GENOTYPE x ENVIRONMENT INTERACTION EFFECT ON COMMON BEAN (*Phaseolus vulgaris* L.) PERFORMANCE AND YIELD STABILITY IN BURUNDI

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ABSTRACT

Most of the common bean (*Phaseolus vulgaris* L.) grown in Burundi are selected with little reference to stability of seed yield performance, resulting to low yields. Seven biofort genotypes were tested across three locations (Gisozi, Murongwe and Moso) during two cropping seasons (2013A and 2013B) using a split plot design replicated three times for each location and in split split plot design in combined locations. WindoStat Version 8.5 computer software was used to analyse the collected data. The G x E interaction was observed and environmental factors significantly affected the performance of the present bean genotypes. Based on good performance, each site presented genotypes which were comparable to the high yielding check variety (GLP2). However, since the check was the latest to mature, the genotypes which performed almost the same to the check variety across seasons (KAB06F2-8-24, KAB06F2-8-78, KAB06F2-8-53 and KAB06F2-8-13) are recommended for confirmation on farmer conditions due to their early maturity trait. Furthermore, these genotypes showed resistance to intermediate reaction to diseases and should possibly be used in bean breeding programs as source of genes for tolerance. The plant population 20cm x 40cm was the best plant density to be recommended for bush bean. In both cropping seasons high heritability was observed for Plant Height (63 and 70%) and Days to Physiological Maturity (66 and 75%). Results revealed the complete absence of genotypes that could be considered to be widely adapted and stable on seed yield. However, genotypes KAB06F2-8-24 and KAB06F2-8-78 were adapted to low yielding environments whereas KAB06F2-8-53 and KAB06F2-8-13 were found suitable in favorable conditions. On the basis of this study, future studies should focus on more seasons and locations in different agro-ecological zones in order to support results obtained in this study.

ABSTRACT

Most of the common bean (*Phaseolus vulgaris* L.) grown in Burundi are selected with little reference to stability of seed yield performance, resulting to low yields. Seven biofort genotypes were tested across three locations (Gisozi, Murongwe and Moso) during two cropping seasons (2013A and 2013B) using a split plot design replicated three times for each location and in split split plot design in combined locations. WindoStat Version 8.5 computer software was used to analyse the collected data. The G x E interaction was observed and environmental factors significantly affected the performance of the present bean genotypes. Based on good performance, each site presented genotypes which were comparable to the high yielding check variety (GLP2). However, since the check was the latest to mature, the genotypes which performed almost the same to the check variety across seasons (KAB06F2-8-24, KAB06F2-8-78, KAB06F2-8-53 and KAB06F2-8-13) are recommended for confirmation on farmer conditions due to their early maturity trait. Furthermore, these genotypes showed resistance to intermediate reaction to diseases and should possibly be used in bean breeding programs as source of genes for tolerance. The plant population 20cm x 40cm was the best plant density to be recommended for bush bean. In both cropping seasons high heritability was observed for Plant Height (63 and 70%) and Days to Physiological Maturity (66 and 75%). Results revealed the complete absence of genotypes that could be considered to be widely adapted and stable on seed yield. However, genotypes KAB06F2-8-24 and KAB06F2-8-78 were adapted to low yielding environments whereas KAB06F2-8-53 and KAB06F2-8-13 were found suitable in favorable conditions. On the basis of this study, future studies should focus on more seasons and locations in different agro-ecological zones in order to support results obtained in this study.

DECLARATION

I, Eric Nduwarugira, do hereby declare to the Senate of Sokoine University of Agriculture that this Dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

Eric Nduwarugira
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Date

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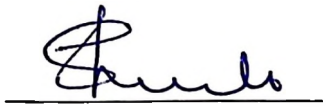

Prof. Susan Nchimbi-Msolla
(Supervisor)

20 / 05 / 2014
Date

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TABLE OF CONTENTS

ABSTRACT ii

DECLARATION iii

COPYRIGHT iv

ACKNOWLEDGEMENTS v

DEDICATION vi

TABLE OF CONTENTS vii

LIST OF TABLES xiv

LIST OF FIGURES xix

LIST OF APPENDICES xxii

LIST OF ABBREVIATIONS AND SYMBOLS xxiii

CHAPTER ONE 1

1.0 INTRODUCTION 1

CHAPTER TWO 5

2. 0 LITERATURE REVIEW 5

2.1 Common Bean 5

2.1.1 Ecology of common bean 5

2.1.2 Bean production constraints 6

2.1.3 Uses of beans 7

2.1.4 Common bean production in Burundi 9

2.2 Study of G x E Interaction 10

2.2.1 G x E interaction 10

2.2.2 Environment factors affecting G x E interaction 14

2.2.3 Stability parameter 15

2.2.4 Assessment of G x E interaction 19

2.3 Heritability 21

2.4 Path Coefficient Analysis 22

CHAPTER THREE 24

3.0 MATERIALS AND METHODS 24

3.1 Materials 24

3.1.1 Genotypes characteristics 24

3.1.2 Sites description 25

3.2 Methods 26

3.2.1 Land preparation and sowing 26

3.2.2 Experimental design and layout treatment 26

3.2.3 Data collection 27

3.2.2.1 Meteorological data 27

3.2.2.2 Soil collection and soil characteristics 27

3.2.2.3 Plant growth characteristics 27

3.2.2.4 Yield and yield components 28

3.2.3 Data analysis 29

3.2.3.1 Stability parameter model for each variable 29

3.2.3.2 Correlation analysis 30

3.2.3.3 Estimation of components of variance 30

3.2.3.4 Computation of phenotypic variance and heritability (broad sense) 30

3.2.3.4 Path coefficient analysis 31

CHAPTER FOUR 33

4.0 RESULTS 33

4.1 Results from the First Cropping Season 33

4.1.1 Gisozi site 33

4.1.1.1 ANOVA for different variables studied during 2013A 33

4.1.1.2 Effect of genotypes and spacings on germination 34

4.1.1.3 Effect of genotypes and spacings on diseases 35

4.1.1.4 Yield components and SY (t/ha) performance 37

4.1.1.5 Simple correlation coefficient between SY and its components 39

4.1.1.6 Influence of yield components on SY 39

4.1.2 Murongwe site 40

4.1.2.1 ANOVA for different variables studied 40

4.1.2.2 Effect of genotypes and spacings on germination 41

4.1.2.3 Effect of genotypes and spacings on diseases 42

4.1.2.4 Yield components and SY (t/ha) performance 43

4.1.2.5 Simple correlation coefficient between seeds yield and its components 45

4.1.2.6 Influence of yield components on seed yield 46

4.1.3 Moso site 47

4.1.3.1 ANOVA for different variables studied during 2013A season 47

4.1.3.2 Effect of genotypes and spacings on germination 48

4.1.3.3 Effect of genotypes and spacings on diseases 49

4.1.3.4 Yield components and SY (t/ha) performance 49

4.1.3.5 Simple correlation coefficients between seed yield and its components 51
4.1.3.6 Influence of yield components on seed yield 51
4.1.4 Combined sites 52
4.1.4.1 ANOVA for different variables studied 52
4.1.4.2 Yield components and seed yield (t/ha) performance 54
4.1.4.3 Combined simple correlation coefficient across sites between SY and its components 56
4.1.4.4 Influence of yield components on seed yield 56
4.1.5 Combined means of G x E interactions for DFL 57
4.1.6 Combined means of G x E interactions for PH (cm) 58
4.1.7 Combined means of G x E interactions for DPM (days) 58
4.1.8 Combined means of G x E interactions for P/P 59
4.1.9 Combined means of G x E interactions for S/P 59
4.1.10 Combined means of G x E interactions for 100SW (g) 60
4.1.11 Combined means of G x E interactions for SY (t/ha) 60
4.1.12 Broad sense-heritability parameters estimates of yield and yield components for common bean genotypes studied 61
4.1.7 Relationship among stability parameters with seed yield and its components 61
4.1.7.1 Relationship among stability parameters with P/P 62
4.1.7.2 Relationship among stability parameters with S/P 63
4.1.7.3 Relationship among stability parameters with 100SW 63
4.1.7.4 Relationship among stability parameters with SY 64
4.2 Results from the Second Cropping Season (2013B) 65
4.2.1 Gisozi site 65

4.2.1.1 ANOVA for different variables studied during 2013B season 65
4.2.1.2 Effect of genotypes and spacings on germination..... 67
4.2.1.3 Effect of genotypes and spacings on diseases..... 68
4.2.1.4 Seed yield (t/ha) and yield components..... 70
4.2.1.5 Simple correlation coefficients between SY and its component 72
4.2.1.6 Influence of yield components on seed yield..... 72
4.2.2 Murongwe site..... 73
4.2.2.1 ANOVA for different variables studied 73
4.2.2.2 Effect of genotypes and spacings on germination..... 75
4.2.2.3 Effect of genotypes and spacings on diseases..... 76
4.2.2.4 Yield components and SY (t/ha) performance..... 78
4.2.2.5 Simple correlation coefficients between SY and its components..... 80
4.2.2.6 Influence of yield components on seed yield..... 81
4.2.3 Moso site..... 82
4.2.3.1 ANOVA for different variables studied during 2013B season 82
4.2.3.2 Effect of genotypes and spacings on germination..... 83
4.2.3.3 Effect of genotypes and spacings on diseases..... 84
4.2.3.4 Yield components and seed yield (t/ha) performance..... 86
4.2.3.5 Simple correlation coefficients between seeds yield and its components..... 88
4.2.3.6 Influence of yield components on seed yield..... 88
4.2.4 Combined sites..... 89

4.2.4.1 ANOVA for different variables studied 89
4.2.4.2 Yield components (t/ha) and seed yield performance 91
4.2.4.3 Combined simple correlation coefficient across sites between SY and its components for the second cropping season 93
4.2.4.4 Influence of yield components on seed yield 93
4.2.5 Combined means of G x E interactions for DFI 94
4.2.6 Combined means of G x E interactions for PH 95
4.2.7 Combined means of G x E interactions for DPM 95
4.2.8 Combined means of G x E interaction for P/P 96
4.2.9 Combined means of G x E interactions for S/P 96
4.2.10 Combined means of G x E interaction for 100SW(g) 97
4.2.11 Combined means of G x E interaction for SY (t/ha) 97
4.2.12 Broad sense-heritability parameters estimates of yield and yield components for the common bean genotypes studied during 2013B 98
4.2.13 Relationship among stability parameters with seed yield and its components 98
4.2.13.1 Relationship among stability parameters with P/P 98
4.2.13.2 Relationship among stability parameters with S/P 99
4.2.13.3 Relationship among stability parameters with 100SW 100
4.2.13.4 Similarity among stability parameters with SY 101

CHAPTER FIVE 103
5.0 DISCUSSION 103
5.1 Yield Components and Yield Perfomance 103
5.2 Diseases Reaction 107

5.3 Effect on Plant Germination 108

5.4 Plant Population Densities 108

5.5 Heritability Estimates 109

5. 6 Simple Correlation 111

5.7 Path Coefficient Analysis 112

5.8 Genotype Stability in Performance 113

CHAPTER SIX **116**

6.0 CONCLUSION AND RECOMMANDATIONS **116**

6.1 Conclusion 116

6.2 Recommendations 117

REFERENCES **118**

APPENDICES **135**

LIST OF TABLES

Table 1: Bean production statistics in Burundi 1996-2011 10

Table 2: ANOVA summary for different variables studied at GISOZI 34

Table 3: Plant germination (%) of eight bean genotypes at three plant spacings at Gisozi sites during 2013A season 35

Table 4: Disease reaction of eight bean genotypes at three plant spacing at Gisozi site during 2013A season 36

Table 5: Mean DFL and DPM for eight genotypes at Gisozi during 2013A season.... 37

Table 6: Mean PH and S/P for eight genotypes at Gisozi during 2013A season 37

Table 7: Mean 100SW and SY (t/ha) for eight genotypes at Gisozi during 2013A season 38

Table 8: Simple correlation coefficient between SY and yield components at Gisozi site during 2013A season 39

Table 9: Path analysis showing direct and indirect effects of different yield components on seed yield at Gisozi site during 2013A 40

Table 10: ANOVA summary for different variables studied at Murongwe during 2013A season 41

Table 11: Plant germination (%) of eight bean genotypes at three plant spacing at Murongwe site during 2013A season 42

Table 12: Disease reaction of eight bean genotypes at three plant spacing at Murongwe site during 2013A season 43

Table 13: Mean DFL and DPM for eight genotypes at Murongwe during 2013A season 43

Table 14: Mean PH and S/P for eight genotypes at Murongwe during 2013A season .. 44

Table 15: Mean 100SW and SY for eight genotypes at Murongwe during 2013A season 45

Table 16: Simple correlation coefficient between seed yield and yield components at Murongwe site during 2013A season 46

Table 17: Path analysis showing direct and indirect effects of different yield components on seed yield at Murongwe site during 2013A 47

Table 18: ANOVA summary for different variables studied at Moso during 2013A season 47

Table 19: Plant germination (%) of eight bean genotypes at three plant spacing at Moso site during 2013A season 48

Table 20: Disease reaction of eight bean genotypes at three plant spacing Moso site during 2013A season 49

Table 21: Mean DFL and DPM for eight genotypes at Moso during 2013A season 49

Table 22: Mean PH and S/P for eight genotypes at Moso during 2013A season 50

Table 23: Mean 100SW and SY for eight genotypes at Moso during 2013A season 50

Table 24: Simple correlation coefficient between grain yield and yield components at Moso site during 2013A season 51

Table 25: Path analysis showing direct and indirect effects of different yield components on seed yield at Moso site during 2013A 52

Table 26: Analysis of variance in combined analysis during 2013A season 53

Table 27: Main effect of genotypes on yield and yields components in combined sites during 2013A season 55

Table 28: Combined simple correlation coefficient between grain yield and yield components across sites during 2013A season 56

Table 29: Path analysis showing direct and indirect effects of different yield components on seed yield in combined sites during 2013A 57

Table 30: Combined means of G x E interactions for DFL during 2013A season 58

Table 31: Combined means of G x E interactions for PH during 2013A season..... 58

Table 32: Combined means of G x E interactions for DPM during 2013A season 59

Table 33: Combined means of G x E interactions for P/P during 2013A season 59

Table 34: Combined means of G x E interactions for S/P during 2013A season 59

Table 35: Combined means of G x E interactions for 100SW during 2013A season.... 60

Table 36: Combined means of G x E interactions for SY during 2013A season..... 60

Table 37: Means, variance and estimates of heritability for yield and its components for beans genotypes evaluated across three sites during 2013A season..... 61

Table 38: ANOVA summary for different variables studied at GISOZI during 2013B season..... 66

Table 39: Plant germination (%) of eight bean genotypes at three plant spacings at Gisozi sites during 2013B season 67

Table 40: Disease reaction of eight bean genotypes at three plant spacings at Gisozi site during 2013B season..... 69

Table 41: Mean DFL and DPM for eight genotypes at Gisozi during 2013B season.... 70

Table 42: Mean 100SW for eight genotypes at Gisozi during 2013B season 71

Table 43: Mean PH (cm) and SY (t/ha) for eight genotypes at Gisozi during 2013B season..... 71

Table 44: Simple correlation coefficient between yield and yield components at Gisozi site during 2013B season..... 72

Table 45: Path analysis showing direct (diagonal) and indirect (off diagonal) effects of different yield components on seed yield at Gisozi site during 2013B 73

Table 46: ANOVA summary for different variables studied at Murongwe during 2013B season 74

Table 47: Plant germination (%) of eight bean genotypes at three plant spacings at Murongwe site during 2013A season 75

