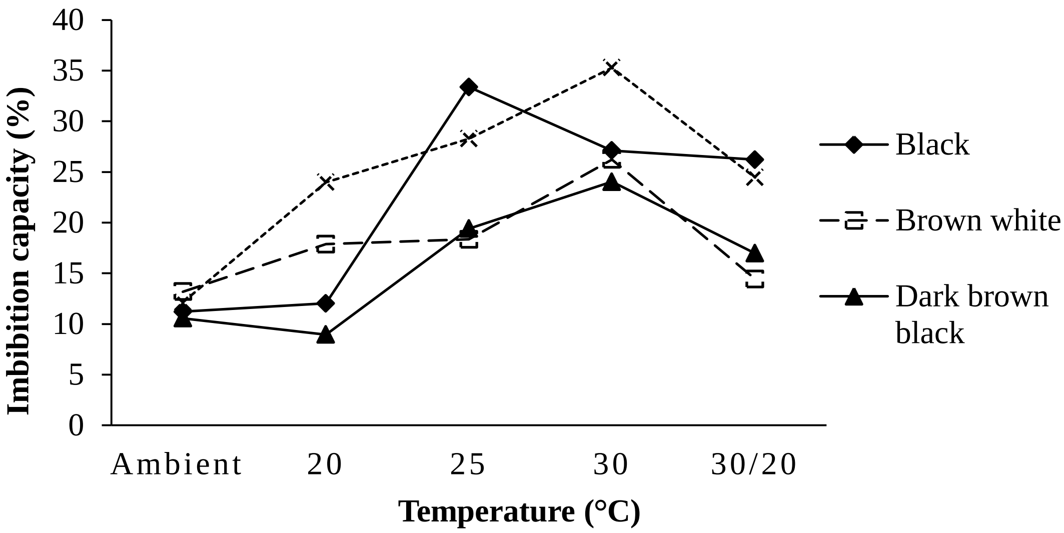


Figure 3.21: Imbibition capacity of velvet bean seed type using sand as media in a laboratory experiment conducted between 17th to 30th June 2019 at the University of Eldoret

3.4 Discussion

3.4.2 Agronomic practices, seed production, and management practices of velvet bean in Bungoma County

Most of the farmers had primary level of education which can affect the use of new technologies on leguminous production. This is consistent to the findings of Icheria (2012), who identified that one of the most significant determinants of increased household food production and acceptance of new habits is the number of years spent in formal education. Because of their low educational levels (most attained primary and secondary school education), there was a limitation in the flow of knowledge and adoption of new food production behaviors within this group.

Farmers in Bumula subcounty were more actively involved in velvet bean production than the other Sub-Counties because majority of the respondents were noted in this Sub-County. Majority of the respondents joined a farmers group for seed production, commodity marketing and social support. This is consistent with findings that farmers primarily organize themselves into groups to learn successful farming methods, procure agricultural inputs collectively, and sell collectively their agricultural products (Adong *et al*., 2012). Due to numerous challenges such as inadequate credit, high interest rates, lack of storage facilities, lack of ready market, high marketing and transaction costs and lack of technical skills, small holder farmers are highly vulnerable to poverty (Abaru *et al*., 2006; Shiferaw *et al*., 2006; Haque *et al*., 2011; Curtis, 2013; Sikwela and Mushunje, 2013). Collective action in the form of a farmer group can provide solutions to these challenges. Furthermore, findings by Tallam (2015) indicated that the principal components that influence effectiveness of collective action in Bungoma County were the level of trust, leadership skills, unity and effective participation.

Majority of the farmers (80%) had less than 0.5 acre under velvet bean cultivation. However, many farmers were about to start growing velvet bean seed. In fact velvet bean growers were training other farmers who wanted to start cultivating the crop. Few farmers had been planting velvet bean more than three years. Velvet bean cultivation has been increasing in Bungoma County. In Western Kenya, a total of 325 farmer groups (7500 individual farmers) are actively involved in velvet bean production (Wabwoba and Mutoro, 2019).

Most farmer groups were involved in food crop farming as their main activity which can be attributed to a more favorable climate for crop farming. Few farmers intercropped velvet bean with maize, groundnut or banana. Some practiced crop rotation with common bean. It has been reported that velvet bean can increase the soil fertility. The cultivation of legumes as green manure or their use as associated or rotation crops, was a technique for soil nitrogen replenishment, as well as providing organic matter needed to keep the soil's chemical and physical conditions which are favorable for long-term crop development (Mulvaney *et al*., 2009). A study by Khan et al (2009) indicated that intercropping has the benefit of lowering the risk of harvest losses by growing many crops at the same time. When beans and maize are grown together, the food supply is spread out over a longer period of time since the bean harvest occurs before the maize harvest. In the same way, if the grains are not consumed, the farmers would have a more consistent cash flow.

The majority of respondents weeded thrice or twice to keep the crop clear of weeds by weeding as soon as they appeared. Land productivity decreases due to weed infestations, pests, and diseases (Mulvaney *et al*., 2009; Yates *et al*., 2011). Velvet bean, on the other hand, is one of the best crops for reclaiming weed-infested soil (Hellin, 2006). Farmers controlled weed populations in the field in order to reduce pathogens and their vector populations.

Less than 30% of the respondents used healthy looking plants, pods and high yielding plant in the field as seed selection criteria. The most seed quality assurance activities carried out in the field by farmers were weeding, removing diseased or off types and planting separately velvet bean from others crop. In Bungoma County, few velvet bean farmers picked seeds from healthy plants and avoided any mechanical damage on other plant parts harvested or the pod. This is consistent to the finding of Salamanca (2015) who indicated any damage, such as small wounds or bruises, may cause microorganisms to reach the seed, compromising its quality while in transit or long term storage. Therefore, farmers need to produce high quality seed to increase production of velvet bean.

3.4.3 Utilization of velvet bean crop in Bungoma County

In Bungoma County, farmers mentioned all parts of velvet bean plant were medicinal. This is consistent to the findings of Lampariello et al (2012) who indicated that all parts of velvet bean possess valuable medicinal properties. Velvet bean has been investigated for its antidiabetic, aphrodisiac, antineoplastic, antiepileptic, and antimicrobial activities (Sathiyanarayanan *et al*., 2007).

Farmers in this study also indicated that seed can be used as food, beverage, soil nutrient, livestock feed, cover crop and oil extraction for soap making. This is consistent with Wabwoba and Mutoro (2019) who indicated that velvet beans can be used for soil rehabilitation and food. Velvet bean is primarily used as green manure and a cover crop because it establishes easily and does not necessitate extensive soil preparation (Cook *et al*., 2005).

Few farmers indicated that they used velvet bean leaf to inhibit *Striga* sp. weed and consumed the leaf. Maize grown in monocropping has also been shown to be more susceptible to *Striga* than maize intercropped with velvet bean (Khan *et al*., 2006). *Striga* is less prevalent in areas with high soil fertility because the crops have higher *Striga* tolerance. Intercropping legumes improves soil productivity and offers shade, which disadvantages *Striga* (Khan *et al*., 2006). It foliage inhibits weed germination, protects the soil from erosion and improves soil moisture retention (Buckles *et al*., 1998). Vine and foliage have been shown to be used as ruminant grass, hay, or silage, while pods and seeds may be ground into a meal and given to both ruminants and monogastrics as food (Eilittä *et al*., 2003; Chikagwa-Malunga *et al*., 2009).

Small percentage of the respondents indicated that velvet bean flower can be used as medicinal and beverage. Few farmers said the pod can be decomposed for fertilizer, used as feeding, as firewood and as medicinal. Seeds and pods can be ground into a high protein meal and fed to all types of livestock, though monogastrics should be fed limited quantities (Chikagwa-Malunga *et al*., 2009).

Farmers in the present study indicated that velvet bean root can be used to improve soil structure (break hard pan, prevent soil erosion). Others said the roots can be used to prevent diseases, as medicinal and to control animal attack. Velvet bean is well known for its resistance to most pests and diseases with the key substance in its allelopathy being L-DOPA, which is released from its root (Yokotani *et al*., 2004) and are not subject to attack by small mammals or insects suggesting a feeding repellent property (Soares *et al*., 2014).

3.4.4 Morphological variability of farmers velvet bean seed

The present study indicated that the variation in velvet bean seed morphology is manifested mainly in seed size, thickness, colour, and coat ornamentation. White and Brown white seed type had significantly longer and wider seed than other seed type. The difference (seed length and width) was no significant between black and dark brown black seed type also between white and brown white. This observation can be explained by the interplay of both genetic and varying environmental conditions (Leidinger *et al*., 2021). Correlation of seed traits showed that seed length correlated with seed width ($r=0,996$, $p\leq0.05$) and seed thickness ($r=0,660$, $p\leq0,05$). Seed length and width positively correlated with germination percentage. This is in line with studies that have indicated that big seed size goes hand in hand with seed viability and vigour (Massimi, 2018). The role of genetic and environment in seed morphology is also supported by the correlation between seed trait. Seed traits are important for identification of species. This is in line with some studies which indicated that seed characters are very helpful for identification of a large number of species or genera (Juan *et al*., 2000; Moro *et al*., 2001; Seggara and Mateu, 2001).

The colour of velvet bean seed is very variable. The seeds color varies from black to dark greyish yellowish brown to yellowish grey. Four colours of seeds were recognized: black seed type (black colour), dark brown black seed type (black colour) brown white seed type (dark greyish yellowish brown) and white seed type (yellowish grey). These four seed types corresponded respectively to four varieties of velvet bean (*Mucuna pruriens* utilis noir, rajada, yardghana, and *Mucuna pruriens* IRZ) described in Madagascar, regarding the color of integument (Kantiono, 2012). Seven different accessions of velvet bean (*Mucuna pruriens* var utilis (L.) DC) were indicated by Gurumoorthi et al (2003), namely thachenmalai (white– coloured seed coat), thachenmalai (black– coloured seed coat), mundanthurai (white – coloured seed coat), kailasanadu (white – coloured seed coat), valanad (black – coloured seed coat), mundanthurai (black –coloured seed coat), mylaru (white – coloured seed coat), have also been gathered from different agroecological regions of Western Ghats, South India which were evaluated their agrobotanical traits.

Dark Greyish Yellowish Brown and Yellowish Grey seed coat spot colour were recognized respectively in Dark Brown Black and Brown White seed type. Pinkish Grey seed coat pattern colour were recognized in White seed type. All seed types had a yellowish white hillium colour but the group differed from Yellow White to White. Pattern and hilium colour are also used for species identification. One study indicated that seed coat pattern or the micro-ornamentation on the surface of the outer cell wall can be considered of taxonomic value in the identification of the species (Zoric *et al*., 2010; Aniszewski *et al*., 2001). Some studies have also indicated that the structure and morphology of the seed coat can be used as a useful taxonomic feature (Algan and Büyükkartal, 2000; Seggara and Mateu, 2001; Bobrov *et al*., 2004; Hassan *et al*., 2005).

3.4.5 Electrical conductivity (EC) of farmers velvet bean seed

There was no significant difference in the average EC among seed type. However, white seed type was more vigorous than Dark brown black, followed by black and brown white seed type. The lower the value of EC, the greater is the seed vigor. The lower the membrane integrity, the greater the electrolyte leakage in the steep water, thus the greater the conductivity measurement (ISTA 2011). The result is in agreement with Mavi (2010) who found that in watermelon, the electrical conductivity decreased from light colored to dark colored seeds. There are factors which influence the EC values such as initial water content, temperature and time of seed soaking, the number of seeds per sample, seed size and genotype (Gilvaneide *et al*.,2016). Conductivity test can be used to predict the field emergence and standard germination. This is consistent with a study which indicated that the EC test has been proved as indicator of seed vigor in wide range of crop species and has been successfully related to field emergence and stand establishment (Khodratien *et al*., 2017).

3.4.6 Germination capacity and speed of germination index of farmers velvet bean seed

White seed type had significantly ($p \leq 0.05$) higher final germination percentage (76.67%) and speed of germination index (5.31) than the others seed types, followed by brown white. Seed colour play a role in seed dormancy and germination. The result observed in black and dark brown black affirms with Chachalis and Smith (2000) who indicated that light coloured seeds absorb water rapidly than dark soybean seeds and consequently have greater rate of imbibition and germination. This present study is in agreement with Ochuodho and Modi (2010) who indicated that in coloured seed of some legumes, the lower germination was attributed to the tight adherence of the seed coat to the embryo and the presence of phenolic compounds. Seed coat structure can be affected by different seed colours resulted from various level of pigment accumulation. This can be explained by the fact that different seed coat colours exert differential germination restrictive actions by providing different levels of impermeability to water and/or oxygen or the mechanical resistance to radicle protrusion (Debeaujon *et al*., 2000). In our study, the lower germination of black seed type could be attributed to the greater amount of pigmentations that solidify the seed coat and increase its impermeability to water and/or oxygen (Marcos, 2005 and Sousa *et al*., 2017). Germination, longevity and dormancy are controlled by seed coats that are resistant to environment factors (Debeaujon 2000). Similarly, it was reported that various factors, such as water uptake by the seed (De Souza and Marcos-Filho 2001), seed quality due to color pigments in seed coat, germination (Nerson 2002) and seed dormancy (Baskin *et al*., 2000) are affected by seed coat. Therefore, it is important to understand dormancy because it is correlated with water content, chemical properties of endosperm or embryo, germination traits, seed shape, seedling size and seed production (Westoby *et al*., 2002; Forbis *et al*., 2002; Hamilton *et al*., 2013).

3.4.7 Imbibition capacity of farmer velvet bean seed

Water imbibing capacity of the seeds significantly ($p \leq 0.05$) differed from seed type. As temperature increased, the water imbibing capacity also increased. The same observation was indicated for three sorghum species which are *Sorghum bicolor*, *Sorghum sudanense*, *Sorghum vulgare* (Golubinova and Vasilevska-Ivanova, 2008). However, the alternative temperature 30/20°C resulted in completely interruption of the water uptake for both media. In all two cases, the seeds revealed the lowest water imbibing capacity at ambient condition. The maximum imbibition was reached at 20°C (black, dark brown black seed types) and 30°C (white, brown white seed types) using filter paper as media. In contrast, dark brown black seed type reached maximum imbibition capacity at 30°C using sand as media. These results mean that the water imbibing capacity depends on conditioning temperature, media and seed type that is specific characteristics of the seeds. The seed coat colour is associated with water absorption. This is in line with Ertekin and Kirdar (2010) who indicated that in several legume species, the reduction of imbibition rates is correlated with seed coat pigmentation. This was demonstrated by honey locust seeds, whose swelling percentage rose increased more rapidly in yellow coated seeds (100% in 48 h) than in light and dark brown seeds. Similar result was found using soybean seeds for seeds with black seed coats (Chachalis and Smith, 2000). Also, the hilium can prevent water uptake by acting as a hygroscopic valve (Hanna, 2006). It is known that imbibition capacity is important for germination. This is consistent with the Ashraf and Foolad (2005) who indicated that during the imbibition process seeds are hydrated to a moisture level sufficient to initiate early events of germination but not sufficient to permit radicle protrusion. Germination starts with imbibition, a process of water uptake by the seed, caused by different water concentration between seed and environment (Osmosis).