Table 48: Disease reaction of 8 bean genotypes at three plant spacings at Murongwe site during 2013B season 77

Table 49: Mean DFL and DPM for eight genotypes at Murongwe during 2013B season 78

Table 50: Mean PH and P/P for eight genotypes at Murongwe during 2013B season .. 79

Table 51: Mean 100SW for eight genotypes at Murongwe during 2013B season..... 79

Table 52: Mean S/P and SY for eight genotypes at Murongwe during 2013B season .. 80

Table 53: Simple correlation coefficient between SY and yield components at Murongwe site during 2013B season 81

Table 54: Path analysis showing direct and indirect effects of different yield components on seed yield at Murongwe site during 2013B 82

Table 55: ANOVA summary for different variables studied at Moso during 2013B season 82

Table 56: Plant germination (%) of eight bean genotypes at three plant spacing at Moso site during 2013A season 83

Table 57: Disease reaction of eight bean genotypes at three plant spacing at Moso site during 2013B season 85

Table 58: Mean DFL and DPM for eight genotypes at Moso during 2013B season 86

Table 59: Mean 100SW for eight genotypes at Moso during 2013B season..... 87

Table 60: Mean PH and SY for eight genotypes at Moso during 2013B season..... 87

Table 61: Simple correlation coefficient between SY and yield components at Moso site during 2013B season 88

Table 62: Path analysis showing direct (diagonal) and indirect (off diagonal) effects of different yield components on seed yield at Moso site during 2013B 89

Table 63: ANOVA summary for different variables studied in combined site during 2013B season 90

Table 64: Main effect of genotype on yield and yields components in combined sites during 2013B season 92

Table 65: Combined simple correlation coefficients between SY and yield components across sites during 2013B season 93

Table 66: Path analysis showing direct (diagonal) and indirect (off diagonal) effects of different yield components on seed yield in combined sites (t/ha) during 2013B 94

Table 67: Combined means of G x E interactions for DFL during 2013B season 95

Table 68: Combined means of G x E interactions for PH during 2013B season 95

Table 69: Combined means of G x E interaction for DPM during 2013B season 96

Table 70: Combined means of G x E interaction for P/P during 2013B season 96

Table 71: Combined means of G x E interaction for S/P during 2013B season 97

Table 72: Combined means of G x E interaction for 100SW during 2013B season 97

Table 73: Combined means of G x E interactions for SY (t/ha) during 2013B 98

Table 74: Means and estimates of heritability parameters for growth characteristics, yield and yield components for bean genotypes evaluated across three sites during 2013B season 98

LIST OF FIGURES

Figure 1: Biofort bean genotypes studied 24

Figure 2: Vegetative growth of different bean genotypes at Gisozi in 2013A season showing low germination in some plots 35

Figure 3: Effect of plant population (spacing) and genotypes on seed yield at Gisozi site during 2013A season 38

Figure 4: Path diagram showing relationship between yield (t/ha) and yield components at Gisozi site during 2013A season 40

Figure 5: Vegetative growth of different bean genotypes at Murongwe in 2013A season 42

Figure 6: Effect of population (spacing) and genotypes on seed yield at Murongwe site during 2013A season 45

Figure 7: Path diagram indicating the interrelationships among the bean yield with its components at Murongwe site during 2013A season 46

Figure 8: Vegetative growth of different genotypes at Moso in 2013A season showing poor germination in some plots 48

Figure 9: Effect of population (spacing) and genotypes on seed yield at Moso site during 2013A season 51

Figure 10: Path diagram indicating the interrelationships among the bean yield with its components at Moso site during 2013A season 52

Figure 11: Effect of population (spacing), sites and genotypes on seed yield in combined site during 2013A season 55

Figure 12: Path diagram indicating the interrelationships among the bean yield with its components in combined sites during 2013A season 57

Figure 13: b-value plotted against mean P/P (a) and S^2d plotted against b-value for P/P (b) during 2013A season 62

Figure 14: b-value plotted against mean S/P (a) and S^2d plotted against b-value for S/P during 2013A season 63

Figure 15: b-value plotted against mean of 100SW (a) and S^2d plotted against b-value for 100SW (b) during 2013A season 64

Figure 16: b-value plotted against the mean SY (a) and S^2d plotted against b-value (b) for SY during 2013A season 65

Figure 17: Development stage of different bean genotypes at Gisozi in 2013B season showing good plant stand 67

Figure 18: Effect of population (spacing) and genotypes on seed yield at Gisozi during 2013B season 71

Figure 19: Path diagram indicating the interrelationships among the bean yield with its components at Gisozi site during 2013B season 73

Figure 20: Development stage of different bean genotypes at Murongwe in 2013B season 75

Figure 21: Effect of population (spacing) and genotypes on seed yield at Murongwe site during 2013B season 80

Figure 22: Path diagram indicating the interrelationships among the bean yield with its components at Murongwe site during 2013B season 81

Figure 23: Development stage of different genotypes at Moso during 2013B season showing vigorous plants 83

Figure 25: Effect of population on yield and mean performance of different genotypes at Moso site during 2013B season 87

Figure 26: Path diagram indicating the interrelationships among the bean yield with its components at Moso site during 2013B season 88

Figure 27: Effect of population on yield and mean performance of different genotypes in combined site during 2013B season 92

Figure 28: Path diagram indicating the interrelationships among the bean yield with its components in combined sites during 2013B season 94

Figure 29: b-value plotted against mean P/P (a) and S^2d plotted against b-value for P/P (b) during 2013B 99

Figure 30: b-value plotted against mean S/P (a) and S^2d plotted against b-value for S/P (b) during 2013B 100

Figure 31: b-value plotted against mean of 100SW (a) and S^2d plotted against b-value for 100SW (b) during 2013B 101

Figure 32: b-value plotted against the mean SY (a) and S^2d plotted against b-value (b) for SY (b) during 2013B 102

LIST OF APPENDICES

Appendix 1: Path diagram showing causal relationships between yield and yield components....135

Appendix 2: Mean monthly temperature and total rainfall during the experimental period October 2012-June 2013 at Moso site....135

Appendix 3: Mean monthly temperature and total rainfall during the experimental period October 2012-June 2013 at Murongwe site....136

Appendix 4: Mean monthly temperature and total rainfall during the experimental period October 2012-June 2013 at Gisozi site 136

Appendix 5: Physical and chemical characteristics of the soil at Gisozi site....137

Appendix 6: Physical and chemical characteristics of the soil at Murongwe site....137

Appendix 7: Physical and chemical characteristics of the soil at Moso site....138

Appendix 8: Regression of P/P for each genotype across locations during 2013A....138

Appendix 9: Regression of S/P for each genotype across locations during 2013A....138

Appendix 10: Regression of 100SW (g) for each genotype across locations during 2013A....139

Appendix 11: Regression of SY (t/ha) for each genotype across locations during 2013A....139

Appendix 12: Regression of P/P for each genotype across locations during 2013B....139

Appendix 13: Regression of S/P for each genotype across locations during 2013B....139

Appendix 14: Regression 100SW (g) for each genotype across locations during 2013B....140

Appendix 15: Regression of SY (t/ha) for each genotype across locations during 2013B....140

LIST OF ABBREVIATIONS AND SYMBOLS

Al	Aluminium
ALS	Angular Leaf Spot
ANOVA	Analysis of Varience
B	Bore
BCMV	Bean Common Mosaic Virus
CBB	Common Bacterial Blight
CEC	Cation Exchange Capacity
CIAT	International Center for Tropical Agriculture
CV	Coefficient of Variation
DAP	Di-Ammonium Phosphate
DF	Degree of Freedom
DFL	Days to 50% Flowering
DNA	Dinucleotide Adenosine
DPM	Days to Physiological Maturity
DSIA	Direction des Statistiques et Informations Agricoles
e.g	For example
EGA	Expected Genetic Advance
FBU	Francs Burundi
G x E	Genotype by Environment
GCV	Genotypic Coefficient of Variation,
Geno	Genotype
$h^2(b)$	Heritability in broad sense,
HB	Halo Blight
HSW	100Seeds Weight

i.e	That is
ILRI	International Livestock Research Institute
ISABU	Burundi Agricultural Sciences Institute
ISTEEBU	Institut de Statistique et d'Etude Economique du Burundi
km^2	Kilometer square
LSD	Least Significant Different
meq/100g	Milliequivalent per 100 grams
METs	Multi-Environmental Trials
MINAGRIE	Ministère de l'Agriculture et de l'Elevage
Mn	Manganese
MPDRN	Ministère de la Planification du Développement et de la Reconstruction Nationale
Na	Sodium
P/P	Pods per Plant
PCV	Phenotypic Coefficient of Variation,
PG	Plant Germination
PH	Plant Height
pH	Hydrogen ion concentration
S/P	Seeds per Pods
Spac	Spacing
SY	Seed Yield
t/ha	Tonne per hectar
UNDP	United Nations Developpment Program
$\delta^2 e$	Component of variance due to environments
$\delta^2 g$	Component of variance due to genotypes
$\delta^2 ph$	Component of variance due to phenotypes

CHAPTER ONE

1.0 INTRODUCTION

In the world, common beans (*Phaseolus vulgaris* L.) are the important food legumes for direct consumption (Katungi *et al.*, 2010). The crop is one of the principal food and cash crop legumes grown in the tropics (Tryphone and Nchimbi-Msolla, 2010). Although this crop is very important to both the developed and developing world as a mean of dietary protein supply (Kalavacharla *et al.*, 2011). It is a subsistence crop eaten by its producers and, hence, is underestimated in production and commerce statistics. Indeed, in many of the countries in the world, especially developing countries, it is consumed as an important part of the diet and not exported (Gepts *et al.*, 2008).

In African countries, *Phaseolus vulgaris* L. is an important leguminous crop of greater nutritional status to poor communities. It is nicknamed as a meat of the poor men due its potential role in the daily diet settings of the poor where expensive animal protein cannot be afforded (Ndakidemi *et al.*, 2011). Similarly, in eastern and southern Africa, common bean is a major staple crop where it is an important food to people of all income categories (Hillocks *et al.*, 2006, Wortmann *et al.*, 1998). However in some developing countries, such as Burundi, Rwanda, and Uganda, bean provides 40%, 31%, and 15% of the daily intake of total protein, respectively (Gepts *et al.*, 2008).

Moreover, bean is among the top most essential subsistence food crop in Burundi as it forms an important part of daily diet providing 20% of required calories and 50% of proteins (ISABU, 2009; Hirst, 2012). It is often cultivated by small-scale farmers in small plots of land in association with other crops or as a sole crop with low external input. It is grown under traditional farming systems, usually as an intercrop with maize, cassava and

colocase (MINAGRIE DSIA, 2012). The crop is playing a significant role in smallholder economy being an imperative source of proteins and income as cash crop. Furthermore, common bean is grown in all agroecological zones of Burundi: low altitude zone (770-1000 m); intermediate altitude zone (1125-1400m); middle altitude zone (1500-1800 m) and high altitude zone (1800-2600 m) differing in soil types and rainfall amount. In such conditions, it is necessary to make available a number of varieties which are adapted in different combination factors (Godderis and Schmit, 1993; ISABU, 2011). Burundi agricultural lands occupied by the beans are estimated to 400 000 ha and production declined from 230 241 tons/year in 2003 to 202,934 tons/year in 2009 (ISTEEBU, 2009).

Despite the importance and role of common beans in Burundi, the productivity of this crop is constrained by biotic and abiotic stresses such as diseases, declining soil fertility, poor crop management practices including low inputs and poor access to improved germplasm and unreliable climatic conditions (ISABU, 2011). This has led to low agricultural productivity by the smallholder farmers (Birachi *et al.*, 2011). The variation in adaptation limits some farmers who would be intersted to grow bean varieties in particular area but restricted by instability of bean yields across environments (Mwale *et al.*, 2008). The variability in environment namely locations, seasonal fluctuations and their interaction highly influence the performance of genotypes in relation to yield potential (Rahman *et al.*, 2010).

In addition, there is currently inadequate information on the stability and response of different cultivars especially common beans in different agro ecological zones of Burundi. Most of the bean genotypes grown in the country are selected with little reference to stability performance, resulting to the low yield and poor quality of seed obtainable. The current potential production on farmer's level is comprised between 600

and 800kg/ha, whereas on research station is 1200-1500kg/ha in the case of bush bean. For the case of climbing bean, potential production on farmer's level is 1000-1500kg/ha; whereas on research station is 2500-3000kg/ha (ISABU, 2011). Recently, statistics showed that beans interest many privates producers and smallscale farmers' associations in various regions of the country (MINAGRIE DSIA, 2012). Because of high population density (325 inhabitants/km^2) there is a high demand for beans within the country and market prices have been increased since 2008 from 800FBU/kg to 1400FBU/kg in 2012 for the case of yellow bean varieties and from 500FBU/kg in 2008 to 1000FBU in 2012 for the case of other improved varieties and mixtures (ISTEEBU, 2009). These have encouraged farmers and associations of smallscale farmers to grow the crop for income generation.

On the other hand, the ultimate of plant breeder in any crop improvement programme is based to the development of cultivars that can be adapted to a wide range of environment. Thus, adaptability of a variety over diverse environments is usually tested by the degree of its interaction with different environment at which it is planted (Khan *et al.*, 2008). The study of G x E interaction is of great importance in genotype testing programs because yield performance of a genotype is a result of the interaction between the genotype and environment. Environmental factors, such as rainfall, temperature and soil structure play an important role in genotype performance, grain yield and quality (Akcura and Kaya, 2008). However, when genotypes are subjected to different environments, their performance, relative to each other may not be the same (McDonald, 2009). The differences in performance among genotypes under different environments necessitate the need to evaluate them as a basis for making informed recommendations to farmers in different agro-ecological zones. Hence, it is important that plant breeders develop bean varieties that are stable and the genotype with wide adaptability if available

can be utilized. This justifies and underlines the importance of identifying genotypes that are stable across a wide range of environments in Burundi.

The overall objective of this study was to identify high yielding and stable bean genotypes that perform well across different environments in Burundi with desirable and superior seed quality for the farmers. The specific objectives were:

i. To determine Genotype x Environment interaction on yield components of seven biofort genotypes.
ii. To estimate stability and relationship among stability parameters with seed yield and its components of the beans genotype studied across different environments.
iii. To estimate the broad-sense heritability parameters of yield and yield components for selected common bean genotypes.
iv. To determine appropriate spacing for bean planting in Burundi.

CHAPTER TWO

2. 0 LITERATURE REVIEW

2.1 Common Bean

2.1.1 Ecology

(a) Climatic conditions

Generally, common bean is considered as a short-season crop with most varieties maturing in a range of 65 to 110 days from emergence to physiological maturing. It grows well in a wide range of environments in temperate, sub tropic and tropical regions (Fivawo and Nchimbi-Msolla, 2011). It is suited in areas with medium rainfall, 500 mm – 2000 mm of mean annual rainfall well distributed and followed by a dry weather season right after maturity for pods and seeds drying (Duke, 1983). The crop is a warm-season, annual, that does not tolerate frost or long periods of exposure to near-freezing temperatures at any stage of growth. Usually, high temperatures do not affect it if adequate soil water is present, although high nocturnal temperatures will inhibit pollination (Katungi *et al.*, 2010).

The crop requires between 200 and 400 mm of rainfall or comparable residual soil moisture during growth and development (Broughton *et al.*, 2003). According to Godderis (1993), a period of drought and a menstrual rainfall below to 40mm are limitant factors for bean production. Optimal seed germination and development during the first month are influenced by the mean temperature located between 22 to 26^0C. More than 26^0C and below 15^0C during the first month are also limitant factors on seed germination and young plants. Furthermore, beans grown in more moisture-retentive soils may not need watering except during particularly dry spells, but those grown in sandy soils almost certainly will require frequent watering (MacKenzie, 2009).