3.5 Conclusion

Velvet bean is an important emerging crop in Bungoma County. Its benefits as food, feed medicine and soil enhancer are well known among the sampled farmers; Measures to obtain high seed quality were not used by a majority of the farmers. There was a wide variety of seed types grown by the farmers. These seed types differed morphologically each other in parameters like seed colour, seed size, germination percentage and vigour. Dormancy could have been a factor that limited the germination of dark coloured seeds types. To increase production of velvet bean seed selection criteria need to be adopted by farmers and the barriers to germination in dark colored seed types need to be addressed. Farmers engaged in velvet bean production, can share their knowledge and expertise to others farmers in order to increase the number of velvet bean growers or velvet bean crop popularity in Western Kenya. Velvet bean production can reduce fertilizer use in small scale farmers growing maize.

CHAPTER FOUR

EFFECT OF PHOSPHORUS FERTILIZATION AND SEED HARVESTING STAGES ON SEED QUALITY OF VELVET BEAN (*Mucuna pruriens* L. DC)

Abstract

Most of the agricultural soils in Africa have phosphorus (P) deficiency which causes yield reduction in leguminous crops. Phosphorus also affects seed quality of many crops. The effect of P on seed quality velvet bean is unknown. The stage at which seeds are harvested affects seed quality. This study was therefore set out to investigate the effect of P fertilizer rates and seed harvesting stages on seed quality of velvet bean genotypes. Field experiments using RCBD with 3 replications were set up at Mabanga Agricultural and Training Center (ATC) and University of Eldoret (UoE). The treatments were 4 Phosphorus levels (P0=0Kg/P/ha; P1=15Kg/P/ha; P2=30Kg/P/ha; P3=45Kg/P/ha (applied during at time of planting) x 4 velvet bean seed types (black, dark brown black, brown white, white). Basal nitrogen (30Kg/N/ha) was applied on all the plots during planting time. Seeds were harvested at 14, 28, 42, 56 and 70 DAF (Days after flowering). Germination tests were conducted using sand substratum. The germination tests were subjected to alternating temperatures of 30/20^{0}C in the light/dark (8h/16h a day) for 14 days. Number of seeds that germinated daily was monitored. Data obtained was analyzed using ANOVA and the mean separations was done using Fischer's least significant difference (LSD) methods at 5% probability. GENSTAT software release 14.1 was used to accomplish this. Velvet bean Pod colour changed from yellow green at 14 DAF to black at 70 DAF. Physiological maturity was reached at 14 DAF or 28 DAF depending on seed type and locality. Seeds harvested at Mabanga Agricultural and training center (ATC) were more dormant than those harvested at the University of Eldoret (UoE). Phosphorus fertilizer rate affected FGP (final germination percentage) and SGI (speed of germination index) ($p<.001$). At Mabanga ATC P0, P1 and P3 exhibited high values of FGP and SGI while at UoE P0, P1 and P2 gave high values depending on seed types. From this result it is recommenced that for high viability and vigour, harvesting should be done at harvest maturity.

Keywords: Phosphorus, Germination, Seed quality, Seed type, Velvet bean

4.1 Introduction

Velvet bean can be used as human food, livestock feed and it has medicinal value. It also improves soil fertility through symbiotic association with N fixing bacteria (a higher nitrogen fixing ability than other legumes crops) (FAO, 2011). It can contribute to sustainable agriculture and crop production improvement (Saria *et al*., 2018)**.** Despite it multiple uses, farmers in Bungoma County are facing problems due to its poor germination and crop establishment in the field.

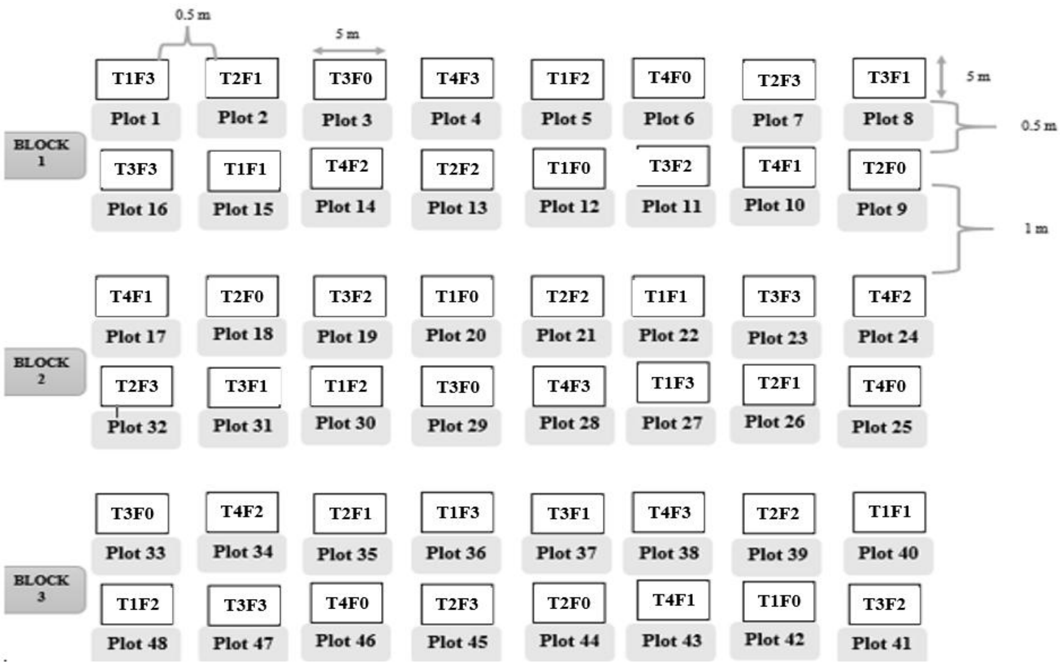
Phosphorus fertilization is an important nutrient for legume cultivation (Klimek-Kopyra *et al*., 2019). It has been show that faster germination, large first leaves and longer roots occur in seeds with high phosphorus (P) content (Zhu and Smith, 2001). Faster root growth initiation and seedling establishment is promoted by a higher seed phosphorus content (White and Veneklaas, 2012 and Nadeem *et al*., 2012). There is limited information on the effect of P nutrition on quality of velvet bean seed.

Seed harvesting stage affects the quality of seed. It is known that early and late harvesting stage result in poor seed quality, therefore it is important to harvest the seeds at optimum maturity stage (Greven *et al*., 2004).

The purpose of this research was to evaluate the influence of P fertilization and seed harvesting stages on quality of velvet bean seed in order to improve farmers' production of velvet bean.

4.2 Materials and Methods

Four types of velvet bean seeds (Black, Dark brown black, Brown white, White) were sourced from farmers during a survey in Bungoma County. They were used for field experiments at Mabanga (ATC) and at the University of Eldoret (UoE). Soil from both sites were analyzed for available phosphorus, and measurement of pH was done in both sites before planting. Land preparation was then done. The experiment design was randomized complete block design (RCBD) with 3 replications four P rates and the control and 4 bean types was established (Figure 4.1).



P0= 0Kg/P/ha; P1= 15Kg/P/ha; P2=30Kg/P/ha; P3 =45Kg/P/ha
Plot Size:47.5 x 37.5 m; 5 rows/plant, 5 plants/row, 25 plants/plot
Spacing: 1 x 1 m, 4 Types (T)
T= type of seed; P= Phosphorus level

Figure 4.1: Field experimental layouts in University of Eldoret and Mabanga ATC

Four level of phosphorus P0= 0Kg/P/ha; P1=1 5Kg/P/ha; P2= 30Kg/P/ha; P3= 45Kg/P/ha. Basal nitrogen of 30kg was also applied on the plots at planting. In order to maintain the crop weed free, weeding was done as soon as weeds appear (thrice). At the time of anthesis, 9 plants per plot were trellised on wooden poles and 30 individual flowers per plant were tagged). Pods were harvested at two weeks intervals from 14 until 70 DAF (Days after flowering) at both sites. The temperature, relative humidity and rainfall amounts were monitored at both sites throughout the duration of the field experiments.

Germination tests were done for the five harvesting stages and the phosphorus levels for each seed type. Germination tests were set in Completely Randomized Design (CRD) with 3 replicates. Sand was taken from the University of Eldoret farm, washed and dried at the greenhouse. It was then sterilized in an oven at (150°C) and put into plastic containers. Fifty seeds were sowed into the plastic containers containing wet sand. Plastic containers were covered with lid and placed into their growth chambers calibrated at alternating temperatures of 30/20 ^{0}C and alternating the light/dark (8h/16h a day) as recommended by ISTA, 2011. A container filled with water was placed in the growth chamber in order to maintain humid conditions in the growth chambers. Seeds were incubated for 14 days and germination count was done daily (ISTA (2011). Seeds were considered germinated if their radicle had protruded at least 2 mm. Seed germination percentage was calculated according to ISTA (2011) as follows:

$$\% \mathbf{FGP} = \frac{\mathbf{NT\ x\ 100}}{\mathbf{N}}$$

Where:

% FGP = Final Germination Percentage

NT = Total Number of Seeds Germinated

N = Number of Seeds Sown.

Percentage of normal seedlings (seedlings that will develop into healthy plants) and percentage of abnormal seedlings, dead seed, and fresh seed were determined. Formulas used are as follows:

$$\% \mathbf{Normal\ seedlings} = \frac{\mathbf{Number\ of\ normal\ seedling}\ x\ \mathbf{100}}{\mathbf{Total\ number\ of\ seed\ used}}$$

$$\% \mathbf{Abnormal\ seedlings} = \frac{\mathbf{Number\ of\ abnormal\ seedling}\ x\ \mathbf{100}}{\mathbf{Total\ number\ of\ seed\ used}}$$

$$\% \textbf{ Dead seed } = \frac{\textbf{Number of dead seed } x \textbf{ 100}}{\textbf{Total number of seed used}}$$

$$\% \textbf{ Fresh seed } = \frac{\textbf{Number of fresh seed } x \textbf{ 100}}{\textbf{Total number of seed used}}$$

The speed of germination index was calculated as follows:

$$\mathbf{SGI} = \sum \frac{\mathbf{n}}{\boldsymbol{d}}$$

Where:

n = Number of Seeds Germinating Each Day ‘d’

d = Number of Day

Data were subjected to analysis of variance (ANOVA) using GENSTAT software release 14.1 and the mean separations was done using least significant difference (LSD) at 5% probability.

4.4 Results

4.4.1 Soil analysis results

Available phosphorus, percentage of nitrogen and pH results are shown in Table 4.1. Available phosphorus was higher in UoE than in Mabanga ATC. Percent Nitrogen did not vary significantly in the two sites. The soil pH was acid for both sites

Table 4.1: Available phosphorus,% Nitrogen and pH level of the soil at Mabanga Agricultural Training Center (ATC) and at the University of Eldoret (UoE) in June 2019

Locality	pH	Available phosphorus (%)	Percentage of nitrogen (%N)
Mabanga ATC	5.25	1.99	0.08
UoE	5.62	7.72	0.10

4.4.2 Temperature and relative humidity of experimental sites

The air temperature, relative humidity and rainfall data observed during the experiment at Mabanga (ATC)and at the University of Eldoret (UoE) are shown in **Error! Reference source not found.**

Table 4.2:Average temperatures (°C), relative humidity (RH)and rainfall recorded at Mabanga Agricultural Training Center (ATC) and at the University of Eldoret (UoE) between October 2019 and September 2020

Location	Minimum Temperature (°C)	Maximum Temperature (°C)	Minimum Relative Humidity (%RH)	Maximum Relative Humidity (%RH)	Rainfall (mm)
Mabanga ATC	15.3 ± 1.2	36.9 ± 3.4	33.0 ± 15.4	98.8 ± 3.8	54.4 ± 8.9
UoE	11.5 ± 1.6	31.4 ± 2.6	7.8 ± 19.9	99.6 ± 1.7	128.9 ± 81.9

4.4.3 Pod maturity Stages

Pod maturity stages were determined using the Royal Horticultural Society (RHS) colour chart (RHS, 2015). Velvet bean Pod colour changes from yellow green at 14 DAF to black at 70 DAF. The pod colours ranged from green to brown to black (Plate 4.1)

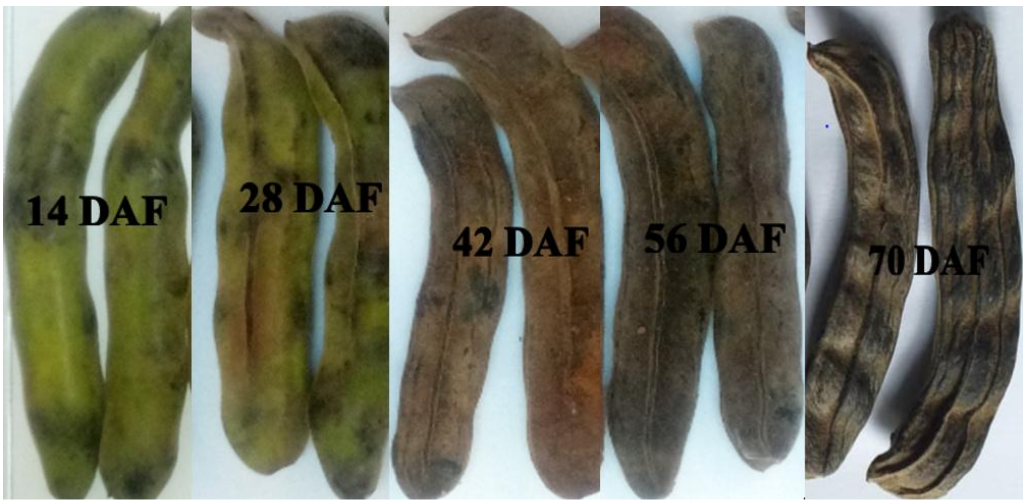


Plate 4.1: Velvet bean Pod maturity stages

4.4.4 Effect of harvesting stage and phosphorus levels on seed quality of velvet bean seed type

There was a significant 4 way interaction between site, phosphorus level, seed type and harvesting stage with respect to final germination percentage (FGP), speed of germination index (SGI), percentage of dead seed, percentage of fresh seed (P<.001)and percentage of normal seedlings ($p \leq 0.05$) (cf. Appendix).

At Mabanga ATC site, the black and white seed types had the highest FGP (50.67% and 78.00%) and SGI (4.79 and 6.83) for the seeds harvested at 14 DAF, at P1 and P3 respectively. The highest FGP (80%) and SGI (6.78) for dark brown black seed type was observed in seeds harvested at 28 DAF at P0. The brown white seed type, at 14 DAF and P2 recorded the highest FGP (77.33%) but SGI was low (6.17) compared to 28 DAF at P1 where SGI was higher (6.906) but whose FGP was lower (70.67%). Across the seed types at 14 and 28 DAF, the proportion of dead seeds was higher than abnormal and fresh seed while the high proportion of fresh seed was observed at 42, 56 and 70 DAF (Figure 4.2 to 4.5).