(b) Edaphic requirement

Bean is a small-scale farmer crop, where it is often cultivated in unfavorable conditions and with minimal inputs (Broughton *et al.*, 2003). Common beans tolerate most environmental conditions in tropical and temperate zones, but do poorly in very wet tropics where rain causes disease and flower drop (Duke, 1983). However, many cultivars tolerate a range of soil conditions but optimum pH range is 5.5 – 6.8 and common beans grow best in slightly acidic to neutral soil, pH between 6 and 7 (MacKenzie, 2009). Beans can tolerate acidic soil with pH comprised between 4.5-5.5. Below this range of pH, Al and/or Mn toxicity may be a problem (Allen *et al.*, 1987; Duke, 1983). They are frequently grown on acid soils that are low in available phosphorus (P) and/or have high P-fixing capacities (Allen *et al.*, 1987).

Beans are grown under quite diverse conditions both in terms of soil and planting systems in Burundi. Soil fertility differs from one region to another and from one farmer to another. Therefore, G x E interaction becomes an important factor in breeding programs since the existence of interaction implies the recommendation of cultivars for certain environment.

2.1.2 Bean production constraints

Yields in beans are limited in part by the short growing season, susceptibility to an array of viral, fungal and bacterial diseases, and insect pests, more prone to stress as recovery time is limited, nutrient deficiencies, and the limited investment in research to improve the crop (Kelly, 2010). Diseases and insect pests represent some of the major risks that farmers confront. At higher altitudes, anthracnose and rust are important limiting factors. Common bacterial blight, Rust and Web Blight are important bean diseases at lower altitudes (Broughton *et al.*, 2003). Lately, angular leaf spot has become an important bean disease at both lower and higher altitudes. Bean common mosaic virus (BCMV) is also an

important widespread disease generally in Africa and Burundi in particular (Allen *et al.*, 1987). Pathogens causing most of the above-mentioned diseases are seed-transmitted or survive for long periods on plant residues, alternate hosts, or in the soil (Gomez, 2004).

Abiotic stresses and drought stress remain others problems that farmers frequently face. Except for a few highland areas with abundant and well-distributed precipitation, and regions where irrigation is available, bean production is exposed to the risk of drought (Broughton *et al.*, 2003). Furthermore, soil problems due to toxic compounds and/or nutritional deficiencies limit productivity (Gomez, 2004). Soil fertility is continually declining, which decline is an increasingly significant constraint to the production of not only beans, but also of all crops (Wortmann *et al.*, 1998).

2.1.3 Uses

Beans are extremely diverse crops in terms of cultivation methods, uses, the range of environments to which they have been adapted, and morphological variability (Broughton *et al.*, 2003). They are well suited to low input systems as they can be stored for long periods without refrigeration and provide an excellent nutritional complement to maize, which is one of the most important grain cereals (Ferris and Kaganzi, 2008).

Throughout the world, the crop is a part of the daily diet of over 300 million people and the species is known as a key nutritional crop for low-income populations since it is the cheapest protein source available (Silva *et al.*, 2008). In general, a significant part of the human world population relies on legumes as a staple food for subsistence, particularly in combination with cereals (Muzquiz *et al.*, 1999). They provide dietary proteins that play an essential role in human nutrition by complementing other foods that are primarily sources of carbohydrates (Broughton *et al.*, 2003). Green beans contain 6.2% protein

0.2% fat and 63% carbohydrates whereas dried bean contains 22.9% protein, 1.3% minerals (Duke, 1983).

Moreover, they have the potential to alleviate micronutrient malnutrition and hunger as they are rich in quality protein, fibre and micronutrients. Compared with meat-based diets, plant based-diets are often limited in the content and bioavailability of essential minerals such as zinc (Zn), iron (Fe), calcium (Ca) and magnesium (Mg) (Akond *et al.*, 2011). The crop is a good source of energy and provides folic acid, dietary fibre and complex carbohydrates (Gichangi *et al.*, 2012). Compared to maize, rice and cassava, common beans (*Phaseolus vulgaris* L.) contain a high percentage of protein. This protein is high in lysine, which is relatively deficient in maize, rice and cassava (Mwale *et al.*, 2008).

In temperate regions the green immature pods are cooked and eaten as a vegetable. Immature pods are marketed fresh, frozen or canned, whole, cut or french-cut. Mature ripe beans, variously called navy beans, white beans, northern beans, or pea beans, are widely consumed (Duke, 1983). In lower latitudes, dry beans furnish a large portion of the protein needs of low and middle class families.

In some parts of the tropics leaves are used as a pot-herb, and to a lesser extent the green-shelled beans are eaten (Duke, 1983). Common bean has several market classes, which include dry beans, canned beans, and green beans (Kalavacharla *et al.*, 2011). However, in many countries of the world, especially developing countries, common bean is consumed as an important part of the diet and not exported. The importance of bean to diets in the developing world is reflected in the fact that for developing countries only

13% of production is exported. This contrasts with developed countries, which export 31% of their production (Gepts *et al.*, 2008).

In Burundi, *Phaseolus vulgaris* L. is grown for its green leaves, mature grain, green pods, and immature and/or dry seeds. The country has a high consumption rate of 60kg/pers/year taking several forms (Broughton *et al.*, 2003). However, for all these forms, beans are not consumed at fresh stage. Recently, new bean based recipes have been developped by ISABU to diversify common bean consumption in this country. Consequently, beans are grown in subsistence agriculture in Burundi where they play an important role for food security.

2.1.4 Common bean production in Burundi

The common bean is produced in higher, middle and lower areas of Burundi. Despite the importance of bean as a leader of all grain legumes in supplying the dietary protein, the yields are still very low (ISABU, 2009; ISTEEBU, 2009). Unfortunately, the rate of increase in bean production has been exceeded by the rate of population growth (Wortmann *et al.*, 1998). However, bean production is decreasing since 1996-2011 and this is due to the fact that farmers allocate small unit of land to this crop because of high population density which involves lack of agricultural land. Furthermore, low soil fertility, diseases and poor agronomic practices are the major constraints to bean production in Burundi. Table 1 indicates the evolution of bean production statistics since 1996 to 2011 (ISTEEBU, 2009; MINAGRIE DSIA, 2012).

Table 1: Bean production statistics in Burundi 1996-2011

Year	1st season (A)	2nd season (B)	3rd season (C)	Total Production (tons)
1996	111 570	157 768	17 623	286 961
1997	907 650	160 584	17 994	269 343
1998	90 765	160 584	17 994	269 343
1999	58 563	155 845	13 020	227 428
2000	53 936	105 801	27 680	187 417
2001	57 680	164 212	27 022	248 914
2002	58 701	159 566	27 022	245 289
2003	46 707	157 860	25 674	230 241
2004	49 372	157 479	13 367	220 218
2005	41 482	145 763	26 961	214 206
2006	33 210	150 921	24 820	208 951
2007	26 466	152 942	25 788	205 196
2008	25 038	136 256	28 367	189 661
2009	24 256	154 566	28 449	207 272
2010	21 754	150 493	29 303	201 551
2011	20 087	155 613	24 973	200 673

Source: ISTEEBU (2009), MINAGRIE DSIA (2012)

According to this table, the second season is more productive compared to the first and third season. This is due to the fact that during the first season, it is a period of heavy rainfall and in the third season requires irrigation and soil moisture.

2.2 Study of G x E Interaction

2.2.1 G x E interaction

G x E interaction is a term used to describe the interaction of environmental factors and genes or particular sets of genes (McDonald, 2009). It is one of the main complications in the selection of broad adaptation in most breeding programs. It has been established that the phenotype of an individual is determined by both the genotype and the environment and these two effects are not always additive which indicates that G x E interactions are present. Hence, G x E interaction results in inconsistent performances between the genotypes across environments (Alberts, 2004). The presence of G x E interaction implies the behaviour of genotypes with respect to the environment to which they are evaluated. An understanding of the causes of G × E interaction can help to identify traits that contribute to better cultivar performance and environments that facilitate cultivar evaluation (Yan and Hunt, 2001).

If there were no interactions, one variety would have been good enough for all environments and variety trials would have been conducted only at one location to provide universal results and if there was no noise, results would be exact and there would be no need for replications (Issa, 2009). But since the reality is quite different, two options are available to deal with these problems. The first one target the genotypes while the second aims at the environment. The first option is to search for high yielding and widely adapted cultivars that are successful across the growing environment of interest. The second alternative is to sub-divide the target regions into several relatively homogeneous macro-environments, then to develop and recommend suitable genotypes for specific regions (Issa, 2009).

Generally, G x E interaction limits breeding efficiency. With the aim to optimize grain yield, having in mind that superior genotype does not win always and everywhere, it is necessary to subdivide large growing regions into smaller target environments. That subdivision can be done more accurately by taking into account pattern in interaction effects in order to group larger numbers of environments into a smaller number of target environments (Babic *et al.*, 2011).

Indeed, when comparing the performance of crop genotypes across environments, G x E interaction is a serious problem as it reduces the efficiency of genetic gain through selection (Ojo *et al.*, 2006). Plant breeders encounter G x E interactions when testing varieties across a number of environments. Therefore, depending on the magnitude of the interactions or the differential genotypic responses to environments, the varietals ranking can differ greatly across environments (Sadeghi *et al.*, 2010). Baker (1988) defined G x E interaction as the failure of genotypes to achieve the same relative performance in different environments. However, in most cases, breeders look for a variety that has good

mean performance over a wide array of environments and years and the concept of stability is overlooked. Such approach is reasonable if there is no G x E interaction, but in most cases there is interaction.

The concepts of G x E interaction and yield stability have been an issue to the breeders and biometricians for a long of time (Adugna, 2007). This concept of G x E interaction is closely related to the concept of selection in plant breeding. The breeder is mainly interested in rank orders of genotypes in different environments and in changes of these rank orders (Yaghotipoor *et al.*, 2007). When the rank of breeding lines changes in different environments, G x E interaction becomes important and this change in rank has been defined as crossover G x E interaction (Baker, 1988).

Usually G x E interaction is the non additive component of two or more experiments with the same genotypes combined over environments. The process for selecting high yield and stable genotypes usually involves three stages of experimentation: at stage-1, genotypes are tested at a single location; at stage-2, the selected genotypes are tested in a multilocation trials (genotype x location); and finally at stage-3, the most promising genotypes with new set of genotypes are tested for several years under a range of locations (genotype x location x year) (Linn and Binns, 1994).

The release and development of new crop cultivars requires screening and extensive testing at several locations. The relative performance of cultivars varies across locations and from season (year) to season (year). Therefore, this phenomenon classically referred to as G x E interaction, should be considered in choosing test sites. Hence, there is a need to study the G x E structure to determine which test sites are essential to assess cultivars (Saindon and Schaalje, 1993). An understanding of the causes of G × E interaction can

help to identify traits that contribute to better cultivar performance and environments that facilitate cultivar evaluation. Amankwa *et al.* (2004) reported that G x E interaction is important in bean breeding under sole crop conditions. However, the changing environmental conditions affect the performance of beans genotypes which requires a breeding program that needs to take into account the consequences of G x E interaction in the selection and release of improved varieties.

When evaluating the stability of breeding plants under different environmental conditions, G x E interactions are great interest and the reliability of genotype performance across different environmental conditions can be an important consideration in plant breeding (Fikere *et al.*, 2008). A successfully developed new cultivar should have a stable performance and broad adaptation over a wide range of environments in addition to high yielding potential. Thus, evaluating stability of performance and range of adaptation has become increasingly important for breeding programs (Fikere *et al.*, 2008). A study of G x E interaction is of much value in the selection of better genotype (Raffi *et al.*, 2004).

In addition, G x E interactions is important in evaluating cultivar adaptation, selecting parents, and developing genotypes with improved end-product quality. Quality tests that are primarily affected by genetics and influenced less by environment also are useful in genotype development (Ames *et al.*, 1999). Diverse climatic conditions and soil types intensify the problem of G x E interaction in Burundi. To overcome this situation, the universal practice of scientists in most crops when selecting genotypes, is to plant them in yield trials over several environments and seasons (minimum 2 seasons) to ensure that the selected genotypes have a high and stable performance over a wide range of environments.

2.2.2 Environment factors affecting G x E interaction

When making decisions on the identification of certain growing regions and the development of varieties, the effects of genotype (G) and G x E are very important. Although the main genotype effect and the interaction effect should be partitioned, there is still a need for their integration in the yield, as both simultaneously affect a ranking of the particular genotype within a certain environment (Babic *et al.*, 2011). G x E interaction occurs when different genotypes respond differently to different environments and environmental factors such as soil characteristics and types, moisture, sowing time, fertility, temperature, day length vary over the years and locations (Ali *et al.*, 2009). The extent to which the genotypes respond can be low that the G x E effect can be ignored or high that the identification of superior genotypes is difficult. However, in case of low G x E interaction, the best genotypes can be recommended for cultivation across a wide range of environments. If the interaction is high, specific genotypes should be recommended for specific environments. This information is very important for the recommendation of new varieties (Pimsaen *et al.*, 2010).

Allard and Bradshaw (1964) considered two categories that contribute to the G x E interaction to which it is submitted. The first category is predictable and it includes those factors that are under human control such as soil type, planting date, row spacing, plant population , rate of nutrients application, amount of irrigation and others that can be artificially created. In some situations, environmental variation can be considered as predictable but can also be corrected. For example, saline soils can be corrected by certain agronomic practices or by addition of some amendments. This is easier and quicker than developing varieties suitable for such situations (Issa, 2009). The second is unpredictable or uncontrollable environments and it includes weather fluctuations such as differences between seasons in terms of amount and distribution of rainfall and the prevailing

temperature during the crop growth and relative humidity. The contribution of predictable environmental fluctuations to genotype x location interactions can be reduced by allocating specific cultivars to specific environments (Allard and Bardshaw, 1964).

Unpredictable environmental variation is more difficult and often leads to large genotype x year and genotype x year x location interactions (Allard and Bardshaw, 1964). Selection of stable cultivars that perform consistently across environments can reduce the magnitude of these interactions. However, the G x E interaction is of major consequences to the breeders in the process of evaluation of new varieties. The target of most of breeders is to evolve strains which may give the maximum mean economic yield over environments and show consistent performance (Nehvi *et al.*, 2007). Moreover, the yielding ability of a variety is the result of its interaction with the prevailing environment (Ali *et al.*, 2009). Hence, correct interpretation of G x E studies depends on testing over a sufficient number of environments, using an appropriate range of genotypes and suitable methods of statistical analysis to determine the cause of significant interactions (Ames *et al.*, 1999).

2.2.3 Stability parameter

In any crop, G x E interactions are important source of variation and are independent of changing environmental conditions. Then, the term stability is sometimes used to characterize a genotype which shows a relatively constant yield (Tiawari *et al.*, 2011). On the basis of this idea, genotypes with a minimal variance for yield across different environments are considered stable (Akcura and Kaya, 2008).

The highest yielding genotypes in high-yielding environments will be genotypes that are not superior in low-yielding environments and vice versa. This can lead to the promotion

of one or a few varieties, which are widely adapted or can be grown over large areas. Selection of stable cultivars that perform consistently across environments can reduce the magnitude of G x E interactions (Gebeyahu and Assefa, 2003). Then, it is important to breed for new cultivars with improved adaptation to the environmental constraints prevailing in the target environments (Gurmu *et al.*, 2009).

Multi-environment trials play an important role in selecting the best cultivars and/or agronomic practices to be used in future years at different locations by assessing a cultivar's stability across environments before its commercial release. Therefore, knowledge of G x E interaction is advantageous to have a cultivar that gives consistently high yield in a broad range of environments and to increase efficiency of breeding programme and selection of best genotypes that are less affected by environmental variation (Mekonnen *et al.*, 2010).

The stability with which a plant breeder is concerned implies stability in those aspects of phenotype which are important economically, such as grain yield and quality. Such stability may depend upon holding some aspects of morphology and physiology in a steady state but allowing others to vary (Issa, 2009). In this way, a genotype is considered to be stable if its among-environment variance is small and the desirable varieties will show low G x E interaction for agriculturally important characters, especially grain yield, but not necessarily for other characteristics (Rahman *et al.*, 2010).

Therefore, two basic concepts of phenotypic stability are distinguished: the biological concept of stability or stability statistic, and the dynamic concept. The biological concept of stability refers to the constant performance of a genotype over a wide range of environments (Issa, 2009). The dynamic stability, also termed as agronomical concept of

stability, implies that a stable genotype should always give high yield expected at the level of productivity of the respective environments, i.e., a variety with G x E interaction as small as possible (Issa, 2009).

According to Adebis (2009), stable genotypes are the ones which perform similar regardless of the productivity level of the environments and they are also considered as stable if, at a given location or plant population they exhibit very little fluctuation in seed quality from year to year. In agricultural sense, stability means whether species display the same production efficiency as predicted, while in biological sense, it is the fixed production efficiency of the species under different environmental conditions (Kan *et al.*, 2010). Stability is one of the most desirable properties of a genotype to be released as a cultivar for wide range of application. Hence, evaluating stability of performance and range of adaptation has become increasingly important for breeding programs and to identify stable genotypes is the primary goal of most plant breeders, whose yield performance remains high across a range of environmental conditions (Shah *et al.*, 2009). The genetic improvement programs of the common bean aim to identify genotypes with high production capacity and yield stability (Chiorato *et al.*, 2008). Gurmu *et al.* (2009) stated that in most cases breeders look for a variety that has good mean performance over a wide array of environments and years and the concept of stability is overlooked.

If there is no G x E interaction such approach is reasonable, but in most cases there is interaction. Indeed, in few environments some genotypes can have high yield and very low yield in other environments, showing better mean performance across environments. But few genotypes may have average yield that is stable over wider environments (Gurmu *et al.*, 2009). Because of that, knowledge of the pattern and magnitude of G x E interaction and the stability analysis is important for understanding the response of

different genotypes to varying environments and for identification of stable and widely adapted and unstable but specifically adapted genotype (Shah *et al.*, 2009). Thus, it is important to breed new cultivars with improved adaptation to the environmental constraints prevailing in the target environments. Stability of yield of a cultivar across a range of production environments is very important for variety recommendation. The cultivars must have the genetic potential for superior performance under ideal growing conditions, and must also produce acceptable yields under less favorable environments (Gurmu *et al.*, 2009).

To implement stability analysis, variance values of the G x E interaction must be statistically significant. If the variance were statistically insignificant, selection of the species would be easier in the studies carried out to determine adaptation of species in different environmental conditions. When the interaction is significant and rank of species performance changes, species should be bred for each location (Kan *et al.*, 2010). Plant breeders should select the lines with the highest average efficiency when the genotype x location x year interaction is significant. Hence, stable lines have low variance, similar performance to their experimental performance average and low mean square for deviation from regression (Kan *et al.*, 2010). Therefore, a stable genotype can be referred to as the one that is capable of utilizing the resources available in high yielding environments and has a mean performance that is above average in all environments (Eberhart and Russell, 1966).

According to Rahman *et al.*, 2010, a genotype is considered to be stable if it possesses an unchanged or least changed performance regardless of any variation of the environmental conditions. Any crop genotype that demonstrates consistency of performance or small variation accross environments is said to show general adaptation (Ojo *et al.*, 2006).

Analysis of interaction of G x E and other agro-ecological conditions would help in getting information on adaptability and stability of performance of genotypes (Das *et al.*, 2010).

2.2.4 Assessment of G x E interaction

For the estimation and partitioning of G x E interactions, different statistical methods have been proposed and can be broadly categorized into four groups (Issa, 2009): analysis of components of variance, stability analysis, multivariate methods and qualitative methods. The most common method used to identify the existence of G x E interaction from replicated multilocation trials is a combined analysis of variance procedure. If the G x E interaction variance is found to be significant, one or more of the various methods for measuring the stability of genotypes can be used to identify the stable genotype(s) (Alberts, 2004).

Determination of G x E interaction requires appropriate experimental procedures. Over years, a number of parametric statistical procedures has been used to analyze G x E interaction and especially yield stability over environments. Different approaches used were joint regression analysis and multivariate statistics, to describe the performance of genotypes over environments (Alberts, 2004). A vast number of univariate and multivariate, parametric and non-parametric stability models have been suggested to determine the response of genotypes to changing environment (Talebi, 2010).

The most common approach is parametric analyses, based on statistical assumptions about the distribution of genotypic, environmental and G x E interaction effects. It is useful when the data are continuous. Another approach is non parametric or analytical clustering, which defines environments and phenotypes in terms of biotic and abiotic

factors and is useful when the data are discontinuous. Non-parametric data analysis has the potential to reduce complex data into intuitive measures of stability. The model that has been in frequent use by breeders is one that is based on linear regression (Adugna, 2007). This was first proposed by Finlay and Wilkinson (1963).

Various methods have been proposed for the statistical analysis of interactions in general, and G x E interaction (Finlay and Wilkinson,1963; Eberhart and Russel,1966; Freeman, 1973; Santos *et al.,* 1982). Eberhart and Russel (1966) later modified it and suggested a different selection measure of stability of a genotype based on high mean yield, unit linear regression and low deviation from regression. Finlay and Wilkinson (1963) defined a genotype with regression coefficient equal to zero (bi= 0) as stable, while Eberhart and Russell (1966) defined a genotype with bi =1 to be stable.

According to the joint regression model, a stable genotype is one with a high mean yield, bi= 1 has average stability but genotypes which have slope greater than one and less than one are below and above average stability respectively. In addition to the bi, the deviation mean square $S^2d=0$ which describes the contribution of genotype to the G x E interaction is used (Eberhart and Russell, 1966). However, Eberhart and Russell's model is one of the best techniques used to rank the genotype for stability. Nath *et al.* (2013) reported that the suitability of genotypes for different environments was considered such as genotype having mean yield greater than the grand mean (population mean), S^2di low or non-significant and 'bi' approaching to unity were regarded as having general adaptability or average stability; 'bi' significantly greater than unity is considered as better adaptable to rich or favorable environment (below average stability) and 'bi' significantly less than unity and or having lower magnitude than unity are considered as better adaptable to poor or unfavorable environment (above average stability).

Other biometricians have considered stability parameters of yield as to be determined by the regression b and its standard deviation s^2d (Santos *et al.*, 1982). With the help of statistical techniques developed to estimate stability parameters, it is possible to determine genotypic response for wider adaptability. The performance of each genotype is regressed on the environment to obtain its mean performance over all environments. Correlation coefficients in general show associations among independent characteristics and the degree of linear relation between these characteristics (Ali *et al.*, 2009).

According to Shah *et al.* (2009), Genotype performance in multi-environment trials (METs) are usually analyzed by parametric analysis of variance (ANOVA) and stability models. Therefore, assessment of G x E interaction is important in plant breeding since the expression of phenotypic trait depends on the degree of plant adaptation. Amankwa *et al.* (2004) pointed out that G x E interaction is important in bean breeding under sole crop conditions. However, the changing environmental conditions affect the performance of beans genotypes which requires a breeding program that needs to take into account the consequences of environment and genotype interaction in the selection and release of improved varieties.

2.3 Heritability

The concept of heritability is used to examine the relative contributions of genes and environments to variation in a specific trait. Heritability is used to indicate the relative degree to which a character is transmitted from parent to offspring. The magnitude of such estimates also suggests the extent to which improvement is possible through selection.

Like other legumes, seed yield in common bean (*Phaseolus vulgaris* L.) is a quantitative character and is influenced by a number of yield contributing traits. The selection of desirable types should therefore be based on yield as well as on other yield components. Information on mutual association between yield and yield components is necessary for efficient utilization of the genetic stock in crop improvement program of this crop (Nechifor *et al.*, 2011).

According to Raffi and Nath, 2004, yield in dry bean like other crops, is a complex character and many morphological and physiological characters constitute it. In common beans, yield is improved by direct selection and by indirect selection for plant ideotype traits affecting yield (Scully *et al.* 1991). Heritability, or the degree of genetic control associated to some interest trait, is one of the most important parameters within the breeding context. Furthermore, heritability values are expressed in percent. If the estimated heritability value (h^2) is high (close to 100 percent), the observed variability is mostly must due to genetic factors. On the other side, if the heritability value is low, the observed variation is mainly due to environmental factors and little gain can be expected from selection in the particular population for the given character (Nechifor *et al.*, 2011).

For any planned breeding programs aimed to improve seed yield potential of a crop, information on the magnitude and type of genetic variability and the corresponding heritability is very important (Nechifor *et al.*, 2011).

2.4 Path Coefficient Analysis

Grain production is a complex phenomenon, entailing several contributing factors. These factors influence grain production both directly and indirectly and the breeder is naturally interested in investigating the extent and type of association of such traits

(Kashif and Khaliq, 2004). Therefore, information on direct and indirect effect of these components is of great importance. Study of such yield components may provide a solid ground for a succesfull varietal development program. Path coefficient analysis has been defined as a statistical technique of partitioning the correlation coefficients into its direct and indirect effects. With path coefficient the contribution of each character to yield can be estimated. In plant breeding programs, it is used to determine the nature of the relationships between yield and yield components that are useful as selection criteria to improve the crop yield (Mugemangango and Kumar, 2011). According to Alkuddsi *et al.*, 2013, the relationship between yield and yield components may be negative or positive but it is the net result of direct effect of that particular trait and indirect effects via other traits.

The goal of the path analysis is to describe correlation between the traits, based on a model of cause and effect relationship and to estimate the importance of the affecting traits on a specific trait. In fact, if the cause and effect relationships between the traits are well defined, it is possible to present the whole system of variables in the form of the diagram, known as path-diagram (Rasaei *et al.*, 2011). Correlation of a particular character with other characters contributing to seed yield is of great importance in indirect selection of genotypes for higher seed yield. In such situations, the correlation coefficients may be confounded with indirect effects due to common association inherent in trait interrelationships (Tahir *et al.*, 2002).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

3.1.1 Genotypes characteristics

Seven biofort genotypes (KAB06F2-8-53, KAB06F2-8-24, KAB06F2-8-78, KAB06F2-8-135, KAB06F2-8-22, KAB10F2-8-40 and KAB06F2-8-13) from CIAT and one local adapted variety (GLP2) from ISABU considered as control were used in the experiment as presented below (Fig. 1). Indeed, biofort bean genotypes are genotypes highly rich in micronutrients (Fe, Zn) and proteins which are supposed to minimize malnutrition and mineral deficiency in the diet of the population. These genotypes are advanced lines of F_5 generation selected from previous variety trials conducted by ISABU at Moso research station. They are of the same seed type with very minor variations (small and big size, shape, dark or deep red mottled and light red mottled) (Fig. 1). These lines need to be assessed for yield performance over a wide range of environments before being released for adoption in Burundi.

Figure 1: Biofort bean genotypes studied

3.1.2 Sites description

The study was conducted at ISABU research institute in Burundi. Cropping trials were conducted in three locations during the first (2013A) and the second(2013B) cropping seasons. The genotypes were evaluated on two research stations of ISABU (Moso and Gisozi) and one research center of ISABU located at Murongwe.

The Moso research station of ISABU is located in low altitude in South-Eastern plain of Burundi at Bukemba commune near Tanzanian border. It is situated at 1241m altitude. The annual rainfall of Moso region is estimated around 1115mm from the end of November to the middle of May. Geographical coordinates of Moso station is at latitude 4°00'24.15"S and longitude 30°04'20.91"E. The temperature is between 14-28^{0}C. Moso region's soils have high natural fertility and are suitable for agriculture (MPDRN and UNDP, 2006a).

Murongwe research center of ISABU is located in the middle altitude interior of the country at Mutaho commune. It is situated at 1511m altitude at Kirimiro region and the annual rainfall of this region is between 1200-1500mm from October to the middle of May. Geographical coordinates of Murongwe research center are 3°11'40.72"S latitude and 29°53'55.41"E longitude. The temperature is comprised between 17-20^{0}C. Because of high population density in Kirimiro region, low soil fertility is becoming a serious issue (MPDRN and UNDP, 2006b).

Gisozi research station of ISABU is located in high altitude at Kayokwe commune. It is situated at 2100 m altitude at Mugamba region and annual rainfall of the region is comprised between 1200-2000mm from October to June. Geographical coordinates of Gisozi research station are 3°33'57.81"S latitude and 29°40'56.26"E longitude.

The temperature is comprised between 14-20^{0}C. Mugamba region is characterized with low soil fertility and cold weather (MPDRN and UNDP, 2006c).

3.2 Methods

3.2.1 Land preparation and sowing

Ploughing, levelling and cleaning were done by a hand hoe. Two seeds per hill were planted. The field experiment was set out on 17 and 18 October 2012 at Gisozi and Murongwe respectively; and on 7 December 2012 in Moso during the first cropping season (2013A). It was also set out during the second cropping season (2013B) on 12, 13 and 18 March, 2013 in Murongwe, Moso and Gisozi respectively.

3.2.2 Experimental design and layout treatment

The experiments were laid out in split plot design in each location and replicated three times. The experiments were conducted in three locations. The Location was considered as main plot (factor A); while the spacing was considered as sub plot (factor B) and genotypes were taken as sub-sub plot (factor C). Three spacings were used at each location in order to create nine micro environments for stability analysis. The plant spacing levels within rows were 0.15m, 0.20m, 0.40m. Two seeds per hill well planted. The plot size was 4m^2 each with six rows in which the spacing between rows remained constant (0.40m). The experimental area was 288m^2 at each location. 100Kg/ha of DAP (18-46-0) and 50Kg/ha of KCl, 10 tons/ha of organic manure were applied as fertilizer at sowing. Two weeds control were done by using a hoe and by removing weeds with a hand. The first weeding was done three weeks after sowing time and the second was done during pods filling stage.

3.2.3 Data collection

3.2.2.1 Meteorological data

Burundi has seven to eight rainfall months which start early in October or November depending on the region and end late in May. During this period the areas received considerable amounts of rainfall. Average weather values during the experiment such as rainfall, minimum and maximum temperature and relative humidity were recorded from weather stations at each location (Appendices 2, 3 and 4).

3.2.2.2 Soil collection and soil characteristics

Soil was exhumed to a depth of 20 cm and was taken randomly from the experimental site using a soil auger before sowing. For each location, five soil samples were taken in order to get a composite soil sample. Then, six composites soil samples (three composites soil for the first season and three others for the second season) were air-dried and passed through 2mm sieve to remove particles, debris and stones. Soil analysis was carried out to the soil laboratory of ISABU to determine physical characteristics. The sieved samples were analyzed for soil chemical characteristics namely organic matter, soil pH, organic carbon, total nitrogen, available phosphorus, CEC, exchangeable bases (Ca, Mg, K, and Na) and texture. Results for physical and chemical properties of the soil analysis are indicated in Appendices 5, 6 and 7.