At UOE site, the dark brown black seed type at 28 DAF recorded the highest FGP and SGI (88.67% and 7.27) at P1 than others within this seed type. At 70 DAF, black, white and brown white seed types recorded the high FGP (respectively 93.33% at P3, 90% at P0 and 96.67% at P1) but the SGI were low (respectively 3.41 at P3, 2.87 at P0 and 3.035 at P1) when compared to SGI (respectively 5.38 at P2, 5.42 at P1, 7.19at P0) at 28 DAF. Percentage of fresh, dead and abnormal seedings varied considerably across seed type, harvesting stage and P levels (Figure. 4.6 to 4.9).

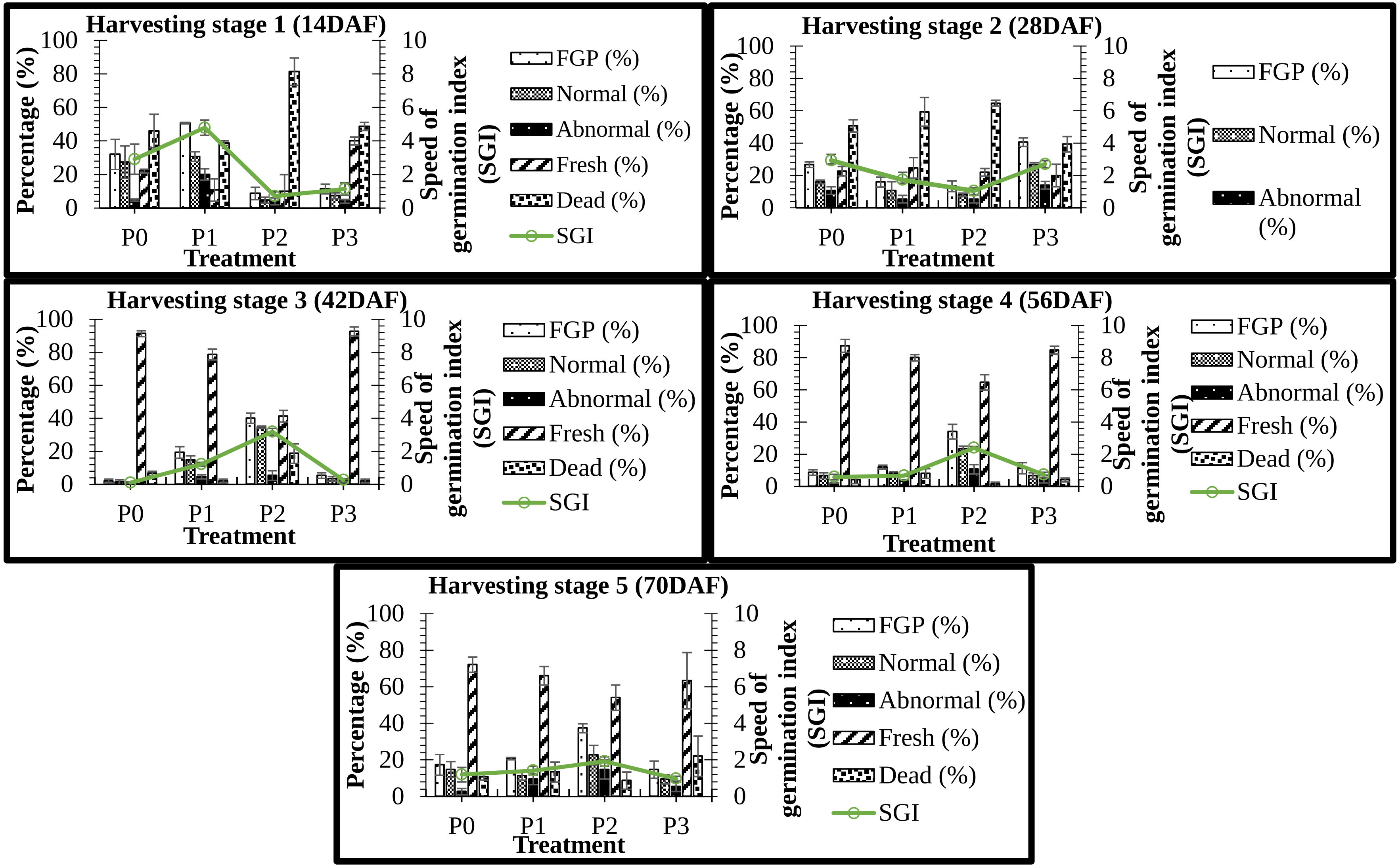


Figure 4.2: Black seed type of velvet bean collected from Mabanga ATC at five harvesting stage in a laboratory experiment conducted during the rainy season, 2019 at the University of Eldoret

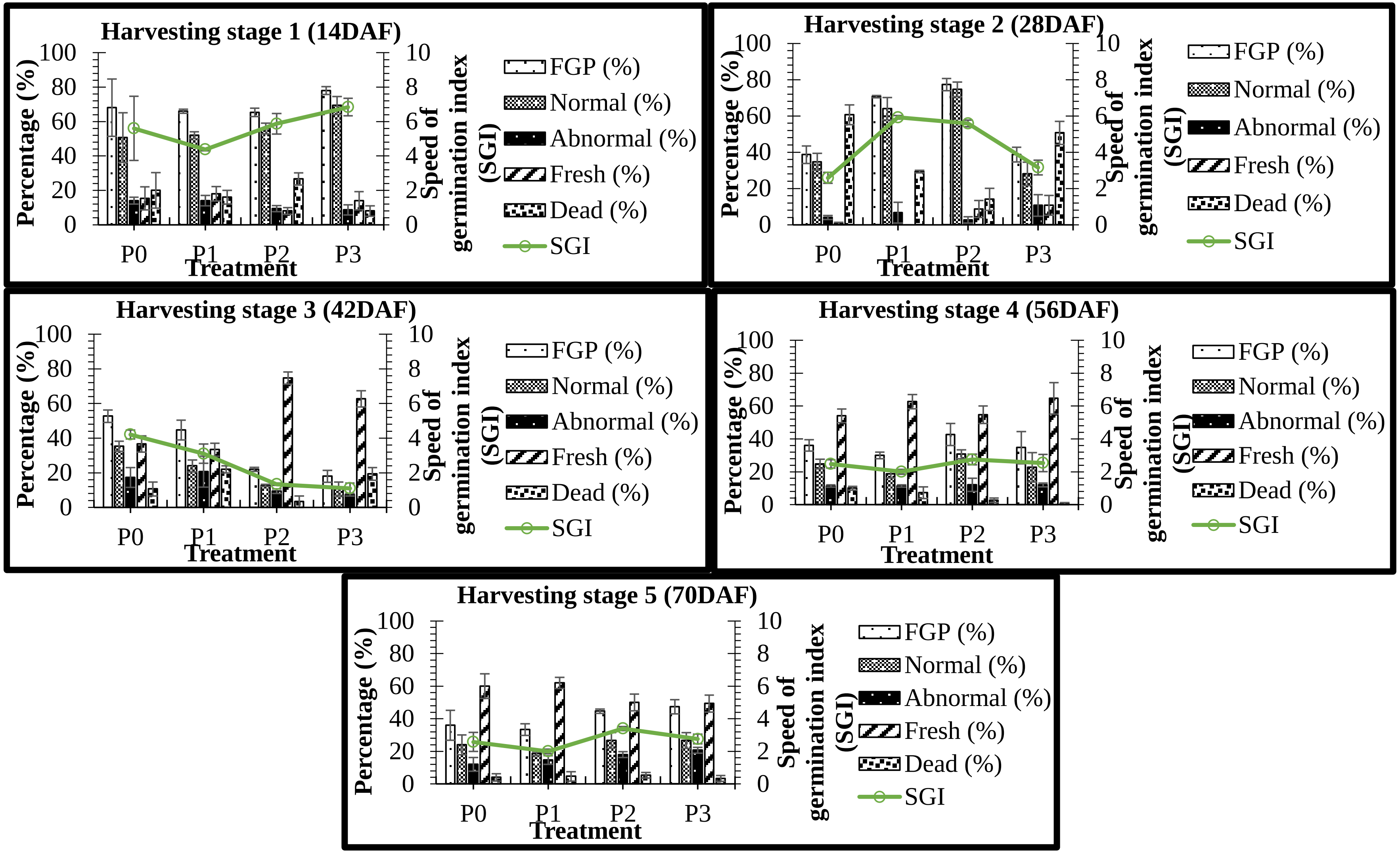


Figure 4.3: White seed type of velvet bean collected from Mabanga ATC at five harvesting stages in a laboratory experiment conducted during the rainy season, 2019 at the University of Eldoret

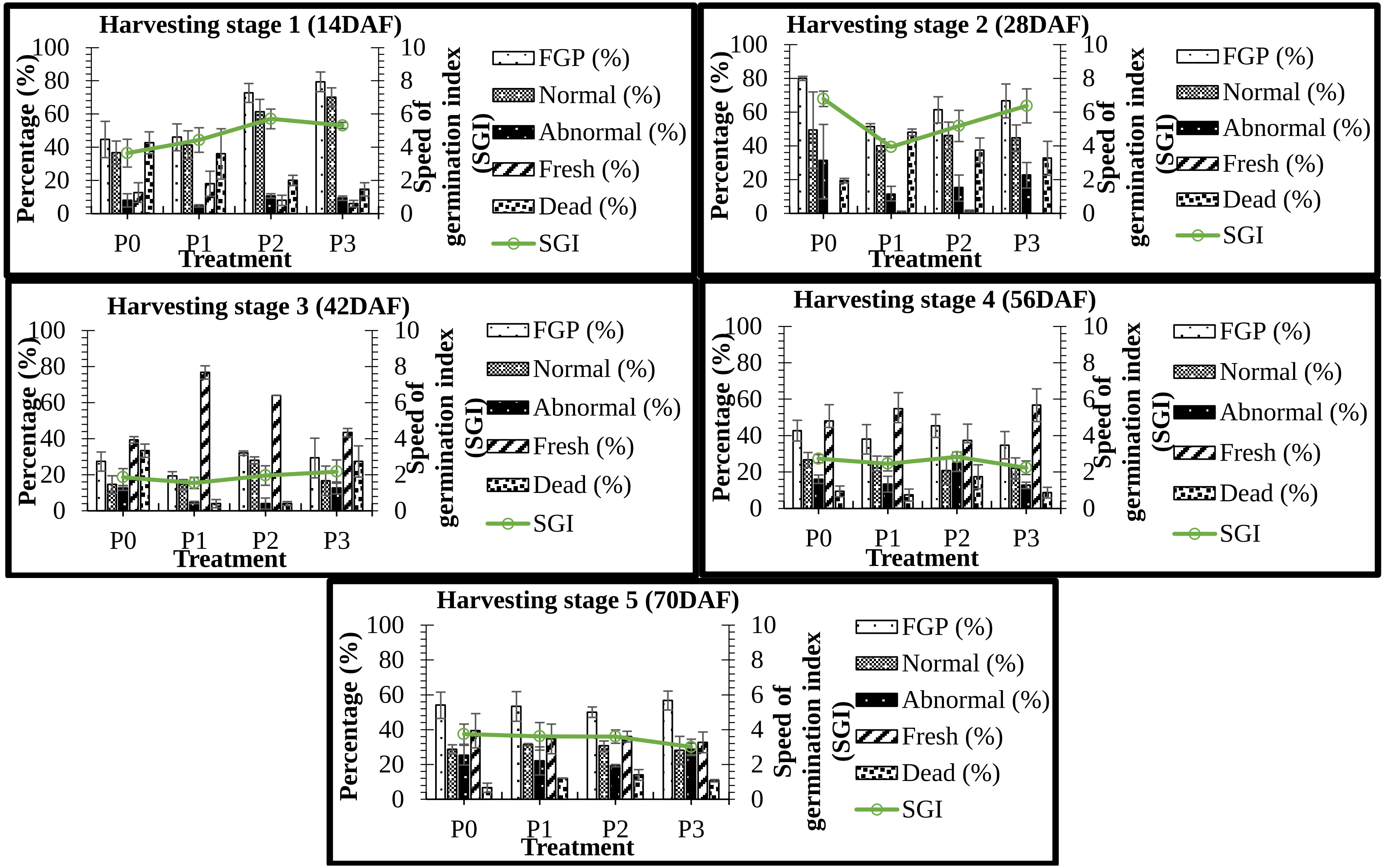


Figure 4.4: Dark brown black seed type of velvet bean collected from Mabanga ATC at five harvesting stages in a laboratory experiment conducted during the rainy season, 2019 at the University of Eldoret

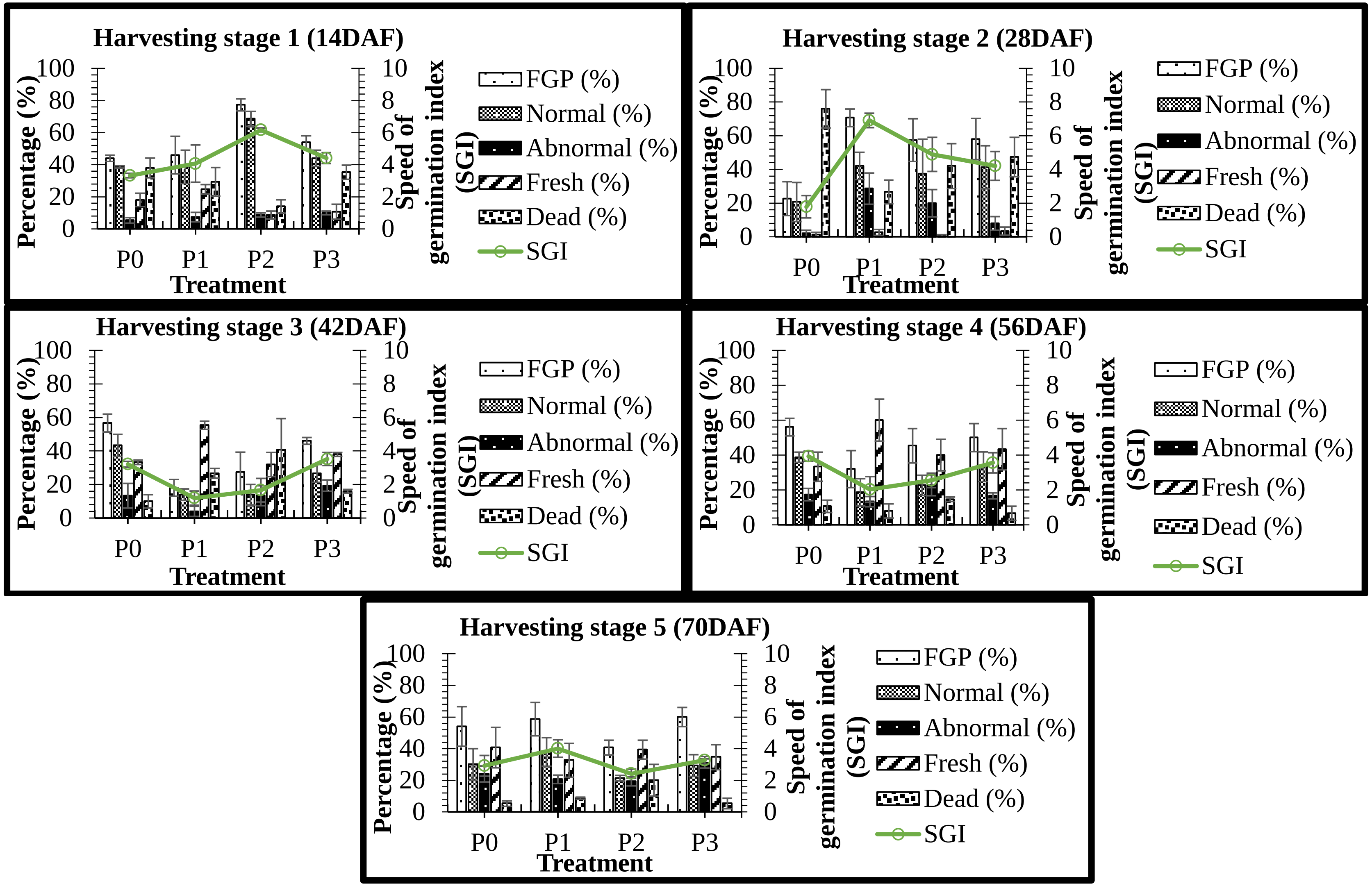


Figure 4.5: Brown white seed type of velvet bean collected from Mabanga ATC at five harvesting stage in a laboratory experiment conducted during the rainy season, 2019 at the University of Eldoret

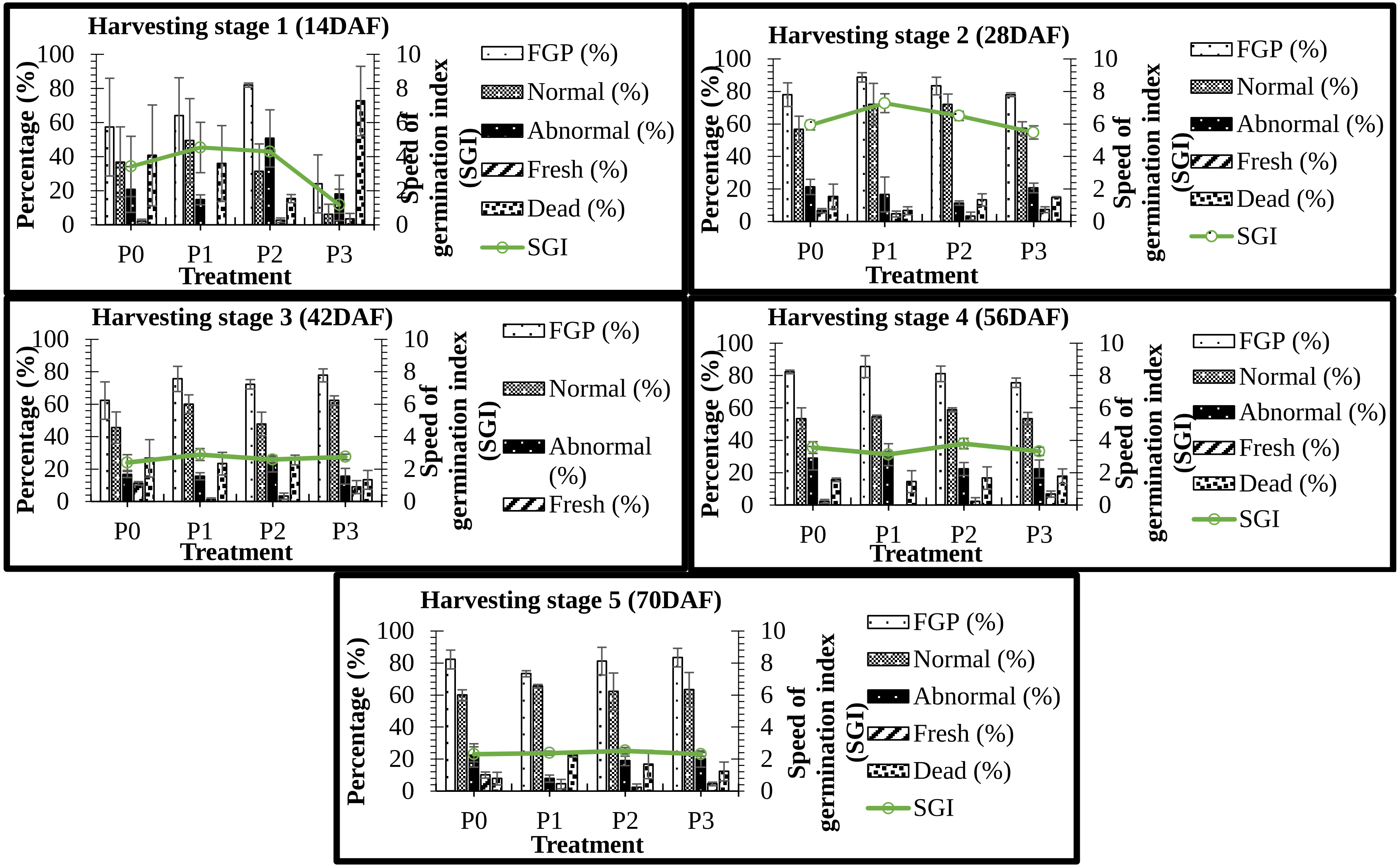


Figure 4.6: Dark brown black seed type of velvet bean collected from UoE at five harvesting stage in a laboratory experiment conducted during the rainy season, 2019 at the University of Eldoret

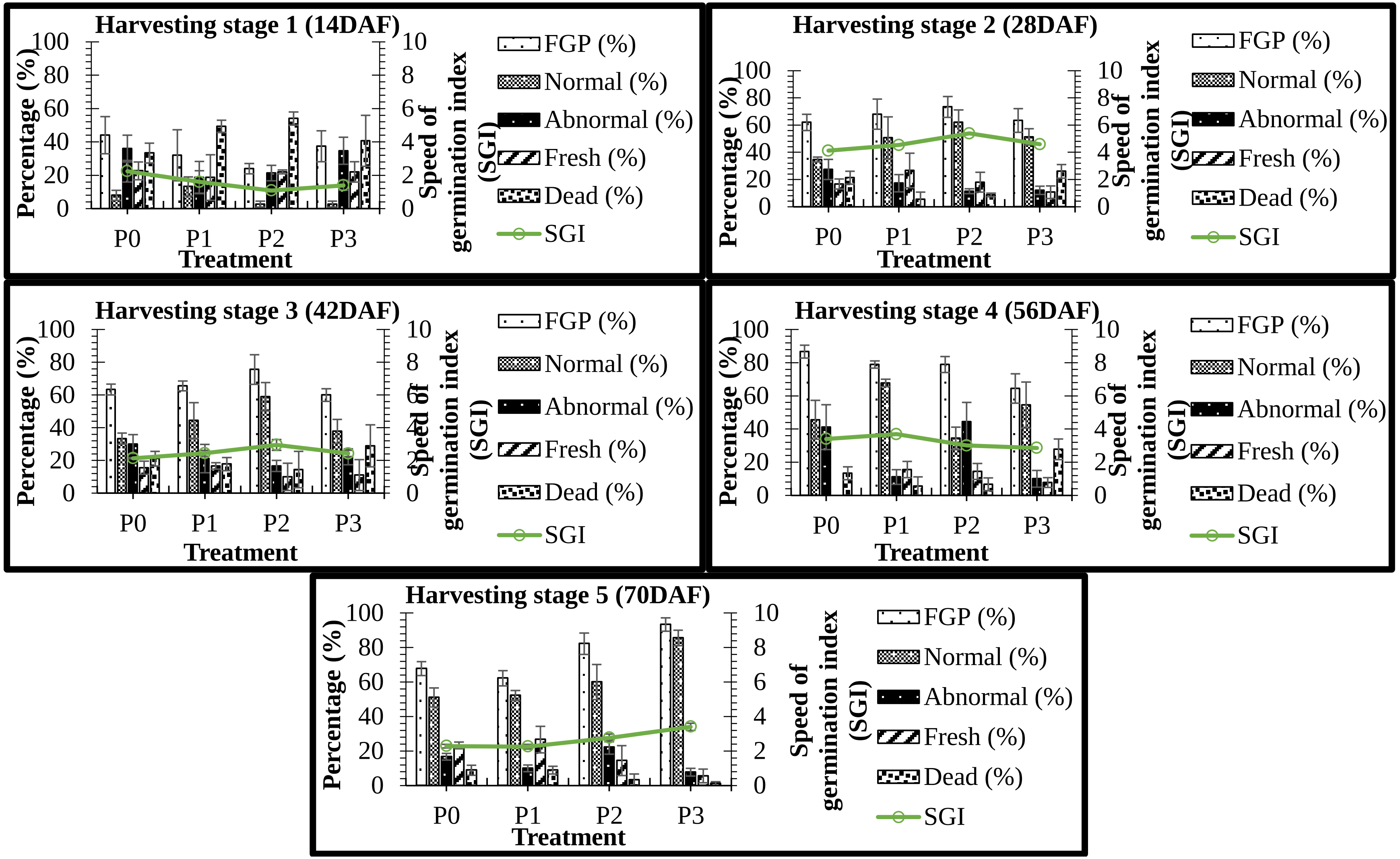


Figure 4.7: Black seed type of velvet bean collected from UoE at five harvesting stage in a laboratory experiment conducted during the rainy season, 2019 at the University of Eldoret

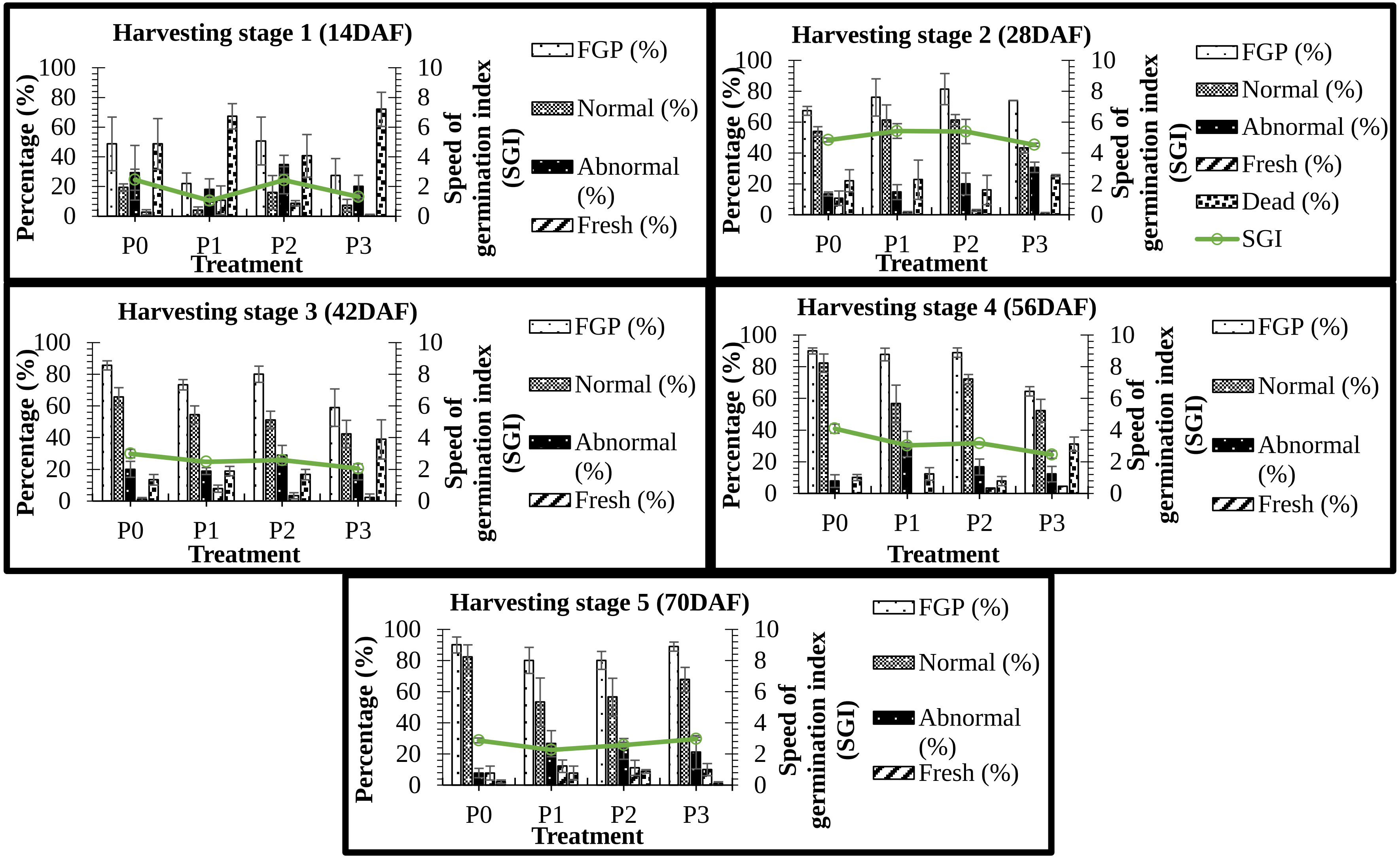


Figure 4.8: White seed type of velvet bean collected from UoE at five harvesting stages in a laboratory experiment conducted during the rainy season, 2019 at the University of Eldoret