3.2.2.3 Plant growth characteristics

From net plot area, the following plant growth characteristics were obtained:

Germination rate: The germinated plant/plot was counted one week after planting and expressed in percentage of the total number of seeds planted.

Days to 50% flowering: Days to 50% flowering was measured by counting the time when 50% of the plot stand has reached flowering from the day of planting.

Disease severity and incidence: Disease scores was done during the pod filling stage using the scoring system of 1-9, where 1= less disease and 9= more disease according to CIAT. The following diseases were evaluated: Anthracnose, Angular leaf spot, Ascochytas, Bean Common Mosaic Virus (BCMV), halo blight, Black root, Common bean bacterial (CBB) , web blight and rust.

Plant height (cm): Total plant height was measured (using meter stick) by taking five randomly sampled plants in each net plot and averaged

Physiological maturity (Number of days to reach maturity): This was taken as number of days from planting to when pods were maturing at 50%.

3.2.2.4 Yield and yield components

Different data of yield and yield component from each plot have been recorded after maturation:

Number of pods per plant: Number of pods per plant was counted by taking five randomly sampled plants in each plot and counting the number of pods then the average for 5 plants was recorded.

Number of seed per pod: Number of seed per pod was counted by taking five randomly sampled pods in each plot and counting the number of grains then the average for 5 pods was recorded.

One hundred seed weight (g): 100 seed for each net plot was counted then measured.

Seed yield (t/ha): Seed yield was measured by weighting total seed harvested from each net plot (using electronic balance) after sun drying to constant weight and the measurements were converted to t/ha.

3.2.3 Data analysis

For each variable data, except meteorological data and soil analysis was subjected to analysis of variance (ANOVA) using WindoStat version 8.5 computer software. In the first stage, analysis was done separately for each location and the second stage consisted of combined analysis for evaluation of the interaction.

The statistical model for each location was:

$Y_{ijkl} = \mu + r_i + \alpha_k + r\alpha_{ik} + \gamma_l + \alpha\gamma_{kl} + \varepsilon_{ijkl}$ ..... (1)

For combined analysis:

$Y_{ijklm} = \mu + r_{i(j)} + \beta_j + \varepsilon_{ij} + r\beta ij + \alpha_k + \beta\alpha_{jk} + \varepsilon_{ijk} + \gamma_l + \beta\gamma_{jl} + \alpha\gamma_{kl} + \alpha\beta\gamma_{ijk} + \varepsilon_{ijklm}$ .....(2)

Whereby: Y_{ijklm} = measurement for l^{th} genotype of the j^{th} location and k^{th} spacing in i^{th} replication and m^{th} plot, μ = General mean of all observations, $r_{i(j)}$= i^{th} replication within j^{th} location, β_j = j^{th} location effect, ε_{ij}= error of i^{th} replication within j^{th} location $r\beta_{ij}$ = interaction effect of i^{th} replication and j^{th} location, α_k=k^{th} spacing effect, $\beta\alpha_{jk}$=interaction effect of j^{th} location and k^{th} spacing, γ_l= l^{th} genotype effect, ε_{ijk}: error of i^{th} replication within j^{th} location and k^{th} spacing, $\beta\gamma_{jl}$ = interaction effect of j^{th} location and l^{th} genotype, $\alpha\gamma_{kl}$=interaction effect of k^{th} spacing and l^{th} genotype, $\alpha\beta\gamma_{kjl}$=interaction effect of k^{th} spacing, j^{th} location and l^{th} genotype, ε_{ijklm}= random experimental error.

3.2.3.1 Stability parameter model for each variable

Stability analysis was performed using the following formula:

$Y_{ij} = \mu_i + \beta_i I_j + \delta_{ij}$ .....(3)

Whereby: Y_{ij} = observation of the i^{th} genotype at the j^{th} environment, μ_i = mean of i^{th} genotype over all environments, β_i = the regression coefficient that measures the response of the i^{th} genotype to varying environments, δ_{ij}= the deviation from regression of the i^{th}

genotype at the j^{th} environment, I_j = the environmental index obtained as the mean of all genotypes at the j^{th} environments.

3.2.3.2 Correlation analysis

Correlation among yield and yield components for each location and across locations as a combined analysis was done by using WindoStat version 8.5 computer software packages. Correlations among pairs of variables and stability of the genotype were assessed using linear regression analysis proposed by Eberhart and Russell (1966). Path coefficient analysis for the variables under investigation was done to discern paths of influence among components of yield following procedures of Dewey and Lu (1959).

3.2.3.3 Estimation of components of variance

Variances pooled over locations and estimates of their components were calculated. The obtained mean squares from the combined analysis of variance was used to separate out the components of variance due to genotypes, spacing, environments and their interactions.

3.2.3.4 Computation of phenotypic variance and heritability (broad sense)

The component of phenotypic variance (δ^2ph) tested in "r" replications and "l" locations were computed by using the following formula:

$$\delta^2ph= \delta^2e+ \delta^2GLS+ \delta^2GS+ \delta^2GL+ \delta^2G+ \delta^2SL+ \delta^2S + \delta^2R(L)L+ \delta^2R(L) +\delta^2L \quad \text{.....(4)}$$

Heritability estimates was computed by using the estimates of phenotypic and genotypic variances, a formula after Hanson *et al.* (1956), as follows:

$$h^2b = (\delta^2g/\delta^2ph) \text{ X } 100 \quad \text{.....(5)}$$

Where: h^2b is heritability in the broad sense,

δ^2g is the component of variance due to genotypes,

δ^2ph is the phenotypic component of variance.

3.2.3.5 Path coefficient analysis

Path coefficient analysis was used to determine direct and indirect effects of days to 50% flowering, total plant height, days to physiological maturity, pods per plant, seeds per pod, one hundred seeds weight and seed yield. This was performed following the method outlined by Dewey and Lu (1959). Computation was done using the following formula arranged in matrix:

$r_{17}=P17+r12P27+r13P37+r14P47+r15P57+r16P67$.....(6)

$r_{27}=r12P17+P27+r23P37+r24P47+r25P57+r26P67$.....(7)

$r_{37}=r13P17+r23P27+P37+r34P47+r35P57+r36P67$.....(8)

$r_{47}=r14P17+r24P27+r34P37+P47+r45P57+r46P67$.....(9)

$r_{57}=r15P17+r25P27+r35P37+r45P47+P57+r56P67$.....(10)

$r_{67}=r16P17+r26P27+r36P37+r46P47+r56P57+P67$.....(11)

The residual factor (P_{X7}) was computed as follows:

$1=P^2_{X5}+P^2_{17}+P^2_{27}+P^2_{37}+P^2_{47}+P^2_{57}+P^2_{67}+2P_{17}r_{12}P_{27}+2P_{17}r_{13}P_{37}+2P_{17}r_{14}P_{47}+2P_{17}+r_{15}P_{57}+2P_{17}r16P_{67}+2P_{27}r_{23}P_{37}+2P_{27}r_{24}P_{47}+2P_{27}r_{25}P_{57}+2P_{27}r_{26}P67+2P_{37}r_{34}P_{47}+2P_{37}r_{35}P_{57}+2P_{37}r_{36}P_{67}+2P_{47}r_{45}P_{57}+2P47r_{46}P67+2P_{57}r_{56}P_{67}$ .....(12)

In the path model:

rij = simple correlation coefficients for measuring the mutual association of two variables

Pij = path coefficient for measuring direct influence between variables to yield

RijPij = indirect effects of variables upon another through the other variable

Px = the residual effect in the path analysis model i and j = (1, . . . 6)

Where: 1 = Days to50% fowering, 2 = Total plant height (cm), 3 = Days to physiological maturity, 4 = Pods per plant (cm), 5 = Seeds per pod, 6 = 100 seed weight (g).

Path diagram showing causal relationships between yield and yield components is showed in Appendix 1.

CHAPTER FOUR

4.0 RESULTS

For each cropping season, results are presented for individual sites in order to provide the effect of G x E interaction between genotypes and micro-environments (plant population densities). Furthermore, results are presented in combined sites to show the effect G x E interaction among sites, plant population densities and genotypes. However, genotypes performance at each site and combined sites respectively are presented.

4.1 Results from the First Cropping Season

4.1.1 Gisozi site

4.1.1.1 ANOVA for different variables studied during 2013A

Results for ANOVA are presented in Table 2. Significant differences at different levels of significance were observed among plant population densities (spacings) for plant germination (PG), Common Bacterial Blight (CBB) diseases and 100 seeds weight (100SW). Moreover, significant differences at different levels of significance were also observed among genotypes for most of the variables except P/P. On the other hand, significant ($P \leq 0.01$) effect was presented in the interaction between genotypes and plant population densities for only 100SW.

Table 2: ANOVA summary for different variables studied at GISOZI

Source of variation	DF	Mean Squares					
		PG	DFL	ALS	ASCO	BCMV	HB
Replication	2	798.60	8.60	10.43***	1.85***	2.63	5.01
Spacing	2	2115.60**	6.93	0.68	0.18	0.29	3.01
Error (A)	4	320.85	2.722	0.58	0.18	0.92	1.93
Genotypes	7	9.325***	28.84***	1.75**	1.98***	0.87**	4.0***
Spacing*Genotype	14	2.534	0.26	0.50	0.15	0.18	0.57
Error (B)	42	2.125	0.65	0.43	0.21	0.23	0.55
Total	71	3.267	3.41	0.87	0.42	0.39	1.16
CV (%)		8.40	3.10	25.74	10.08	12.80	19.34

Table 2: (Continued)

Source of variation	DF	Mean Squares						
		CBB	PH	DPM	P/P	S/P	HSW	SY
Replication	2	10.43***	94.54	8.43	3.85	1.01	29.43 ***	0.004
Spacing	2	1.85 *	50.38	2.72	0.68	0.35	47.18 ***	0.002
Error (A)	4	0.45	33.60	3.04	3.87	1.18	0.35	0.006
Genotypes	7	1.80**	366.89***	29.08***	3.33	0.92**	62.00***	0.032***
Spa*Geno	14	0.59	50.88	1.93	1.47	0.24	2.86 **	0.002
Error (B)	42	0.43	74.55	1.29	1.54	0.22	1.06	0.003
Total	71	0.91	96.28	4.29	1.88	0.37	9.48	0.005
CV (%)		20.86	45.05	2.29	37.58	17.24	2.61	68.449

Key: *=probability significant level at 0.05; **=probability significant level at 0.01 and ***=probability significant level at 0.001; DF= Degree of Freedom, PG= % of Plant Germination, DFL= days to 50% flowering, ALS= Angular Leaf Spot, ASCO=Ascochyta, BCMV= Bean Common Mosaic Virus, HB= Halo Blight, CBB= Common Bacterial Blight, PH= Plant Height (cm), DPM= Days to Physiological Maturity, P/P=Pods per plant, S/P= Seeds per Pods, HSW= 100 Seeds Weight (g), SY= Seed Yield (t/ha), Spac= Spacing, Geno= Genotype, CV= Coefficient of Variation.

4.1.1.2 Effect of genotypes and spacings on germination

Plants grown under different spacings showed significant differences on germination where genotypes under spacing 40cm x 40cm exhibited the highest PG (Table 3). Among the genotypes, GLP2 presented highest percentage of germinated plants compared to other genotypes. Fig. 2 represents vegetative growth of different genotypes at Gisozi during 2013A showing poor germination in some plots.

Table 3: Plant germination (%) of eight bean genotypes at three plant spacings at Gisozi site during 2013A season

Genotypes	Spacing			Mean
	15cm x 40cm	20cm x 40cm	40cm x 40cm	
KAB06F2-8-53	52	63	81	65c
KAB06F2-8-24	56	78	79	71ab
KAB06F2-8-78	56	78	78	71abc
KAB06F2-8-135	63	72	79	71ab
KAB06F2-8-22	59	71	74	68bc
KAB10F2-8-136	61	69	82	71abc
KAB06F2-8-13	61	69	78	69bc
GLP2	73	75	80	76a
Mean	60c	72ab	79a	70
SE	2.5	1.8	0.9	1.7
CV (%)	20.3	12.4	5.7	12.8

Figure 2: Vegetative growth of different bean genotypes at Gisozi in 2013A season showing low germination in some plots

4.1.1.3 Effect of genotypes and spacings on diseases

In the overall, disease reaction was moderate for most of the diseases ranging from 2-5 with the exception of Ascochyta wich had the highest score. Results show that the check variety GLP2 was highly susceptible to Ascochyta and HB. According to the standard system for evaluation of bean germplasm (Van-Schoonhoven and Pastor-Corrales, 1987), genotypes showed resistance for ALS. Furthermore, results showed that plants under different spacings presented resistance to tolerant reaction to diseases studied (Table 4).

Table 4: Disease reaction of eight bean genotypes at three plant spacings at Gisozi site during 2013A season

Genotypes	15cm x 40cm					20cm x 40cm					40cm x 40cm					Mean				
	ALS	ASCO	BCMV	HB	CBB	ALS	ASCO	BCMV	HB	CBB	ALS	ASCO	BCMV	HB	CBB	ALS	ASCO	BCMV	HB	CBB
KAB06F2-8-53	3	4	3	4	2	3	4	4	4	3	3	4	4	2	3	3a	4c	4a	3bc	3b
KAB06F2-8-24	3	4	4	3	3	2	5	4	4	3	3	5	3	4	3	3a	5b	4a	4b	3b
KAB06F2-8-78	2	4	4	4	2	2	4	4	4	4	2	5	4	4	3	2b	4c	4ab	4b	3b
KAB06F2-8-135	2	4	3	4	3	2	4	3	4	3	3	4	3	2	2	3a	4c	3c	3c	3b
KAB06F2-8-22	2	4	4	4	3	2	5	3	4	3	2	4	4	3	3	2b	4c	4ab	3c	3b
KAB10F2-8-136	2	5	4	4	3	3	5	4	4	3	2	4	4	3	2	3a	5b	4a	4b	3b
KAB06F2-8-13	3	5	4	4	2	2	5	4	4	4	2	4	4	3	3	2b	5b	4a	4b	3b
GLP2	3	6	5	6	4	3	6	4	5	4	3	5	4	5	4	3a	6a	4a	5a	4a
Mean	3a	5a	4a	4a	3a	2a	5a	4a	4a	3a	3a	5a	4a	3a	3a	3	5	4	4	3
SE	0.2	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.2	0.2
CV (%)	29.8	15.9	15.8	25.2	31.1	42.7	13.7	18.3	23.9	24.1	37.8	13.1	15.4	34.4	35.2	36.7	14.2	16.5	27.8	30.1

Key: Means followed by the same latter (s) within column are not significantly different from each other according to L.S.D.
ALS: Angular Leaf Spot, ASCO: Ascochyta, BCMV: Bean Common Mosaic Virus,HB: Halo Blight,CBB: Common Bacterial Blight.

4.1.1.4 Yield components and SY (t/ha) performance

The latest genotype (GLP2) to reach DFL was also the latest to reach DPM. The genotypes KAB06F2-8-53, KAB06F2-8-24 and KAB06F2-8-78 were found to be the earliest to reach maturity and DFL. On the other hand, plant population densities were not significantly different for both DFL and DPM. (Table 5).