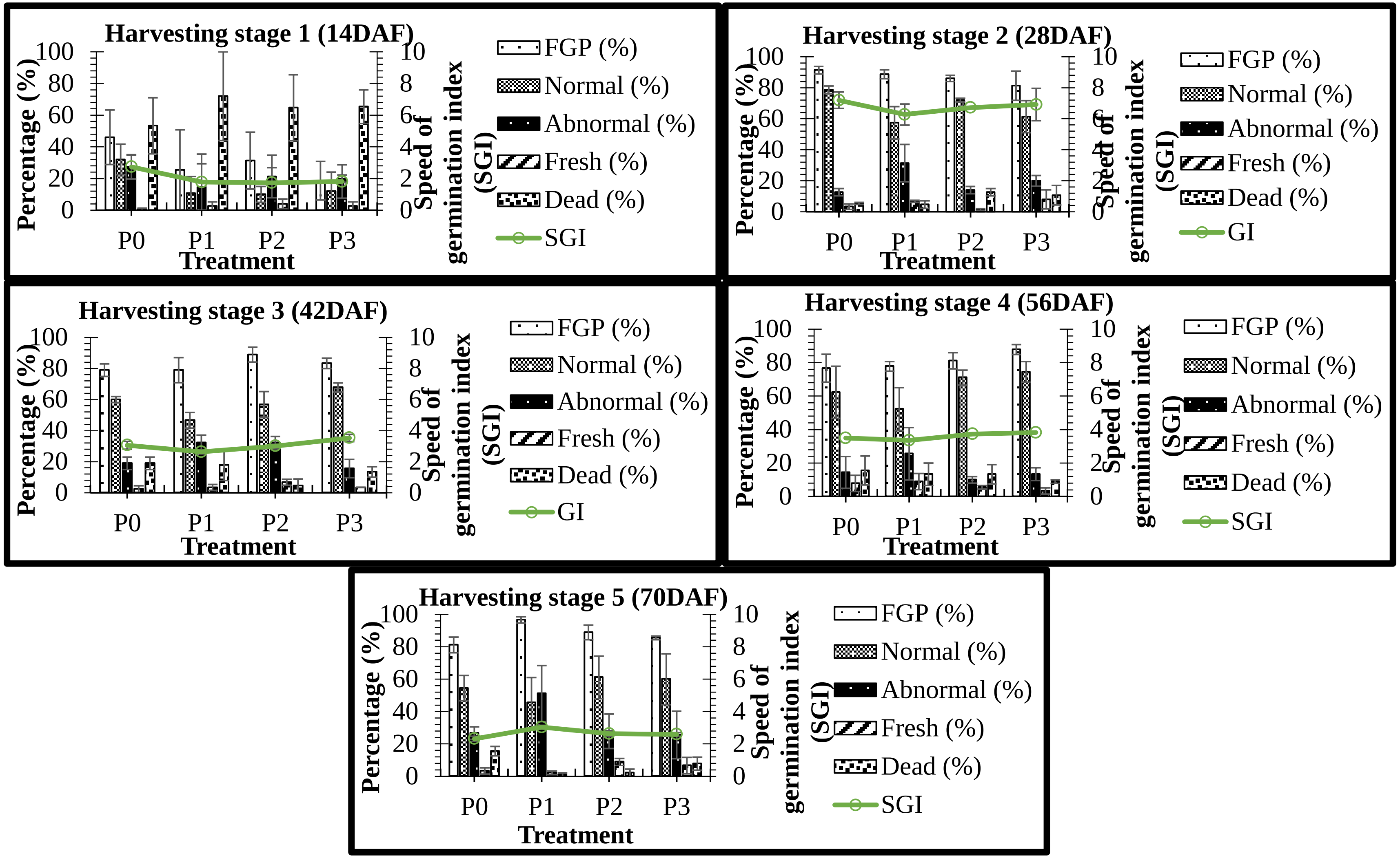


Figure 4.9: Brown white seed type of velvet bean collected from UoE at five harvesting stages in a laboratory experiment conducted during the rainy season, 2019 at the University of Eldoret

4.5 Discussion

The soil pH in Mabanga ATC (5.25) and UoE (5.62) was acid before planting. Velvet bean seed grown on various types of soil, with a pH between 4.5 and 7.7 (Pugalenthi *et al.*, 2005). The United States Department of Agriculture and Natural Resources Conservation Service (2014) indicated that temperature, relative humidity, rainfall and pH affect P mineralization rate from organic matter decomposition. Also it have been shown that organic matter decomposes quickly in warm humid climates compared to cool dry climates (Rishi and Debolina, 2019). Availability of phosphorus to plant use is limited by values of soil pH less than 5.5 and 7.5 to 8.5 (USDA and NRCS, 2014). The soils at Mabanga may have been affected by mineralization due to their pH and the amount of available P at Mabanga.

Velvet bean pod colour changes changed during the maturation process from yellow green at 14 DAF to black at 70 DAF. Pod colour is a visual indication of seed maturity. This is supported by Lopez et al (2014) who indicated that pod colour has been used as a good indicator of the harvest point however the differences in colouring can be caused by environmental factors.

Phosphorus fertilizer level significantly affected final germination percentage and speed of germination index (p<.001). The highest seed viability (FGP) and vigour (SGI) were observed at 14 or 28 DAF in Mabanga ATC (depending on seed type) and at 28 DAF in UoE. This indicated that in Mabanga ATC, physiological maturity (PM) was achieved at 14 DAF for black and white seed type and at 28 DAF for dark brown black and brown white seed type. At UoE site PM was achieved at 28 DAF for all seed types. One of the most critical factors that influence the final quality of seeds is the stage of maturity (Demir *et al.*, 2008). Physiological maturity is the stage of seed development where the seed viability and vigour is at the maximum. Physiological maturity varies with the climatic condition and seed type. However, harvesting the seed at this stage may lead to the damaging of seeds during harvesting drying and threshing which affects their quality (Zubaida *et al*., 2016). Harvesting should be as close as possible to when physiological maturity is achieved but the seed should be allowed to dry further to avoid mechanical damage during harvesting. This is in line with Khan, 2010 who indicated that a crop harvested too early at high moisture content result in poor seed viability and vigour. Moisture content of legumes should be between 35 and 45% to avoid seed damage Susana and Alma 2016).

Germination capacity is the prime indicator of seed quality (Sakthivel *et al*., 2020). The proportion of dead seed was higher than abnormal and fresh seed at 14 and 28 DAF and proportion of fresh seed was higher at 42, 56 and 70 DAF in Mabanga ATC while in UoE at 28, 42, 56 and 70 DAF, FGP and percentage of normal seedling were higher than the proportion of abnormal seedling, dead and fresh seed. These results indicate that velvet bean seeds harvested in Mabanga ATC were dormant after harvesting at 42, 56 and 70 DAF compared to seed harvested at UoE. This is in line with Melavanki and Kumar (2020) who indicated that velvet bean seeds have been reported to be dormant immediately after harvest and poses difficult problem in germination and crop establishment when sown immediately. Velvet bean Seeds are known to have hard coats (Yogeesha and Shivananda, 2003; Ravindra *et al*., 2010) that completely prevent the imbibition of water and exchange of gases.

Results at Mabanga ATC showed that P0, P1 and P3 were given good values of FGP and SGI while P0, P1 and P2 at UoE depending on seed type. This results show different response of seed type to phosphorus application. There was variability in seed quality among seed type. The results shown that response to phosphorus levels varied with climatic and site conditions.

The process of seed maturation is generally controlled and involves an organized sequence of physiological changes from the fertilization until the complete independence from the plant (Cruz *et al*., 2019).

Phosphorus is a plant nutrient required for optimum crop production. It can enhance the quality of vegetative crop growth. It has been shown that phosphorus deficiency can slow plant growth and delay crop maturity (Ross *et al*., 2013). Phosphorus is needed for growth, sugar and starch utilization, nucleus and fat formation, cell division and photosynthesis (Khan *et al*., 2014). This explains the findings in the current study. In this study FGP varied according to site, seed type, harvesting stages and P levels. At both sites all the seed types except the dark brown black type in Mabanga ATC and dark brown black type and white seed type at UOE site, had high FGP when P was applied. This could indicate the dark brown black type had lower requirements for P or could have a physical or physiological adaptation to survive less P. For the white seed type it required P at Mbanga ATC but none at UOE site. This may be because the available P tests done before the field experiments were established Mabanga had low P value but UOE had high P.

4.6 Conclusion

There were significant interactions between locality, seed type, harvesting stage and phosphorus levels. The physiological maturity varied with the climatic condition depending on seed type and phosphorus fertilizer level. Velvet bean seeds harvested in Mabanga ATC were dormant immediately after harvesting at 42, 56 and 70 DAF compared to seed harvested at UoE. Phosphorus fertilizer level affected final germination percentage and speed of germination index significantly ($p<.001$). Interaction between seed type and phosphorus fertilisation indicate different response of seed type to phosphorus application. The optimum phosphorus application differed in the same seed type according to the environmental condition of the locality. Seed harvesting should be done at harvest maturity in order that seeds can express their full potential with high germination potential and vigour.

CHAPTER FIVE

EFFICACY OF DORMANCY BREAKING TREATMENTS ON VELVET BEAN SEEDS (*Mucuna pruriens* L. DC)

Abstract

Most of the species in the family of Fabaceae possess seed coat dormancy. Velvet bean seeds undergo dormancy immediately after harvest and poses problem during germination and field performance. Limited research has been done on appropriate dormancy breaking methods for this legume. The present research was conducted in order to know the efficacy of different dormancy breaking treatments on velvet bean seeds. Four seeds types of velvet beans sourced from a field experiment at Mabanga Agricultural and training center (ATC) and the University of Eldoret (UoE) were subjected to six different dormancy breaking treatments. These were T0: Control, T1: Cold water for 24 hours at room temperature, T2: Soaking seeds in hot water (boiled water at 90°) for 24 hours, T3: Soaking seeds in Conc. H_2SO_4 for 10 min, followed by 12 hours in cold water, T4: Soaking seeds in Conc. H_2SO_4 for 20 min, followed by 12 hours in cold water and T5: Scarification by rubbing the dorsal surface of seeds between two sand papers for about 5 minutes. Completely randomized design (CRD) with three replications of 50 seeds each was used to establish the germination tests to test the efficacy of the treatments. Treated seeds were placed into their respective plastic containers filled with sterilized sand as substratum. The plastic containers were placed into their respective growth chambers calibrated at $30/20^0$C and light/dark (8h/16h a day). Seeds were incubated for 14 days while the number of seeds that germinated was recorded daily for each treatment. Data obtained was subjected to analysis of variance (ANOVA) using GENSTAT software release 14.1 and the mean separations was done using least significant difference (LSD) at 5%. The results indicated that mechanical scarification using sand paper was the most effective treatment in eliminating the dormancy. It enhanced the seed germination percentage for white and brown white seed types harvested at Mabanga ATC and dark brown black seed type harvested at UoE. The final germination percentage of the control was higher than others treatments for dark brown black seed type. Black seed soaked in Conc. H_2SO_4 (98%) for 20 min, followed by 12 hours in cold water (T4) resulted in better germination (45.33%) than others treatments. In contrast, it was recorded that, the final germination percentage of seed collected at UoE, from treatments T1 T2 T3 T4 T5 was significantly lower (at $p<0.05$) than the control except dark brown black seed where T5 was significantly higher than control and others treatment. Mechanical scarification can be used by farmers to break dormancy.

Keywords: Dormancy, Germination, Treatment, Seed type, Velvet bean

5.1 Introduction

In order to boost livestock feed, improve food security, enhance soil conservation and fertility in different cropping systems, the use of legumes such as velvet bean has been recommended (Muoni *et al*., 2019).

Despite its potential, velvet bean seeds are known to have hard coats (Yogeesha and Shivananda, 2003; Ravindra *et al*., 2010) that completely prevent the imbibition of water and exchange of gases. Such physical seed coat dormancy occurs most frequently in species adapted to alternating dry and wet seasons (Elmghadmi and Harris, 2009). Dormancy can be defined as a period in an organism's life cycle where growth and development are temporarily ceased. Dormancy tends to be closely associated with environmental conditions. Sometimes, chemicals inhibition inside the seed result in dormancy. Seeds with seed coat dormancy can remain on/in the ground without germinating until the seed coat is broken down to allow water and oxygen to enter the seed or the inhibiting chemicals are broken down by the metabolic activities in the seed (Yildiz *et al*., 2017). The hard seed coat character in leguminous plants is thought to be due to the thick palisade cell layer.

Dormancy is advantageous as it helps in the maintenance of the seed quality, preventing post-harvest sprouting. Dormant seeds are usually observed in the species of the perennial crops. However in crop production dormancy results in poor field emergence and therefore needs to be broken in crop seeds.

Velvet bean seeds undergo dormancy immediately after harvest and can affect germination and crop establishment when sown immediately (Melavanki and Kumar, 2020). This is supported by the result from the survey where smallholder farmers in Bungoma County indicated that the major constraint to the production of velvet bean was dormancy and poor crop establishment. Farmers in this county sow large quantities of seed in order to get good plant stands, however low seed quality and high cost of seed result in small portions of land under velvet bean and low productivity of velvet bean.

Lack of knowledge on suitable methods of breaking dormancy among small scale farmers in western Kenya, is a major obstacle to successful production and utilization of velvet bean. Immersion in Cold/hot water, chemical scarification with sulfuric acid, mechanical scarification with sandpaper are methods successfully used to overcome hard seededness in crop seeds.

Therefore, this study was done in order to find the suitable methods of breaking dormancy in velvet bean seeds.

5.2 Material and Methods

5.2.1 Seed source

Velvet bean seeds were sourced from the experimental fields at Mabanga ATC and the University of Eldoret, School of Agriculture (SAGR) field. Velvet bean pods were harvested under control treatment at 70 Days after flowering (DAF) which coincide with maximum dry pods (time mentioned by farmers for harvesting velvet bean) for both sites. Pod harvesting was done from twenty randomly selected plants and bulked together to form a composite sample for each seed type. The pods were sun dried for seven days at the University of Eldoret, School of Agriculture (SAGR) greenhouse. Seeds were removed from the pods by hand. The seeds were put into paper bags labeled and dried for one week in the greenhouse ready for the dormancy breaking experiments.

5.2.2 Dormancy breaking experiments

The experiments were conducted at the Seed Physiology Laboratory of Department of Seed, Crop and Horticultural Sciences, UoE during the month of July 2020 to investigate the efficacy of dormancy breaking treatments on Velvet Bean seeds. Four types (black, dark brown black, white, brown white) of matured dried Velvet Bean seed were used.

Seeds were treated with different treatments such as:

T0: Control

T1: Soaking in cold water at room temperature for 24 hours

T2: Soaking seeds in hot water (boiled water at 90°) for 24 hours

T3: Soaking seeds in Conc. H_2SO_4 (98%) for 10 min, followed by 12 hours in cold water

T4: Soaking seeds in Conc. H_2SO_4 (98%) for 20 min, followed by 12 hours in cold water

T5: Scarification by rubbing the dorsal surface of seeds between two sand papers for about 5 minutes.

Completely randomized design (CRD) with 3 replicates of 50 seeds were subjected to each treatment. These methods were chosen as they addressed various causes of seed dormancy.

Sand was obtained from University of Eldoret farm, washed and dried in the greenhouse. It was, sterilized in an oven at 150°C. The wet sand was put into plastic containers. Fifty seeds were placed into their respective plastic containers for each treatment. Plastic containers (covered with lid) were placed into their respective growth chambers calibrated at $30/20^0$C (ISTA, 2011) in the light/dark (8h/16h a day).

Seeds were incubated for 14 days while monitoring germination count daily, according to ISTA (2011).

Seeds were considered germinated if their radicle had protruded at least 2 mm. Final germination percentage was calculated according to ISTA (2011) as follows:

$$\% \, \mathbf{F}\boldsymbol{GP} = \frac{\mathrm{NT}\ \boldsymbol{x100}}{N}$$

Where:

% FGP = Final Germination Percentage

NT = Number of Seeds Germinated

N = Number of Seeds Sown.

Data were subjected to analysis of variance (ANOVA) using GENSTAT software release 14.1 and the mean separations was done using least significant difference (LSD) at 5%.