Table 5: Mean DFL and DPM for eight genotypes at Gisozi during 2013A season

Genotypes	Days to 50% Flowering				Days to Physiological Maturity			
	Spac.1	Spac. 2	Spac.3	Mean	Spac.1	Spac. 2	Spac.3	Mean
KAB06F2-8-53	46.0	46.0	46.0	46.0bc	89.0	89.0	89.0	89.0c
KAB06F2-8-24	46.0	46.0	46.0	46.0bc	88.0	89.0	89.0	89.0c
KAB06F2-8-78	46.0	46.0	46.0	46.0bc	89.0	89.0	89.0	89.0c
KAB06F2-8-135	47.0	48.0	48.0	48.0a	93.0	93.0	92.0	93.0a
KAB06F2-8-22	47.0	47.0	48.0	47.0ab	91.0	91.0	92.0	91.0ab
KAB10F2-8-136	46.0	46.0	46.0	46.0bc	92.0	89.0	88.0	90.0bc
KAB06F2-8-13	46.0	47.0	51.0	48.0a	92.0	89.0	90.0	90.0bc
GLP2	48.0	48.0	49.0	48.0a	93.0	93.0	93.0	93.0a
Mean	47.0a	47.0a	48.0a	47.0	91.0	90.0a	90.0a	90.0a
SE	0.2	0.2	0.6	0.2	1.0	0.4	0.4	0.3
CV (%)	2.1	2.2	5.7	3.3	3.7	2.2	2.2	2.7

Key: Spac.1 = 15cm x 40cm; Spac. 2 = 20cm x 40cm; Spac. 3 = 40cm x 40cm

The tallest genotypes were found under spacing 20cm x 40cm. Genotype GLP2 genotype was the tallest whereas KAB06F2-8-78 genotype was the shortest. On the other hand, most of the genotypes presented the same number of seeds per pod except KAB06F2-8-13 and KAB10F2-8-136 which presented the lowest number (Table 6).

Table 6: Mean PH and S/P for eight genotypes at Gisozi during 2013A season

Genotypes	Plant height (cm)				Seed per pod			
	Spac.1	Spac. 2	Spac.3	Mean	Spac.1	Spac. 2	Spac.3	Mean
KAB06F2-8-53	18.0	27.7	18.7	21.4b	2.0	3.0	3.0	3.0a
KAB06F2-8-24	15.0	14.3	21.3	16.9b	3.0	2.0	3.0	3.0a
KAB06F2-8-78	14.3	12.7	13.0	13.3b	3.0	3.0	3.0	3.0a
KAB06F2-8-135	19.0	13.3	18.7	17b	3.0	3.0	3.0	3.0a
KAB06F2-8-22	16.0	17.3	15.3	16.2b	3.0	3.0	3.0	3.0a
KAB10F2-8-136	17.3	18.0	16.3	17.2b	2.0	2.0	3.0	2.0b
KAB06F2-8-13	14.3	20.0	17.3	17.2b	3.0	2.0	3.0	2.0b
GLP2	31.7	43.3	27.0	34a	4.0	3.0	3.0	3.0a
Mean	18.2a	20.8a	18.5a	19.2	3.0a	3.0a	3.0a	3.0
SE	1.7	2.9	5.1	3.2	0.1	0.1	0.1	0.1
CV (%)	45.9	67.3	1.0	38.0	21.1	22.6	23.6	22.4

Key: Spac.1= Spacing1 (15cmx40cm), Spac.2= Spacing 2 (20cmx40cm), Spac.3: Spacing3 (40cmx40cm).

The highest mean weight of 100 seeds was found for the genotypes under spacing 15cm x 40cm whereas the lowest mean weight was found for genotypes under spacing 40cm x 40cm. The genotype KAB06F2-8-53 exhibited the lowest weight whereas GLP2 presented the highest mean weight. Similarly, the genotype GLP2 presented highest mean yield performance followed by KAB10F2-8-136 genotype (Fig. 3). Among plant population densities, genotypes were not statistically different, but genotypes under spacings 20cm x 40cm and 40cm x 40cm showed the highest mean SY compared to other spacing levels (Table 7).

Table 7: Mean 100SW and SY (t/ha) for eight genotypes at Gisozi during 2013A season

	One Hundred seed weight (g)				Seed Yield (t/ha)			
Genotypes	Spac.1	Spac. 2	Spac.3	Mean	Spac.1	Spac. 2	Spac.3	Mean
KAB06F2-8-53	39.0	39.3	38.7	39.0d	0.04	0.08	0.03	0.05bc
KAB06F2-8-24	41.3	39.3	39.3	40.1bc	0.06	0.04	0.05	0.05bc
KAB06F2-8-78	42.3	40.7	37.3	40.0bc	0.07	0.05	0.07	0.06bc
KAB06F2-8-135	35.0	34.3	31.0	33.4c	0.05	0.04	0.05	0.05bc
KAB06F2-8-22	41.3	40.0	39.3	40.2bc	0.04	0.05	0.03	0.04c
KAB10F2-8-136	41.0	39.0	38.0	39.3cd	0.04	0.10	0.12	0.09b
KAB06F2-8-13	40.7	41.3	39.3	40.4b	0.05	0.06	0.05	0.05bc
GLP2	45.0	42.3	40.3	42.6a	0.18	0.22	0.26	0.22a
Mean	40.7a	39.5b	37.9c	39.4	0.065a	0.08a	0.08a	0.08
SE	0.6	0.3	0.6	0.5	0.01	0.01	0.02	0.01
CV (%)	7.5	6.5	8.1	7.3	85.75	81.87	120.51	72.03

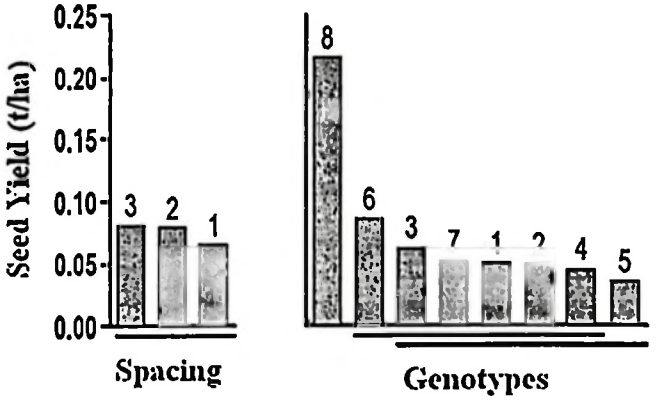

Figure 3: Effect of plant population (spacing) and genotypes on seed yield at Gisozi site during 2013A season

4.1.1.5 Simple correlation coefficient between SY and its components

Results for simple correlation analysis are presented in Table 8. Positive and significant correlations were found between DFL and DPM. Moreover, positive and significant correlations at different levels of significance were observed between PH and DPM, P/P, S/P and SY. Furthermore, positive and significant correlations were observed between P/P and S/P and also between P/P and SY. Seed per Pod was positively and significantly associated with SY. Similarly, a positive correlation was found between 100SW and SY. The highest correlation coefficient was observed between P/P and SY followed by correlations between PH and SY.

Table 8: Simple correlation coefficient between SY and yield components at Gisozi site during 2013A season

Variables	2	3	4	5	6	7
1.DFL (days)	0.105	0.340**	-0.112	0.0454	-0.096	0.104
2.PH (cm)		0.286*	0.321**	0.238*	0.197	0.424***
3. DPM (days)			-0.004	0.093	-0.096	0.214
4. P/P				0.322**	0.065	0.702***
5. S/P					0.186	0.375**
6. HSW (g)						0.269*
7.SY (t/ha)						

4.1.1.6 Influence of yield components on SY

In the study, SY was taken as a dependent variable and DFL, PH, DPM, P/P, S/P and 100SW as independent variables. Using path coefficient analysis, SY was determined by appreciable positive direct effect of P/P and to a lesser extent 100SW. The direct effect of these predictor variables on seed yield were 0.646 and 0.220, respectively (Fig. 4). Moreover, results showed that P/P had high and positive indirect effect on SY through S/P and PH (Table 9).

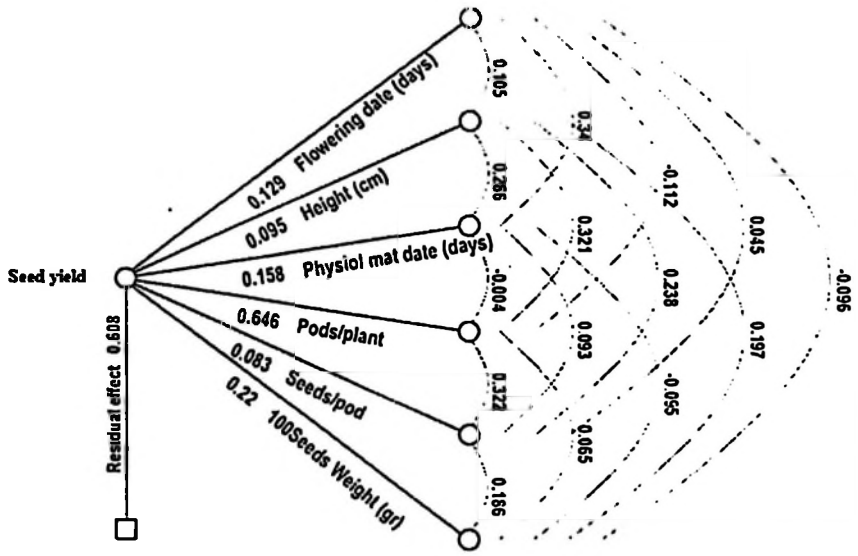

Figure 4: Path diagram showing relationship between yield (t/ha) and yield components at Gisozi site during 2013A season

Table 9: Path analysis showing direct and indirect effects of different yield components on seed yield at Gisozi site during 2013A

Variables	1	2	3	4	5	6
1..DFL (days)	0.129	0.014	0.044	-0.014	0.006	-0.012
2. Height (cm)	0.010	0.095	0.027	0.031	0.023	0.019
3. DPM (days)	0.054	0.045	0.158	-0.001	0.015	-0.015
4. P/P	-0.072	0.207	-0.002	0.646	0.208	0.042
5. S/P	0.004	0.020	0.008	0.027	0.083	0.015
6. HSW (gr)	-0.021	0.043	-0.021	0.014	0.041	0.220
Residual effect (PX7)						0.608

Key: Direct effects are presented in diagonal and indirect effects are presented off diagonal

4.1.2 Murongwe site

4.1.2.1 ANOVA for different variables studied

Very highly significant differences (P ≤0.001) were observed among plant population densities (spacings) for PG, CBB diseases, 100SW and SY whereas high significant difference (P≤0.01) was observed for ALS. While highly significant differences (P ≤0.001) were showed for DFL, Rust, DPM, S/P, 100SW and SY among genotypes, high significant differences (P≤0.01) were observed among genotypes for PG, CBB diseases and TPH. Furthermore, highly significant differences (P ≤0.001) were exhibited for the interaction between genotypes and plant population densities for SY (Table 10).

Table 10: ANOVA summary for different variables studied at Murongwe during 2013A season

Source of variation	DF	Mean Squares					
		PG	DFL	ALS	CBB	RU	TPH
Replication	2	66.54	15.79***	0.79**	1.39***	1.13	387.04
Spacings	2	1060.04***	0.88	1.04**	1.56***	0.13	68.79
Error (A)	4	42.30	1.67	0.15	0.16	0.44	154.33
Genotypes	7	140.16**	13.87***	0.63	0.98 **	18.47***	251.93**
Spacings*Geno	14	22.77	1.80	0.31	0.48	0.57	122.17
Error (B)	42	32.95	2.28	0.33	0.25	1.14	71.06
Total	71	71.92	3.63	0.38	0.43	2.67	112.50
CV (%)		7.42	3.53	12.19	10.42	28.60	13.91

Key: RU = Rust

Table 10: (continued)

Source of variation	DF	Mean Squares				
		DPM	P/P	S/P	HSW	SY
Replication	2	14.26	8.68	0.54	9.56**	1.06
Spacings	2	1.43	2.26	1.17	15.26***	3.53***
Error (A)	4	5.74	9.51	0.65	1.39	0.42
Genotypes	7	64.16***	5.32	2.34***	42.56***	1.07***
Spacings*Geno	14	1.51	6.57	0.10	0.87	0.21*
Error (B)	42	1.49	4.36	0.28	0.49	0.11
Total	71	8.27	5.24	0.5	5.44	0.37
CV (%)		1.60	20.19	14.80	1.82	23.67

4.1.2.2 Effect of genotypes and spacings on germination

Plants grown under different spacings showed significant differences in germination where genotypes under spacing 40cm x 40cm exhibited a high mean of PG followed by genotypes under spacing 20cm x 40cm. Among the genotypes, KAB06F2-8-13 and GLP2 presented higher percentage of germinated plants compared to other genotypes (Table 11). Fig. 5 represents vegetative growth of different bean genotypes at Murongwe during 2013A showing good germination in some plots.

Table 11: Plant germination (%) of eight bean genotypes at three plant spacing at Murongwe site during 2013A season

Genotypes	Spacing			Mean
	15cm x 40cm	20cm x 40cm	40cm x 40cm	
KAB06F2-8-53	69	83	80	77ab
KAB06F2-8-24	74	81	83	79a
KAB06F2-8-78	68	84	86	79a
KAB06F2-8-135	62	73	74	69c
KAB06F2-8-22	64	78	76	72bc
KAB10F2-8-136	71	80	86	78a
KAB06F2-8-13	73	82	85	80a
GLP2	77	78	88	80a
Mean	70b	80a	82a	77
SE	1.3	1.4	1.4	1.4
CV (%)	8.9	8.3	8.4	8.5

Figure 5: Vegetative growth of different bean genotypes at Murongwe in 2013A season

4.1.2.3 Effect of genotypes and spacings on diseases

The genotypes exhibited resistance to intermediate reaction to ALS, CBB and Rust diseases. Similarly, between plant population densities results also showed resistance to intermediate reaction to diseases studied and plant population densities did not have effect on diseases reaction (Table 12).

Table 12: Disease reaction of eight bean genotypes at three plant spacings at Murongwe site during 2013A season

Genotypes	Spc.1 (15cm x 40cm)			Spac.2 (20 x 40cm)			Spac.3 (40cm x 40cm)			Mean		
	ALS	CBB	RU	ALS	CBB	RU	ALS	CBB	RU	ALS	CBB	RU
KAB06F2-8-53	5	5	3	5	5	2	5	5	2	5a	5a	2d
KAB06F2-8-24	5	5	4	5	5	4	5	5	3	5a	5a	3cd
KAB06F2-8-78	5	5	4	5	5	4	4	4	4	5a	5a	3c
KAB06F2-8-135	4	5	4	4	4	5	4	4	6	4b	4b	5ab
KAB06F2-8-22	5	4	6	5	5	6	4	4	6	5a	4b	6a
KAB10F2-8-136	5	5	4	5	5	3	5	4	4	5a	4a	4c
KAB06F2-8-13	5	5	4	5	5	5	4	5	4	5a	5a	4c
GLP2	4	5	1	4	5	2	5	5	1	4b	5a	1c
Mean	5a	5a	4a	5a	5a	4a	5a	5b	4a	5	5	4
SE	0.1	0.1	0.3	0.1	0.1	0.3	0.1	0.1	0.3	0.1	0.1	0.3
CV (%)	9.9	12.4	43.2	13.3	12.6	45.3	14.7	15.5	44.0	12.6	13.2	44.1

4.1.2.4 Yield components and SY (t/ha) performance

Results showed that most of the genotypes were slightly earlier to reach DFL than genotypes KAB06F2-8-135, GLP2 and KAB06F2-8-78. However, genotypes under different levels of spacing presented the same period to reach both DFL and DPM ie there was no effect of spacing on both DFL and DPM. On the other hand genotypes KAB10F2-8-136 and KAB06F2-8-13 were earliest to reach DPM while GLP2 was the latest (Table 13).