5.3 Results

5.3.1 Final germination percentage of velvet bean seeds sourced from Mabanga ATC

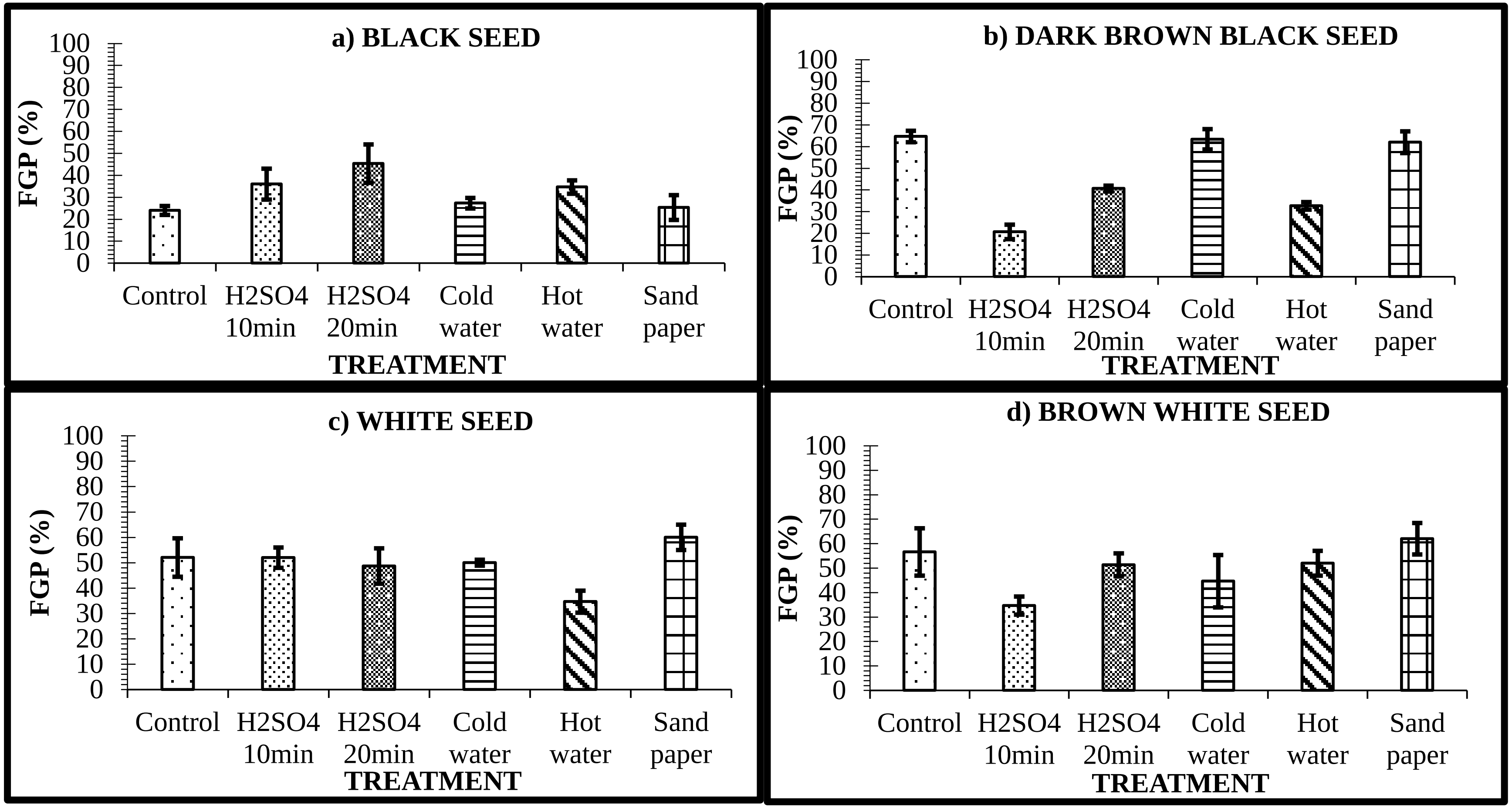
Generally from the FGP of all the control experiment in all the seed types (24% for black seed, dark brown black 63%, white seed 52% and brown white seed 56.667%) it can be deduced that some of the seed types are more dormant than others (Figure 5.1). The most dormant seed type is the black seed while the least dormant is dark brown black.

The final germination percentage of black seed from physical (25.33% sand paper, 27.33% cold water, 34,67% hot water) and chemical treatments (36% H_2SO_4 10 min, 45.33% H_2SO_4 20 min) was significantly higher ($p<0.05$) than the 24.00 % of the control (T0) (Figure 5.1a). For the dark brown black seeds all treatments reduced germination compared with the control (64.67%) (Figure 5.1b). Soaking white seeds in hot water for 24 hours (T2) reduced germination to 34.67% compared with the control (52.00%) while 48.67% of seeds germinated with a combination of Conc. H_2SO_4 (98%) for 20 min and cold water for 12 hours (T4) followed by Cold water treatment for 24 hours at room temperature (50.00%). The FGP of seeds from these three treatments was significantly lower ($p<0.05$) than the control (Figure 5.1c). In contrast, 60.00% of seeds scarified using sand papers (T5) germinated and this was significantly higher ($p<0.05$) than for all other treatments. Scarification by rubbing the dorsal surface of brown white seed between two sand papers for about 5 minutes resulted in better germination (62.00%) than others treatments (Figure 5.1d). FGP from the control seed was significantly higher ($p<0.05$) than treatments T1, T2, T3, and T4.

5.3.2 Final germination percentage of velvet bean seed sourced from UoE site

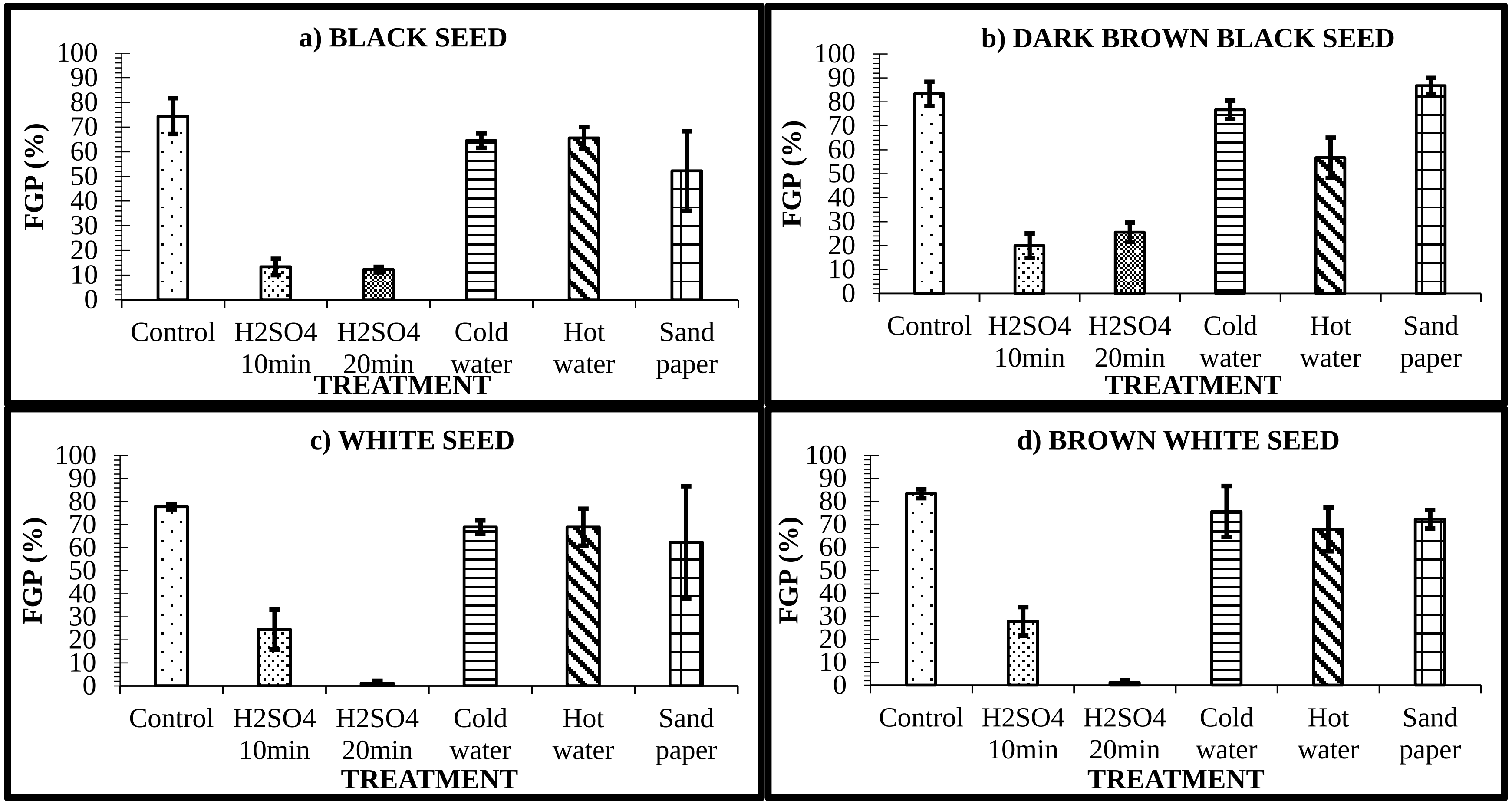
Generally, all the seed types did not exhibit any dormancy as the FGP is high (black seed – 74%, dark brown black – 83.33%, white seeds – 77% and brown white seed – 83%) (Figure 5.2).

Final germination percentage of seed germinated for the control (T0) was higher than treatments T1, T2, T3, T4, T5 for all seed types (Figure 5.2). Soaking seeds in Conc. H_2SO_4 (98%) for 10 min, followed by 12 hours in cold water and soaking seeds in Conc. H_2SO_4 (98%) for 20 min, followed by 12 hours in cold water reduced germination to less than 30% compared with others treatments.



FGP=final germination percentage, Control=T0, Cold water for 24 hours at room temperature=T1, Soaking seeds in hot water (boiled water at 90°) for 24 hours= T2, Soaking seeds in Conc. H_2SO_4 (98%) for 10 min, followed by 12 hours in cold water=T3, Soaking seeds in Conc. H_2SO_4 (98%) for 20 min, followed by 12 hours in cold water=T4, Scarification by rubbing the dorsal surface of seeds between two sand papers for about 5 minutes=T5

Figure 5.1: Final germination percentage for dormancy breaking methods using seed sourced from Mabanga ATC in a laboratory experiment conducted in July 2020 *at the University of Eldoret*



FGP=final germination percentage, Control=T0, Cold water for 24 hours at room temperature=T1, Soaking seeds in hot water (boiled water at 90°) for 24 hours= T2, Soaking seeds in Conc. H_2SO_4 (98%) for 10 min, followed by 12 hours in cold water=T3, Soaking seeds in Conc. H_2SO_4 (98%) for 20 min, followed by 12 hours in cold water=T4, Scarification by rubbing the dorsal surface of seeds between two sand papers for about 5 minutes=T5

Figure 5.2: Final germination percentage dormancy breaking methods using seed sourced from UoE in a laboratory experiment conducted in July 2020

5.4 Discussion

The results show that the behavior of seed dormancy varied among seed type and locality. It has been reported that variety influenced the effectiveness of dormancy breaking method (Wahyuni and Nugraha, 2007). Dormancy behaviour such as mechanism of dormancy, persistency and intensity can strongly influence the effectiveness of dormancy breaking (Soejadi and Nugraha, 2002).

At the Mabanga ATC the black seed type T3 (Soaking in Conc. H_2SO_4 for 20 minutes (45.5%) significantly improved germination. This implies that the seed coat was chemical scarified or broken down by the acid allowing water and oxygen into the seeds for germination to take place (Ravindra *et al*., 2010). This result is in contrast to Melavanki and Kumar (2020) who indicated that *Mucuna pruriens* (seed type or varieties used was not specified) did not show any response to sulphuric acid (H_2SO_4) hot water treatment and mechanical scarification by using sand paper. However, various studies reported that there were significant improvement of breaking hard seed coat dormancy with conc. Sulphuricacid in *Neonoto niawightii* by Leonardo et al (2014), in *Parkia biglobosa* by Abubakar and Maimuma (2013). The combination of soaking black seed in Conc. H_2SO_4 for 20 min and 12 hours in cold water (T4) resulted in better germination (45.333%) followed by soaking seeds in Conc. H_2SO_4 for 10 min and 12 hours in cold water (T3) 36% than others treatments. Increased in germination can be explained by the fact that T4 was more effective in breaking dormancy of black seed type in Mabanga ATC due to hard seed coat. Some studies reported that velvet bean seeds treated with sulphuric acid (H_2SO_4) increased germination percentage with the increase in the duration of soaking (Yogeesha and Shivananda, 2003; Ravindra *et al*., 2010).

Soaking in Conc. H2SO4 for 20 and 10 minutes) significantly reduced germination in the dark brown black seed types T3 and T4. This implies that the acid may have penetrated the seed coat and affected the seed tissues reducing their ability to germinate. The FGP of the control set up for this seed type was high (64%) implying that dormancy level was low. Other treatments (soaking in hot/cold water and sandpaper) did not significantly differ from control implying that they did not address the cause of dormancy. For the white seed type T6 (rubbing with sand paper) significantly improved germination compared to the control. This implies that for this seed type the sand paper sanding is sufficient to break seed coat and allow water and oxygen in the seed for germination. This method can easily be used by farmers as it does not entail use of concentrated acid. In the same seed type concentrated H_2SO_4 treatments and cold water had similar values of FGP as the control implying that they did not scarify or soften the seed coat for germination. However, hot water significantly reduced germination implying farmers should not dip their velvet bean seed in hot water to break dormancy. For the brown white seed type sand paper slightly improved germination compared to the control. This is in agreement with some studies which indicated that mechanical scarification using sand paper was also found to be effective for velvet bean seeds (Veena and Gupta, 2003; Ravindra *et al*., 2010; Mohan *et al*., 2012).

For the seeds harvested from University of Eldoret, the control setup had a higher final germination percentage than all the treatments except dark brown black seed where T5 (scarification by rubbing the dorsal surface of seeds between two sand papers for about 5 minutes) was given higher final germination percentage than control. Seed harvested at UoE therefore did not required breaking dormancy because control was higher than others treatment except dark brown black which T5 increased final germination percentage. Velvet bean seeds experience both primary and secondary. This observation could be explained by the fact that mother plant under suitable environmental growth conditions like nutrient availability, light and temperature result in lower primary dormancy of the seeds (He *et al*., 2014). Secondary dormancy occurs after harvesting or dispersal and may be induced by environmental conditions while primary dormancy occurs during seed maturation (Buijs, 2020). Yuningsih and Wahyuni (2015) reported that species, varieties, stage of seed development and location influence dormancy in term of differences persistency.

5.5 Conclusion

Velvet bean seeds possess hard seed coat dormancy. The level of dormancy varied from one seed type to another. The final germination percentage varied among the seed source significantly and among the treatments. For the seed types sourced from Mabanga ATC, scarification by rubbing the dorsal surface of seeds between two sand papers for about 5 minutes was the most effective treatment for white and brown white seed type. Black seed type, soaking seed in Conc. H_2SO_4 (98%) for 20 min, followed by 12 hours in cold water (T4) resulted in better final germination percentage. For the dark brown black seeds all treatments reduced germination compared with the control. For seed types from all treatments reduced the final germination percentage compared to control for black, white, brown white seed type except dark brown black seed type where scarification by rubbing the dorsal surface of seeds between two sand papers for about 5 minutes was the most effective treatment. Mechanical scarification can be used by farmers to break dormancy.

CHAPTER SIX

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.1 General discussion

In order to improve velvet bean production in Western Kenya, the influence of phosphorus (P) on growth seed harvesting stages on seed quality of velvet bean was investigated. The efficacy of different dormancy breaking treatments on velvet bean was also investigated.