Table 13: Mean DFL and DPM for eight genotypes at Murongwe during 2013A season

	Days to 50% Flowering				Days to Physiological Maturity			
Genotypes	Spac.1	Spac.2	Spac.3	Mean	Spac.1	Spac.2	Spac.3	Mean
KAB06F2-8-53	42.0	41.0	42.0	42.0c	80.0	80.0	79.0	80.0cd
KAB06F2-8-24	41.0	42.0	42.0	42.0c	79.0	81.0	79.0	80.0cd
KAB06F2-8-78	42.0	43.0	44.0	43.0bc	79.0	80.0	80.0	80.0cd
KAB06F2-8-135	46.0	45.0	45.0	45.0a	81.0	80.0	82.0	81.0b
KAB06F2-8-22	44.0	42.0	41.0	42.0c	81.0	83.0	81.0	81.0b
KAB10F2-8-136	43.0	41.0	42.0	42.0c	79.0	80.0	79.0	79.0d
KAB06F2-8-13	42.0	41.0	42.0	42.0c	79.0	80.0	80.0	79.0d
GLP2	44.0	45.0	44.0	44.0ab	88.0	87.0	87.0	87.0a
Mean	43.0a	43.0a	43.0a	43.0	81.0a	81.0a	81.0a	81.0
SE	0.4	0.4	0.4	0.4	0.6	0.6	0.6	0.6
CV (%)	4.2	4.8	4.4	4.5	3.6	3.8	3.5	3.6

Furthermore, genotypes under spacing 20cm x 40cm were the tallest followed by genotypes under spacing 15cm x 40cm. Among genotypes, KAB06F2-8-24 was the tallest whereas KAB10F2-8-78 was the shortest. On the other hand, genotype GLP2 presented the highest mean of S/P. Moreover, genotypes under spacing 40cm x 40cm and spacing 20cm x 40cm exhibited the highest mean S/P (Table 14).

Table 14: Mean PH and S/P for eight genotypes at Murongwe during 2013A season

	Plant height (cm)				Seed per pods			
Genotypes	Spac.1	Spac.2	Spac.3	Mean	Spac.1	Spac.2	Spac.3	Mean
KAB06F2-8-53	70.0	66.0	56.3	64.1abc	3.0	3.0	3.0	3.0b
KAB06F2-8-24	64.3	67.0	71.3	67.6a	3.0	4.0	4.0	4.0b
KAB06F2-8-78	53.0	62.0	45.3	53.4e	3.0	4.0	4.0	4.0b
KAB06F2-8-135	55.7	44.3	64.3	54.8de	3.0	3.0	3.0	3.0b
KAB06F2-8-22	65.7	68.0	54.3	62.7abcd	3.0	4.0	4.0	4.0b
KAB10F2-8-136	55.3	58.0	59.7	57.7cde	3.0	3.0	4.0	3.0b
KAB06F2-8-13	66.7	68.7	63.3	66.2ab	3.0	4.0	3.0	3.0b
GLP2	59.0	61.0	54.7	58.2bcde	4.0	5.0	5.0	5.0a
Mean	61.2a	61.9a	58.7a	60.6	3.0a	4a	4.0a	4.0
SE	1.9	2.0	2.6	2.2	0.1	0.2	0.2	0.2
CV (%)	15.0	15.6	21.8	17.5	17.0	19.7	20.8	19.2

The genotype KAB10F2-8-136 presented a high mean weight of 100 seeds whereas KAB06F2-8-78 exhibited the lowest mean weight. Between plant population densities, genotypes under spacing 40cm x 40cm presented a high mean weight of 100 seeds. The check genotype (GLP2) presented highest mean SY followed by KAB06F2-8-13 and KAB10F2-8-136. However, the lowest mean SY was observed for KAB06F2-8-135. Among plant population densities, genotypes under spacing 20cm x 40cm exhibited highest mean of SY (Table 15 and Fig. 6).

Table 15: Mean 100SW and SY for eight genotypes at Murongwe during 2013A season

Genotypes	100 seeds weight (g)				Seed Yield (t/ha)			
	Spac.1	Spac. 2	Spac.3	Mean	Spac.1	Spac. 2	Spac.3	Mean
KAB06F2-8-53	38.7	38.0	39.0	38.6b	1.833	1.87	0.90	1.54bc
KAB06F2-8-24	36.3	35.0	37.0	36.1d	1.590	1.42	0.89	1.30cd
KAB06F2-8-78	36.0	35.0	36.7	36.0d	1.653	1.59	0.82	1.36bc
KAB06F2-8-135	38.0	38.0	39.7	38.6b	1.067	0.91	0.60	0.86c
KAB06F2-8-22	43.0	42.0	42.7	42.6a	1.130	1.16	0.66	0.98dc
KAB10F2-8-136	39.7	39.7	40.7	40.0a	1.553	2.42	0.85	1.61abc
KAB06F2-8-13	39.0	38.7	40.0	39.2b	1.880	2.00	1.06	1.65ab
GLP2	36.7	36.0	39.3	37.3c	1.863	1.91	1.88	1.88a
Mean	38.4b	37.79b	39.4a	38.5	1.57a	1.66a	0.96b	1.40
SE	0.5	0.5	0.4	0.5	0.08	0.12	0.12	0.1
CV (%)	6.1	6.4	5.1	5.9	23.92	35.91	59.48	39.8

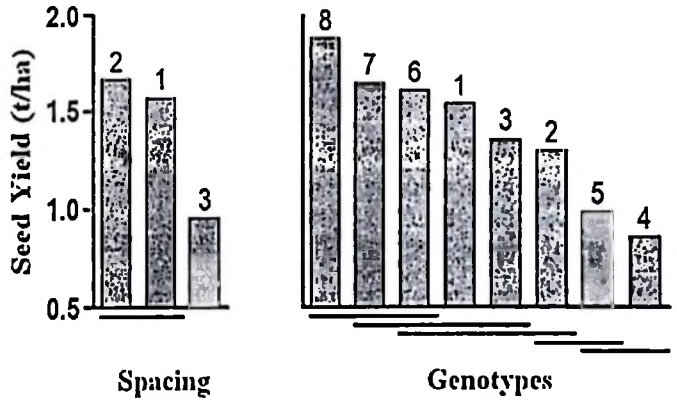

Figure 6: Effect of population (spacing) and genotypes on seed yield at Murongwe site during 2013A season

4.1.2.5 Simple correlation coefficient between seeds yield and its components

The correlations among traits at Murongwe during the first cropping season are presented in Table 16. Positive and significant correlations were found between DFL and DPM. However, negative and significant correlations were determined between DFL and SY. Furthermore, positive and significant correlation was observed between PH and SY. Positive and significant correlation was also observed between DPM and S/P. On the other hand, correlation was found positive and significantly between S/P and SY.

Table 16: Simple correlation coefficient between seed yield and yield components at Murongwe site during 2013A season

Variables	2	3	4	5	6	7
1 .DFL (days)	-0.125	0.388***	-0.048	0.084	0.014	-0.238*
2. PH (cm)		0.029	-0.013	0.037	0.074	0.352**
3. DPM (days)			-0.052	0.559***	-0.008	0.154
4. P/P				0.073	-0.148	0.216
5. S/P					-0.164	0.296*
6. HSW (g)						-0.227
7. SY (t/ha)						

4.1.2.6 Influence of yield components on seed yield

How yield is influenced by various yield components is shown in Fig. 7. Plant height had the highest positive direct effect on SY followed by S/P and P/P. However, DFL showed high and negative direct effect on SY. Similarly, S/P provided high and positive indirect effect on SY via DPM (Table 17).

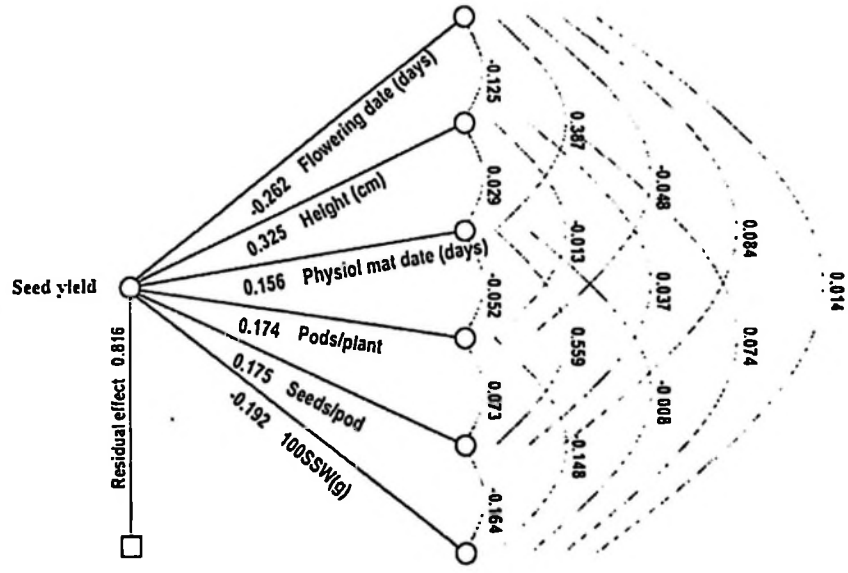

Figure 7: Path diagram indicating the interrelationships among the bean yield with its components at Murongwe site during 2013A season

Table 17: Path analysis showing direct and indirect effects of different yield components on seed yield at Murongwe site during 2013A

Variables	1	2	3	4	5	6
1.DFL (days)	-0.262	0.033	-0.101	0.013	-0.022	-0.004
2. Height (cm)	-0.041	0.325	0.009	-0.004	0.012	0.024
3. DPM (days)	0.060	0.005	0.156	-0.008	0.087	-0.001
4. P/P	-0.008	-0.002	-0.009	0.174	0.013	-0.026
5. S/P	0.015	0.006	0.098	0.013	0.175	-0.029
6. HSW (gr)	-0.003	-0.014	0.002	0.029	0.031	-0.192
Residual effect (PX7)						0.816

Key: Direct effects are presented in diagonal and indirect effects are presented off diagonal

4.1.3 Moso site

4.1.3.1 ANOVA for different variables studied during 2013A season

Significant differences at different levels of significance were observed among plant population densities for PG, DFL, 100SW and SY (Table 18). Between genotypes significant differences at different levels of significance were showed for PG, DFL, BR, Rust, PH, DPM, S/P, 100SW and SY. Highly significant ($P \leq 0.001$) effect was found in the interaction between genotypes and plant population densities for 100SW.

Table 18: ANOVA summary for different variables studied at Moso during 2013A season

SV	DF	Mean Squares				
		PG	DFL	BR	RU	PH
Replication	2	58.68	67.54 ***	0.01	1.29	5.72
Spacings	2	715.39 **	26.54 *	0.18	1.63	37.35
Error (A)	4	100.91	6.90	0.26	0.60	20.45
Genotypes	7	217.59 ***	41.75*	0.49 **	7.20***	233.82***
Spac*Geno	14	52.85	19.40	0.18	0.42	41.16
Error (B)	42	38.55	16.56	0.12	0.74	26.61
Total	71	82.17	20.76	0.17	1.34	49.27
CV (%)		9.01	11.79	31.18	32.73	11.49

Key: BR = Black Root; RU = Rust

Table 18: Continued

Source of Variation	DF	Mean Squares				
		DPM	P/P	S/P	HSW	SY
Replication	2	42.72**	24.04	1.51	4.76 ***	0.091 ***
Spacings	2	18.60	3.79	1.93	6.22 ***	0.056 **
Error (A)	4	8.10	12.15	0.7	0.35	0.01
Genotypes	7	86.67***	18.54	1.94 *	80.47 ***	0.025 **
Spaci*Geno	14	21.11	3.19	0.41	2.87 ***	0.011
Error (B)	42	11.37	8.5	0.7	0.55	0.006
Total	71	21.62	8.93	0.82	9.16	0.013
CV (%)		4.39	42.57	25.57	1.78	48.437

4.1.3.2 Effect of genotypes and spacings on germination

The genotype GLP2 presented highest mean of plant germination compared to other genotypes. Genotypes under spacing 40cm x 40cm exhibited highest mean of PG without being statistically different to the spacing 20cm x 40cm (Table 19). There was very poor germination in some plots as shown in Fig. 8.

Table 19: Plant germination (%) of eight bean genotypes at three plant spacings at Moso site during 2013A season

Genotypes	Spacing			Mean
	15cm x 40cm	20cm x 40cm	40cm x 40cm	
KAB06F2-8-53	64.0	73.0	70.0	69.0a
KAB06F2-8-24	68.0	72.0	71.0	70.0a
KAB06F2-8-78	67.0	76.0	75.0	73.0a
KAB06F2-8-135	55.0	62.0	71.0	63.0b
KAB06F2-8-22	48.0	62.0	71.0	60.0c
KAB10F2-8-136	64.0	72.0	77.0	70.0a
KAB06F2-8-13	70.0	74.0	70.0	71.0a
GLP2	66.0	82.0	76.0	74.0a
Mean	63.0b	72.0a	73.0a	69.0
SE	1.8	1.4	1.7	1.6
CV (%)	13.9	9.9	11.2	11.7

Figure 8: Vegetative growth of different genotypes at Moso in 2013A season showing poor germination in some plots

4.1.3.3 Effect of genotypes and spacings on diseases

According to the standard system for evaluation of bean germplasm, genotypes showed resistance reaction to BR and Rust diseases. Generally, KAB06F2-8-24 appeared to be resistant to all two diseases regardeless of the plant spacing. Plant spacing did not have effect on diseases reaction. Genotypes under various spacing levels presented resistance to intermediate reaction to the diseases studied (Table 20).

Table 20: Disease reaction of eight bean genotypes at three plant spacings Moso site during 2013A season

Genotypes	15cm x 40cm		20cm x 40cm		40cm x 40cm		Mean	
	BR	RU	BR	RU	BR	RU	BR	RU
KAB06F2-8-53	1.0	4.0	1.0	3.0	1.0	2.0	1.0b	3.0a
KAB06F2-8-24	1.0	2.0	1.0	1.0	1.0	1.0	1.0b	1.0b
KAB06F2-8-78	1.0	3.0	1.0	4.0	1.0	3.0	1.0b	3.0a
KAB06F2-8-135	1.0	2.0	1.0	2.0	1.0	2.0	1.0b	2.0b
KAB06F2-8-22	1.0	3.0	1.0	4.0	1.0	3.0	1.0b	3.0a
KAB10F2-8-136	1.0	3.0	1.0	3.0	1.0	3.0	1.0b	3.0a
KAB06F2-8-13	1.0	4.0	1.0	3.0	1.0	3.0	1.0b	4.0a
GLP2	2.0	2.0	2.0	2.0	1.0	2.0	2.0a	2.0b
Mean	1.0a	3.0a	1.0a	3.0a	1.0a	2.0a	1.0	3.0
SE	0.1	0.3	0.1	0.2	0.1	0.2	0.1	0.2
CV (%)	48.4	48.5	39.7	40.0	41.1	41.3	43.1	43.3

4.1.3.4 Yield components and SY (t/ha) performance

The genotype KAB10F2-8-136 was the earliest to reach both DFL and DPM whereas GLP2 was the latest. Between plant population densities, genotypes under spacing 15cm x 40cm were the earliest for both DFL and DPM (Table 21).