Majority of the farmers (80%) had a proportion of land under velvet bean cultivation less than 0.5 acre (chapter three - figure 5). Farmers were organized to form farmers' groups which can provide solutions to various challenges faced by farmers in Bungoma County. Most farmer groups were involved in food crop farming as their main activity (chapter 3 - figure 4). Good quality seeds are not always available to farmers. One of the key contributors to crop and food production is seed quality (Poudel *et al*., 2003). Efforts to increase velvet bean production should be training farmers on successful farming methods including production of good seeds, procure agricultural inputs collectively true farmers group in Western Kenya. This was in line with Adong et al (2012) and Tallam (2015) who indicated that collective action in form of farmer group can provide solutions to various challenges faced by farmers.

Farmers in Bungoma County used velvet bean as intercropped with maize, groundnut or banana, some practiced crop rotation with common bean (chapter three - figure 8) in order to improve soil fertility. In fact, velvet bean has been reported to increase the soil fertility (chapter three - figure 14 and 16) (Mulvaney *et al*., 2009; Khan *et al*., 2009). It also has ability to suppress the grass population (Coultas *et al*., 1996), pest and disease tolerance (chapter three - figure 6), reclaim weed-infested soil (chapter three - figure 14) (Hellin, 2006 and Yates *et al*., 2011). All these practices improve soil fertility and aid in soil conservation (Wabwoba and Mutoro, 2019).

Less than 30% of the farmers picked seeds from healthy plants and avoided any mechanical damage on the pod or other plant parts harvested (chapter three - figure 11). Mechanical damage due to threshing negatively affect seed quality at farm level (Salamanca, 2015). Farmers need to assure high quality products to increase production of velvet bean.

All parts of velvet bean were useful the seed could be used as food, beverage, soil nutrient, livestock feed, cover crop and oil extraction for soap making; the leaf can be used as consumption, to inhibit weed germination, protect soil from erosion, improve soil moisture; flowers can be used as medicinal and beverage; pods as fertilizer, feeding, firewood and medicinal; roots can be used to improve soil structure (chapter three - figure 13, 14, 15, 16, 17). Farmers mentioned that all part of velvet bean can be used as medicinal which is in line with the findings of Lampariello et al (2012) who indicated that all part of velvet bean possess valuable medicinal properties.

The results indicated seed morphology variation manifested mainly in seed size, thickness, colour, seed coat color and hilium. It could be due to interplay of both genetic and environmental conditions variations (Leidinger *et al*., 2021). Various study indicated that seed characters are very helpful for identification of a large number of species or genera (Zoric *et al*., 2010; Bobrov *et al*., 2004; Hassan *et al*., 2005).

The present study indicated that the variation in velvet bean seed morphology is manifested mainly in seed size, thickness, colour, seed coat ornamentation and hilum morphology can explained by the interplay of both genetic and varying environmental conditions (Leidinger *et al*., 2021).

The electrical conductivity, final germination percentage, speed of germination index and water imbibition capacity of velvet bean seed were influenced by seed coat colour. This is in agreement with various studies who indicated that the electrical conductivity decreased from light colored to dark colored seeds (Mavi, 2010); light coloured seeds absorb water rapidly, and consequently have greater rate of imbibition and fast germination (Chachalis and Smith, 2000); in several legume species, the seed coat pigmentation is correlated with reduced rates of imbibition (Ertekin and Kirdar, 2010).

Physiological maturity of velvet bean seed harvested in Mabanga ATC was fast and occurred between 14 and 28 DAF depending on seed type while in UoE, it was achieved at 28 DAF for all seed types. This result showed that physiological maturity varied with the climatic condition depending on seed type. One of the most critical factors that influence the final quality of seeds is the stage of maturity (Demir *et al*., 2008 and Ferreira *et al*., 2019).

However, harvesting the seed at PM stage may lead to the damaging of seeds during harvesting drying and threshing and affect their quality (Zubaida *et al*., 2016).

The high proportion of fresh seed harvested at 42, 56 and 70 DAF indicated that velvet bean seeds harvested in Mabanga ATC were dormant immediately after harvesting compared to seed harvested at UoE. This is in line with Melavanki and Kumar (2020) who indicated that velvet bean seeds have been reported to be dormant immediately after harvest and poses difficult problem in germination and crop establishment when sown immediately.

The results shown that phosphorus levels varied with seed type, climatic and site conditions. For optimum crop production, phosphorus is a plant nutrient required. This is in line with Khan et al (2014) who indicated that phosphorus can enhance the quality of vegetative crop growth It have been shown that phosphorus deficiency can slow plant growth and delay crop maturity (Ross *et al*., 2013). Phosphorus is needed for growth, sugar and starch utilization, nucleus and fat formation, cell division and photosynthesis (Khan *et al*., 2014).

The results indicated that mechanical scarification using sand paper was the most effective treatment for eliminating the dormancy and enhanced the seed germination percentage for white and brown white seed type harvested at Mabanga ATC and dark brown black seed type harvested at UoE. Velvet bean seed have been reported to exhibit hard seed coat dormancy (Yogeesha and Shivananda, 2003; Melavanki and Kumar 2020). This is in line with various studies which show that mechanical scarification using sand paper was found to be effective for velvet bean seeds (Veena and Gupta, 2003; Ravindra *et al*., 2010; Mohan *et al*., 2012).
In Mabanga ATC, soaking seed in Conc. H_2SO_4 (98%) for 20 min, followed by 12 hours in cold water (T4) resulted in better germination (45.33%) than others treatments for black seed. Various studies reported that there were significant improvement of breaking hard seed coat dormancy with conc. sulphuric acid (Leonardo *et al*., 2014; Abubakar and Maimuma, 2013). The results show that seed dormancy varied among seed type and locality. This is in line with various studies on seed dormancy variation in different varieties (Soejadi and Nugraha, 2002;Wahyuni and Nugraha, 2007; Yuningsih and Wahyuni, 2015).

6.2 Conclusion

From the survey it was concluded farmers grew velvet bean for multiple reasons such as soil fertility enhancement, nutrition, drought tolerance, pest and disease tolerance, food security and medicinal uses. Most of the farmers did not deploy seed selection criteria in the field which affected seed quality. Among seed type in all seed traits measured, there were significant differences ($p \leq 0.05$) except seed coat thickness. Four seed types were identified from farmers seed by using the colour chart. No significant difference was noted in the average EC among seed type. White seed type was more vigorous, had higher final germination percentage, speed of germination index than others seed types. As temperature increased, the water imbibing capacity increased but the alternative temperature 30/20°C resulted in completely interruption of the water uptake for both media. From the germination test it was concluded that dormancy exists for velvet bean seeds and it level varied from seed type to seed type. From the field experiments it was concluded that seed types harvested from Mabanga ATC were dormant compared to seeds harvested from UoE. Also, the interaction between seed type and phosphorus fertilization indicate different response of seed type to phosphorus application. The most effective treatment varied with locality, seed type.

6.3 Recommendations

- Farmers engaged in velvet bean production, can share their knowledge and expertise to others farmers in order to increase the number of velvet bean growers or velvet bean crop popularity in Western Kenya.
- Training on production, management of seed and marketing aspects should be organised each time before planting of velvet bean to improve seed quality of farmer saved seeds.
- There is a need to standardize agronomic and seed management practices of velvet bean in order to improve seed quality and yield at farm level.

- Velvet bean production can reduce fertilizer use in small scale farmers growing maize because it will alleviate the deterioration of soil under continuous cropping conditions.
- Farmers growing velvet bean should be encouraged to intercrop or practice crop rotation because of its N fixing ability as well as its high dry matter content.
- Farmers should be encouraged to obtain their seeds from healthy looking and highly yield plants and avoid mechanical damage to the seeds to improve seed quality.
- Physiological maturity was achieved at 14 DAF or 28 DAF depending on seed type and locality. However, harvesting the seed at this harvesting stage will affect their quality. In order that seeds can express their full potential with high germination potential and vigour, it is recommended that harvesting should be done at harvest maturity.
- Mechanical scarification can be used by farmers to break dormancy for white and brown white seed type harvested at Mabanga ATC and dark brown black seed type harvested at UoE to ensure rapid and high germination.

6.4 Suggestions for further studies

- Further study on the effect of harvesting, drying , threshing short and long term storage can be done.
- The effect of phosphorus fertilization on nutrient composition of velvet bean seeds can be investigated.
- Suitability and efficiency of intercropping velvet bean with others food crops require further investigation.

- Genetic diversity exists among the evaluated seed of velvet bean. Genetic characterization of velvet bean found in western Kenya should be done in order to help differentiate the various morphotypes for breeding purposes.
- The exact point when the seeds reach physiological and harvest maturity should be established in order to give proper recommendations on the stage that seed should be harvested.
- Results showed that black seed type have low germination percentage compared to other seed types. Further study can be done on genetic and physiological properties of velvet bean black seed type in order to improve it germination capacity.

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APPENDICES

Appendix I: Questionnaire used in the survey

UNIVERSITY OF ELDORET

SCHOOL OF AGRICULTURE AND BIOTECHNOLOGY

P.O. BOX 1125-30100, ELDORET, KENYA

Velvet bean (*Mucuna pruriens*) production and utilization in Kenya, May 2019

Objectives

1. To determine the characteristic of family members involved in velvet bean production.
2. The asses seed management and agronomic practices involved in Velvet Bean production
3. To identify the utilization strategies of Velvet Bean.

Declaration: The information you provide will be kept confidential and used for this purpose only. Your full name will never be used anywhere to ensure confidentiality.

Objective 1:

1. **GENERAL INFORMATION**

Date of interview ☐	Farmer ID ☐
Name ☐	Contact ☐
Age ☐	Farmer group ☐
Region ☐	County ☐
Sub county ☐	Village ☐
Agro Ecological Zone ☐	Soil Type ☐
Latitude ☐	Longitude ☐

2. **DEMOGRAPHIC INFORMATION**

(i) Education level attained

No formal education ☐
Primary ☐
Secondary ☐
Tertiary ☐
University ☐

(ii) What is your main source of income?

Cash crop farming
Livestock rearing ☐
Food crop farming ☐
Business ☐
Salaried employment ☐
Causal labour ☐
Others
(specify)……………………………………………………………………….

(iii) What is the type of land?

Upland ☐
Swampland ☐
Flat land ☐

(iv) What is the use of the land?

…………………………………………………………………………………………..
.

(v) Do you belong to a group? Yes ☐ No ☐
If yes, which one?

....

(vi) Why did you join the farmers´ group?
Credit and savings ☐
Accessing seed Market ☐
Support ☐
Seed production ☐
Other
(specify)………………………………………………………………………..

Objective 2:

1. **AGRONOMY OF VELVET BEAN**

Tick where appropriate:

(i) What proportion of your farm is under Velvet Bean cultivation?

Less than 0.5 acre ☐
[0.5-1[acre ☐
1 acre ☐
2 acres ☐
More than 2 acres ☐

(ii) How much did you harvest from that proportion of your farm?

Estimated Kgs or bags……………………………………………………………………

(iii) What do you grow Velvet Bean for?

Home consumption ☐
Sale of seeds/grains ☐

Both ☐
Seed maintenance ☐
Other specify)……………………………………………………………………….

(iv) What is the reasons for the crop popularity (Velvet Bean)?

Drought tolerance ☐
Pest and disease tolerance ☐
Soil fertility ☐
Nutrition ☐
Food security ☐
Cultural ☐
Other (specify)…………………………………………………………………

(v) What is the reasons for non-popularity of the crop?

Germination and crop establishment take long ☐
Not easy to cook ☐
Seed maturation take long ☐
Seed access ☐
Not easy to manage the crop ☐
Difficulty in seed marketing ☐
Other
(specify)……………………………………………………………………..

(vi) When did you last plant Velvet Bean?
……………………………………………………………………………………..
(vii) What is the land size that is occupied by Velvet Bean?
……………………………………………………...
(viii) Spacing of Velvet Bean?
Inter-row spacing………………………… Inter-plant spacing……………………………
Sowing date …………/………… (Month/Year)
First harvesting date ……../………… (Month/Year)
Last harvesting date ……../………… (Month/Year)
What are the indices of maturity?
……………………………………………………...
……………………………………………………...
……………………………………………………...
(ix) How many times did you harvest?
Once ☐
Twice ☐
Thrice ☐
Other (specify) ……………………………………………………………………..

(xi) What is the interval of harvesting times?
……………………………………………………………………………………..
(xii) Do you normally cultivate any other crops on your land? Yes ☐ No ☐

If yes, specify………………………………………………………………………

……………………………………………………………………………………..

(xiii) Which cropping system did you use?
Intercropped ☐ (specify the distance)…………………....................................
Pure crop stand ☐
Crop rotation ☐ (specify duration of rotation)…………………………………

Other (specify)
…………………………………………………………………………………………….

(xiv) How many times do you weed Velvet Bean field?
Once ☐
Twice ☐
Thrice ☐

(xv) Did you use any fertilizer during planting? Yes ☐ No ☐

a) If yes, which one? (specify fertilizer rate)
………………………………………………………………………………
………………………………………………………………………………
………………………………………………………………………………
……..

b) If yes, when did you apply the fertilizer?
Before planting ☐
At planting ☐
After weeding ☐
Other (specify)……………………..

(xvi) Do you know any disease on Velvet Bean? ☐Yes ☐No
If yes, which one do you know?
……..
....
……..

(xvii) Which of the following plant disease causing organisms do you know as problem to Velvet Bean? By which pathogen? And what are the symptoms?

Nematodes ☐
……..
....
……..

Fungi ☐
……..
....
……..

Bacteria ☐
……..
....
……..

Viruses ☐
……..
....
……..

Insect pests ☐
……..
....
……..

(xviii) How do you control/manage them? (Give them options)
……..
....
……..
....
……..
....

……..
....
……..
....

e. Have you been trained in any Integrated Crop Management practices?Yes ☐ No ☐

By which Organization?

……………………………………………………………………………………..

f. In your opinion, is Velvet Bean cultivation profitable? Yes ☐ No ☐

g. Would you like to make any other comment about Velvet Bean production?

……..
....
……..
....

2. SEED MANAGEMENT PRACTICES

(i) Where did you obtain your seeds for planting?

Own ☐
Neighbors ☐
Local market ☐
Agro-shop ☐
Others (specify)……………………………………………………………………

(ii) What do you know about seed morphological variability of Velvet Bean? Colour, shape, size

……..
....
……..
....
……..
....
……..
....

(iii) How many year have you been planting velvet bean?

One year ☐
Two years ☐
Three years ☐
More than three years ☐

(iv) When is Velvet Bean seed selection done ?

Before whole crop is harvested ☐
During crop harvest ☐
After crop harvest, but in the field ☐
During drying ☐
At planting time ☐
Other (specify)……………………………………………………………………

(v) Do you deploy any seed selection criteria in velvet bean field? Yes ☐ No ☐

If yes, which one?
Healthy looking plants and pods ☐
High yielding plant ☐
Big pods ☐
Other (specify)……………………………………………………………………

(vi) Do you carry out any seed quality assurance activities in velvet bean field?

None ☐
Weeding ☐
Removing diseased or off types ☐
Planting separately ☐
Other

(specify)…………………………………………………………………………..

(vii) How are Velvet Bean seeds harvested?

……..
....
……..
....

(viii) How do Velvet Bean seeds dry?

Using the sun ☐
Using the shade ☐
Other

(specify)…………………………………………………………………………..

(ix) Where are Velvet Bean seeds stored?

In a gunny bags ☐
In pots ☐
Open containers ☐
Other

(specify)…………………………………………………………………………..

(x) Are Velvet Bean seed damaged during storage? Yes ☐ No ☐

If yes, specify:
Pest damage ☐
Rotting (bad smell) ☐
Other

(specify)…………………………………………………………………………..

(xi) How do you done Velvet Bean seed processing?

Hand threshing ☐
Sorting seeds ☐
Other

(specify)…………………………………………………………………………..

(xii) What seed treatment have you been used?

None ☐
Soaking ☐
Hot water treatment ☐
Scarification by using sand paper ☐
Other

(specify)…………………………………………………………………………..

Objective 3:
UTILISATION AND MARKETING

(i) How and why do you use the following parts of the plant ?

Seed ☐
……..
....

Leaf ☐
……..
....

Flower/inflorescence ☐

……..
....
Root ☐
……..
....
Shell (pod) ☐
……..
....
Other
(specify)……………………………………………………………………………………
……..

(ii) Which of these groups use Velvet Bean and for what purpose?

Children ☐
Man ☐
Woman ☐
Older people ☐

Feasts ☐
Religious purpose ☐
Medicinal ☐
Other
(specify)……………………………………………………………………………..

(iii) How many times do you use velvet bean plant?

Daily ☐
Weekly ☐
Monthly ☐
Occasional ☐
Other
(specify)……………………………………………………………………………..

(iv) What are your main cooking methods velvet bean seed?

Boiling ☐
Baking ☐
Roasting ☐
Infusion ☐
Local specialties ☐
Other
(specify)……………………………………………………………………………..

(v) Before cooking, what preparatory methods do you use?

None ☐
Soaking ☐
Cracking ☐
Removal of seed coat ☐
Other
(specify)……………………………………………………………………………..

(vi) Does Velvet Bean has any other benefits?

……..
....

(vii) Do you sell Velvet Bean seeds? Yes ☐ No ☐

How many Kgs did you lastly harvest and what was the price per Kg
Kg..............................…… Price per kg...............................Kenya Shilling

a. If yes, how and where do you sell seeds (Briefly describe)

....
....

b. If yes, are this seeds certified and regulated? Yes ☐ No ☐

(viii) How did you get certification and regulation?(Briefly describe) Is KEPHIS involved?

....
....

<u>NB:</u> 1) Request samples seeds if available and label appropriately.

Thank you for your time and cooperation.

Appendix II: Analysis of variance (ANOVA) seed length of velvet bean farmers seed

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Seed_Type	3	21.099	7.033	4.84	0.020
Residual	12	17.450	1.454		
Total	15	38.549			

Appendix III: Analysis of variance (ANOVA) seed width of velvet bean farmers seed

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Seed_Type	3	22.232	7.411	4.92	0.019
Residual	12	18.090	1.508		
Total	15	40.322			

Appendix IV: Analysis of variance (ANOVA) thickness of velvet bean farmers seed

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Seed_Type	3	0.42474	0.14158	2.79	0.086
Residual	12	0.60871	0.05073		
Total	15	1.03345			

Appendix V: Analysis of variance (ANOVA) final germination percentage (FGP) of velvet bean farmers seed

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Seed_Type	3	6619.67	2206.56	35.59	<.001

Residual	8	496.00	62.00
Total	11	7115.67	

Appendix VI: Analysis of variance (ANOVA) speed of germination index (SGI) of velvet bean farmers seed

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Seed_Type	3	28.3788	9.4596	20.03	<.001
Residual	8	3.7777	0.4722		
Total	11	32.1565			

Appendix VII: Analysis of variance (ANOVA) for electrical conductivity (EC) of velvet bean farmers seed

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Seed_Type	3	8.997E-07	2.999E-07	1.00	0.427
Residual	12	3.608E-06	3.007E-07		
Total	15	4.508E-06			

Appendix VIII: Analysis of variance (ANOVA) for imbibition rate of velvet bean farmers seed

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Seed type	3	7431.6	2477.2	17.56	<.001
Temperature	4	14135.6	3533.9	25.05	<.001
Duration_of_Imbibition_hour	5	172244.9	34449.0	244.23	<.001
Media	1	3621.2	3621.2	25.67	<.001

Seed type. Temperature	12	4740.0	395.0	2.80	0.001
Seed_type. Duration_of_Imbibition_hour	15	15846.6	1056.4	7.49	<.001
Temperature. Duration_of_Imbibition_hour	20	10444.5	522.2	3.70	<.001
Seed_type. Media	3	389.2	129.7	0.92	0.431
Temperature. Media	4	2056.5	514.1	3.64	0.006
Duration_of_Imbibition_hour . Media	5	1827.1	365.4	2.59	0.025
Seed_type.Temperature. Duration_of_Imbibition_hour	60	14313.7	238.6	1.69	0.002
Seed_type.Temperature.Media	12	1634.1	136.2	0.97	0.481
Seed_type.Duration_of_ Imbibition_hour.Media	15	888.1	59.2	0.42	0.973
Temperature.Duration_of_ Imbibition_hour.Media	20	3168.7	158.4	1.12	0.321
Seed_type.Temperature. Duration_of_Imbibition_hour . Media	60	7906.9	131.8	0.93	0.617
Residual	480	67705.3	141.1		
Total	719	328354.0			

Appendix IX: Analysis of variance (ANOVA) final germination percentage (FGP) of velvet bean seed harvested at different phosphorus levels in ATC and UoE

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Site	1	103292.4	103292.4	563.61	<.001
P_level	3	2013.5	671.2	3.66	0.013
Seed_type	3	30271.4	10090.5	55.06	<.001

Harvesting_stage	4	20017.1	5004.3	27.31	<.001
Site.P_level	3	740.4	246.8	1.35	0.259
Site.Seed_type	3	7587.5	2529.2	13.80	<.001
P_level.Seed_type	9	1670.5	185.6	1.01	0.429
Site.Harvesting_stage	4	56679.7	14169.9	77.32	<.001
P_level.Harvesting_stage	12	2994.4	249.5	1.36	0.183
Seed_type.Harvesting_stage	12	6581.9	548.5	2.99	<.001
Site.P_level.Seed_type	9	2580.1	286.7	1.56	0.125
Site.P_level.Harvesting_stage	12	3337.6	278.1	1.52	0.116
Site.Seed_type.Harvesting_stage	12	6148.6	512.4	2.80	0.001
P_level.Seed_type. Harvesting_stage	36	18263.0	507.3	2.77	<.001
Site.P_level.Seed_type. Harvesting_stage	36	17379.0	482.7	2.63	<.001
Rep stratum	2	97.9	48.9	0.27	
Residual	318	58279.9	183.3		
Total	479	337934.9			

Appendix X: Analysis of variance (ANOVA) percentage of normal seedlings of velvet bean harvested at different phosphorus levels in ATC and UoE

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Site	1	49518.5	49518.5	269.68	<.001
P_level	3	909.4	303.1	1.65	0.178

Seed_type	3	18795.1	6265.0	34.12	<.001
Harvesting_stage	4	18688.9	4672.2	25.44	<.001
Site. P_level	3	177.6	59.2	0.32	0.809
Site. Seed_type	3	2813.8	937.9	5.11	0.002
P_level. Seed_type	9	4039.5	448.8	2.44	0.011
Site. Harvesting_stage	4	73622.2	18405.6	100.24	<.001
P_level. Harvesting_stage	12	2456.3	204.7	1.11	0.347
Seed_type. Harvesting_stage	12	6678.0	556.5	3.03	<.001
Site. P_level. Seed_type	9	3792.4	421.4	2.29	0.017
Site. P_level. Harvesting_stage	12	3385.4	282.1	1.54	0.110
Site. Seed_type. Harvesting_stage	12	6704.7	558.7	3.04	<.001
P_level. Seed_type. Harvesting_stage	36	12928.4	359.1	1.96	0.001
Site. P_level. Seed_type. Harvesting_stage	36	12111.8	336.4	1.83	0.003
Rep stratum	2	902.1	451.0	2.46	
Residual	318	58391.5	183.6		
Total	479	275915.6			

Appendix XI: Analysis of variance (ANOVA) percentage of abnormal seedlings of velvet bean harvested at different phosphorus levels in ATC and UoE

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Site	1	10052.8	10052.8	88.86	<.001

P_level	3	260.7	86.9	0.77	0.513
Seed_type	3	1686.2	562.1	4.97	0.002
Harvesting_stage	4	1036.7	259.2	2.29	0.060
Site. P_level	3	464.8	154.9	1.37	0.252
Site. Seed_type	3	1487.7	495.9	4.38	0.005
P_level. Seed_type	9	2132.2	236.9	2.09	0.030
Site. Harvesting_stage	4	2507.4	626.8	5.54	<.001
P_level. Harvesting_stage	12	1542.2	128.5	1.14	0.330
Seed_type. Harvesting_stage	12	4103.7	342.0	3.02	<.001
Site. P_level. Seed_type	9	2648.3	294.3	2.60	0.007
Site. P_level. Harvesting_stage	12	1948.5	162.4	1.44	0.148
Site. Seed_type. Harvesting_stage	12	2530.5	210.9	1.86	0.038
P_level. Seed_type. Harvesting_stage	36	6352.8	176.5	1.56	0.025
Site. P_level. Seed_type. Harvesting_stage	36	4547.1	126.3	1.12	0.303
Rep stratum	2	1372.9	686.5	6.07	
Residual	318	35974.3	113.1		
Total	479	80648.7			

Appendix XII: Analysis of variance (ANOVA) percentage of fresh seed of velvet bean harvested at different phosphorus levels in ATC and UoE

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Site	1	103723.20	103723.20	1403.74	<.001
P_level	3	1012.87	337.62	4.57	0.004
Seed_type	3	24553.09	8184.36	110.76	<.001
Harvesting_stage	4	51222.42	12805.61	173.31	<.001
Site. P_level	3	814.73	271.58	3.68	0.013
Site. Seed_type	3	3223.07	1074.36	14.54	<.001
P_level. Seed_type	9	2044.65	227.18	3.07	0.001
Site. Harvesting_stage	4	57471.03	14367.76	194.45	<.001
P_level. Harvesting_stage	12	1234.31	102.86	1.39	0.168
Seed_type. Harvesting_stage	12	2640.65	220.05	2.98	<.001
Site. P_level. Seed_type	9	4106.61	456.29	6.18	<.001
Site. P_level. Harvesting_stage	12	1331.12	110.93	1.50	0.122
Site. Seed_type. Harvesting_stage	12	4601.55	383.46	5.19	<.001
P_level. Seed_type. Harvesting_stage	36	6617.62	183.82	2.49	<.001
Site. P_level. Seed_type. Harvesting_stage	36	5612.99	155.92	2.11	<.001
Rep stratum	2	58.69	29.34	0.40	
Residual	318	23497.16	73.89		
Total	479	293765.74			

Appendix XIII: Analysis of variance (ANOVA) percentage of dead seed of velvet bean harvested at different phosphorus levels in ATC and UoE

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Site	1	1.1	1.1	0.01	0.937
P_level	3	639.0	213.0	1.24	0.296
Seed_type	3	763.0	254.3	1.48	0.221
Harvesting_stage	4	73060.4	18265.1	106.08	<.001
Site. P_level	3	2150.6	716.9	4.16	0.007
Site. Seed_type	3	3684.7	1228.2	7.13	<.001
P_level. Seed_type	9	2307.0	256.3	1.49	0.151
Site. Harvesting_stage	4	31127.3	7781.8	45.20	<.001
P_level. Harvesting_stage	12	1441.6	120.1	0.70	0.754
Seed_type. Harvesting_stage	12	5686.7	473.9	2.75	0.001
Site. P_level. Seed_type	9	1498.8	166.5	0.97	0.467
Site. P_level. Harvesting_stage	12	3143.6	262.0	1.52	0.115
Site. Seed_type. Harvesting_stage	12	10115.2	842.9	4.90	<.001
P_level. Seed_type. Harvesting_stage	36	11414.3	317.1	1.84	0.003
Site. P_level. Seed_type. Harvesting_stage	36	15288.8	424.7	2.47	<.001
Rep stratum	2	121.1	60.5	0.35	
Residual	318	54753.0	172.2		
Total	479	217196.2			

Appendix XIV: Analysis of variance (ANOVA) speed of germination index (SGI) of velvet bean seed harvested at different phosphorus levels in ATC and UoE

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Site	1	6.3379	6.3379	7.85	0.005
P_level	3	5.5781	1.8594	2.30	0.077
Seed_type	3	140.9565	46.9855	58.19	<.001
Harvesting_stage	4	395.1327	98.7832	122.33	<.001
Site. P_level	3	2.1275	0.7092	0.88	0.453
Site. Seed_type	3	51.1477	17.0492	21.11	<.001
P_level. Seed_type	9	9.4221	1.0469	1.30	0.238
Site. Harvesting_stage	4	204.5152	51.1288	63.32	<.001
P_level. Harvesting_stage	12	12.9187	1.0766	1.33	0.198
Seed_type. Harvesting_stage	12	52.8219	4.4018	5.45	<.001
Site. P_level. Seed_type	9	17.2181	1.9131	2.37	0.013
Site. P_level. Harvesting_stage	12	15.5677	1.2973	1.61	0.088
Site. Seed_type. Harvesting_stage	12	31.7042	2.6420	3.27	<.001
P_level. Seed_type. Harvesting_stage	36	111.4976	3.0972	3.84	<.001
Site. P_level. Seed_type. Harvesting_stage	36	105.8303	2.9397	3.64	<.001
Rep stratum	2	1.1091	0.5546	0.69	
Residual	318	256.7856	0.8075		
Total	479	1420.6708			

Appendix XV: Analysis of variance (ANOVA) final germination percentage (FGP) for dormancy breaking treatments of velvet bean seed harvested at ATC

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Seed_Type	3	3949.94	1316.65	14.36	<.001
Dormancy_Treatment	5	2431.61	486.32	5.31	<.001
Seed_Type. Dormancy_Treatment	15	6191.72	412.78	4.50	<.001
Residual	48	4400.00	91.67		
Total	71	16973.28			

Appendix XVI: Analysis of variance (ANOVA) final germination percentage (FGP) for dormancy breaking treatments of velvet bean seed harvested at UoE

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Seed_Type	3	1260.5	420.2	2.18	0.102
Dormancy_Treatment	5	51264.2	10252.8	53.28	<.001
Seed_Type. Dormancy_Treatment	15	2998.8	199.9	1.04	0.435
Residual	48	9237.0	192.4		
Total	71	64760.5			

Appendix XVII: Similarity Report

DrillBit

The Report is Generated by DrillBit Plagiarism Detection Software

Submission Information

Author Name	Mamie Souadou Diop
Title	INFLUENCE OF SEED ASPECTS AND PHOSPHORUS FERTIL...
Paper/Submission ID	949554
Submission Date	2023-09-04 13:58:43
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