Table 21: Mean DFL and DPM for eight genotypes at Moso during 2013A season

	Days to 50% Flowering				Days to Physiological Maturity			
Genotypes	Spac.1	Spac. 2	Spac.3	Mean	Spac.1	Spac. 2	Spac.3	Mean
KAB06F2-8-53	35.0	35.0	31.0	34.0a	73.0	76.0	76.0	75.0cd
KAB06F2-8-24	34.0	34.0	31.0	33.0ab	75.0	74.0	79.0	76.0bc
KAB06F2-8-78	31.0	35.0	37.0	34.0a	77.0	76.0	78.0	77.0abc
KAB06F2-8-135	36.0	35.0	37.0	36.0a	79.0	76.0	80.0	78.0ab
KAB06F2-8-22	35.0	34.0	40.0	36.0a	76.0	78.0	81.0	78.0ab
KAB10F2-8-136	26.0	34.0	31.0	30.0b	75.0	67.0	69.0	70.0d
KAB06F2-8-13	36.0	36.0	36.0	36.0a	75.0	75.0	78.0	76.0bc
GLP2	35.0	36.0	39.0	37.0a	78.0	78.0	80.0	79.0a
Mean	33.0a	.35.0a	35.0a	35.0	76.0b	76.0b	77.0a	76.0
SE	1.2	0.5	1.0	0.7	1.9	1.1	0.1	1.4
CV (%)	17.1	6.5	14.0	4.5	12.2	7.2	6.2	8.9

The tallest bean genotypes were presented by genotypes under spacing 15cm x 40cm. Among genotypes, GLP2 was tall compared to others genotypes studied (Table 20). Genotypes under spacing 40cm x 40cm showed highest mean of S/P. Between genotypes, KAB10F2-8-136 and GLP2 presented highest means of S/P (Table 22).

Table 22: Mean PH and S/P for eight genotypes at Moso during 2013A season

Genotypes	Plant height (cm)				Seed per pod			
	Spac.1	Spac.2	Spac.3	Mean	Spac.1	Spac.2	Spac.3	Mean
KAB06F2-8-53	43.7	43.0	43.7	43.4b	2.0	3.0	3.0	3.0b
KAB06F2-8-24	42.7	43.3	42.7	42.9b	3.0	3.0	4.0	3.0b
KAB06F2-8-78	43.7	42.3	44.7	43.6b	3.0	3.0	3.0	3.0b
KAB06F2-8-135	42.7	42.3	44.3	43.1b	2.0	3.0	3.0	3.0b
KAB06F2-8-22	43.0	44.3	43.0	43.4b	3.0	3.0	3.0	3.0b
KAB10F2-8-136	44.0	43.7	36.0	41.2b	4.0	3.0	4.0	4.0a
KAB06F2-8-13	43.7	46.0	43.0	44.2b	3.0	4.0	3.0	3.0b
GLP2	67.3	49.7	55.0	57.3a	4.0	4.0	4.0	4.0a
Mean	46.3a	44.3a	44.0a	44.9	3.0a	3.0a	4.0a	3.0
SE	1.7	0.8	1.6	1.4	0.2	0.2	0.2	0.2
CV (%)	18.2	9.1	17.8	15.0	27.3	25.9	27.9	27.0

The check genotype GLP2 exhibited the highest mean weight of 100 seeds followed by KAB06F2-8-53 and KAB06F2-8-135 whereas among plant population densities, genotypes under spacing 15cmx40cm presented the highest mean weight (Table 21). On the other hand, genotype KAB06F2-8-78 presented highest mean SY followed by genotypes KAB06F2-8-53, KAB06F2-8-24 and GLP2. Between plant population densities, genotypes under spacing 20cm x 40cm presented the highest mean SY (Table 23 and Fig.9).

Table 23: Mean 100SW and SY for eight genotypes at Moso during 2013A season

Genotypes	100 Seeds Weight				Seed Yield (t/ha)			
	Spac.1	Spac.2	Spac.3	Mean	Spac.1	Spac.2	Spac.3	Mean
KAB06F2-8-53	45.00	43.00	44.00	44.00a	0.31	0.19	0.13	0.21ab
KAB06F2-8-24	41.00	41.30	40.70	41.00b	0.27	0.19	0.12	0.19ab
KAB06F2-8-78	36.70	35.00	37.70	36.40c	0.21	0.33	0.17	0.24a
KAB06F2-8-135	43.70	43.00	41.30	42.70a	0.06	0.16	0.10	0.11cd
KAB06F2-8-22	42.00	40.70	41.30	41.30b	0.10	0.08	0.05	0.08d
KAB10F2-8-136	41.70	41.70	40.70	41.30b	0.22	0.10	0.12	0.14bcd
KAB06F2-8-13	38.70	37.70	40.30	39.00c	0.18	0.21	0.08	0.15bc
GLP2	47.70	46.00	45.00	46.00a	0.15	0.31	0.11	0.19ab
Mean	42.00a	41.0b	41.40b	41.0	0.19a	0.20ab	0.11b	0.16
SE	0.7	0.7	0.5	0.6	0.03	0.03	0.01	0.02
CV (%)	8.0	8.1	5.6	7.2	65.8	67.2	54.5	62.50

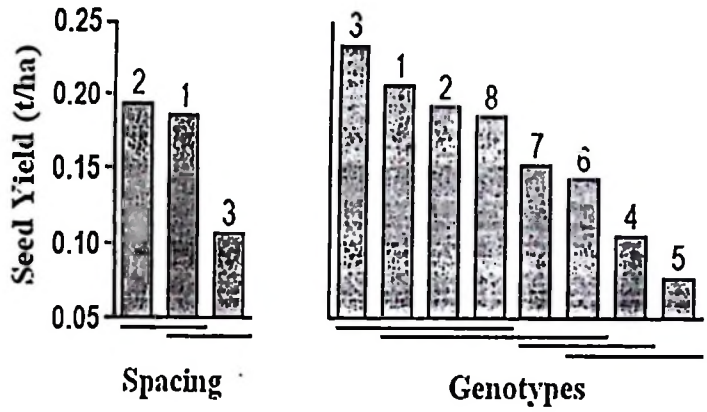

Figure 9: Effect of population (spacing) and genotypes on seed yield at Moso site during 2013A season

4.1.3.5 Simple correlation coefficients between seed yield and its components

Positive and significant correlations were observed between DFL and DPM. On the other hand, the highest correlation coefficient was given relationship between PH and 100SW. The same trends were observed between P/P and S/P followed by correlation between P/P and SY. Negative and significant correlations were found among DPM with S/P (Table 24).

Table 24: Simple correlation coefficient between grain yield and yield components at Moso site during 2013A season

Variables	2	3	4	5	6	7
1. DFL (days)	0.114	0.238*	-0.103	-0.061	0.009	-0.136
2. PH (cm)		0.110	-0.027	0.183	0.386***	-0.028
3. DPM (days)			-0.119	-0.255*	-0.030	-0.159
4. P/P				0.386***	0.131	0.317**
5. S/P					0.191	0.012
6. HSW (g)						-0.055
7. SY (t/ha)						

4.1.3.6 Influence of yield components on seed yield

How yield is influenced by various yield components is shown in Fig. 10. The number of P/P had the highest positive direct effect on SY. On the other hand, S/P showed high and negative direct effect on SY followed by DPM. However, P/P displayed high and positive indirect effect on SY through DFL (Table 25).

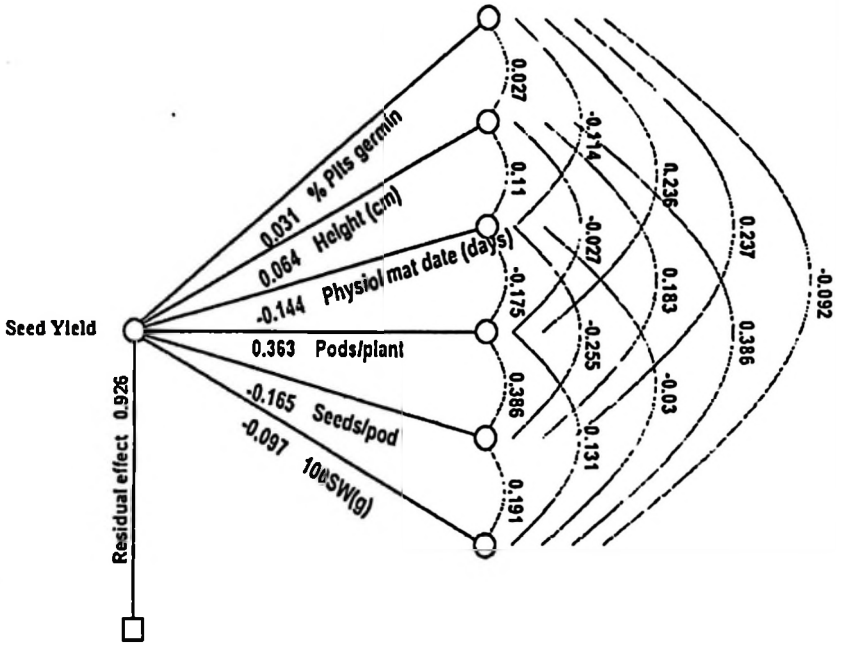

Figure 10: Path diagram indicating the interrelationships among the bean yield with its components at Moso site during 2013A season

Table 25: Path analysis showing direct and indirect effects of different yield components on seed yield at Moso site during 2013A

Variables	1	2	3	4	5	6
1..DFL (days)	0.031	0.001	-0.004	0.007	0.007	-0.003
2. Height (cm)	0.002	0.064	0.007	-0.002	0.012	0.025
3. DPM (days)	0.016	-0.016	-0.144	0.025	0.037	0.004
4. P/P	0.086	-0.010	-0.063	0.363	0.140	0.047
5. S/P	-0.039	-0.030	0.042	-0.064	-0.165	-0.032
6. HSW (gr)	0.009	-0.037	0.003	-0.013	-0.019	-0.097
Residual effect (PX7)						0.926

Key: Direct effects are presented in diagonal and indirect effects are presented off diagonal

4.1.4 Combined sites

4.1.4.1 ANOVA for different variables studied

Highly significant differences ($P \leq 0.001$) were observed between sites for most of the variables except for PG which showed high significant differences ($P \leq 0.01$) (Table 26). Among plant population densities, significant differences at different levels of significance were found for PG, DFL, CBB, 100SW and SY. Furthermore, significant differences at different levels of significance were presented in the interaction between

site and plant population densities for CBB, 100SW and SY. Between genotypes, significant differences at different levels of significance were observed for all variables. In the interaction between site and genotypes, significant differences at different levels of significance were observed for most of the variables except for PG, BCMV, BR, P/P and S/P. However, significant differences ($P \leq 0.05$) were shown in the interaction between plant population densities and genotypes for DPM, 100SW and SY. Similarly, highly significant effect was found in the interaction of plant population densities x Sites x Genotypes ($P \leq 0.001$) for 100SW whereas high significant effect ($P \leq 0.01$) was observed for SY (Table 26).

Table 26: Analysis of variance in combined analysis during 2013A season

SV	DF	PG	DFL	ALS	ASCO	BCMV
Replication	2	419.06	11.616	5.931	0.907	1.056
Site	2	1457.505**	2927.796***	87.181***	385.227***	18.722***
Error (A)	4	252.38	40.157	2.653	0.741	0.861
Spacings	2	3641.088***	19.130**	0.847	0.13	0.042
Site*Spac	4	124.97	7.609	0.799	0.088	0.347
Error (B)	12	154.655	3.762	0.398	0.22	0.488
Genotypes	7	314.645***	44.653***	1.249***	1.095***	0.761***
Site*Geno	14	61.415	10.146*	0.731*	0.587***	0.22
Spac*Geno	14	38.062	6.463	0.445	0.045	0.142
Site*Spac*Geno	28	50.721	8.601	0.246	0.114	0.202
Error (C)	126	35.242	6.987	0.329	0.158	0.179
Total	215	110.96	36.370	1.302	3.805	0.414
CV (%)		8.222	6.376	16.381	10.94	11.861

Table 26: Continued

SV	DF	HB	BR	CBB	RU	PH
Replication	2	0.292	2.574	1.852	2.671***	328.907*
Site	2	214.847***	161.171***	261.866***	122.144***	31482.810***
Error (A)	4	3.222	1.97	4.991	0.13	79.199
Spacings	2	0.389	1.255	1.560***	0.352	76.255
Site*Spac	4	2.444	1.025	0.928 **	0.748	40.13
Error (B)	12	1.03	1.609	0.208	0.574	69.463
Genotypes	7	1.470***	0.857**	1.193***	11.331***	443.158***
Site*Geno	14	1.371***	0.319	0.755***	7.202***	204.741***
Spac*Geno	14	0.214	0.276	0.386	0.743	79.614
Site*Spac*Geno	28	0.294	0.182	0.349	0.314	67.299
Error (C)	126	0.335	0.241	0.231	0.729	57.406
Total	215	2.553	1.912	2.884	2.567	378.081
CV (%)		19.373	17.547	16.087	34.038	18.235

Table 26: Continued

SV	DF	DPM	P/P	S/P	HSW	SY
Replication	2	23.338	4.394	0.681	38.088***	0.471
Site	2	3498.977***	892.532***	13.722***	166.699***	39.317***
Error (A)	4	21.039	16.088	1.194	2.831	0.342
Spacings	2	3.130	5.921	1.625	18.838***	1.460***
Site*Spac	4	9.810	0.407	0.91	24.914***	1.061***
Error (B)	12	5.625	8.509	0.843	0.694	0.145
Genotypes	7	108.085***	17.629**	4.251***	64.380***	0.526***
Site*Geno	14	35.908***	4.776	0.474	60.329***	0.302**
Spac*Geno	14	11.394*	5.244	0.297	1.531*	0.073*
Site*Spac*Geno	28	6.575	2.992	0.225	2.536***	0.077**
Error (C)	126	5.717	4.789	0.4	0.7	0.039
Total	215	44.489	13.603	0.688	9.5	0.493
CV (%)		2.891	32.047	19.802	2.102	36.426

4.1.4.2 Yield components and seed yield (t/ha) performance

Regardless of plant population densities, genotypes KAB06F2-8-24 and KAB10F2-8-136 were the earliest to reach DFL. Genotypes under spacing 15cm x 40cm showed the shortest period to reach DFL. Between sites, genotypes planted at Moso exhibited the shortest period to reach DFL followed by genotypes grown at Murongwe. On the other hand, the tallest genotype was GLP2 and the shortest was KAB06F2-8-78. Among sites genotypes planted at Murongwe were tall followed by genotypes planted at Moso. Moreover, genotype KAB10F2-8-136 presented the shortest vegetative period cycle followed by KAB06F2-8-53. Between plant population densities, genotypes were not statistically different and presented the same days to reach DPM (Table 27).

Furthermore, genotype GLP2 presented a high mean P/P followed by KAB06F2-8-53, KAB06F2-8-78, KAB10F2-8-136 and KAB06F2-8-13 while KAB06F2-8-22 had the lowest number of pods per plant. Among the sites, genotypes at Murongwe exhibited the highest mean P/P compared to other sites. However, pods per plant were the same for the three types of spacing. The highest mean S/P was observed for genotypes GLP2 and the rest of the genotypes had the same S/P. Regardless sites, genotypes planted at Murongwe presented the highest mean S/P. Regarding 100 seeds weight, genotype GLP2 showed the highest weight followed by KAB06F2-8-22. With regard to spacing, genotypes under

spacing 15cm x 40cm presented the highest mean weight. Among sites; the highest mean weight of 100 seeds was observed at Moso. Moreover, among genotypes GLP2 presented a high mean SY compared to other genotypes whereas between plant population densities, genotypes under spacing 20cm x 40cm and 40cm x 40cm presented the highest mean SY. Between sites, genotypes planted at Murongwe exhibited high mean SY compared to other sites (Table 27 and Fig. 11).

Table 27: Main effect of genotypes on yield and yields components in combined sites during 2013A season

Genotypes	DFL	PH	DPM	P/P	S/P	HSW	SY
1.KAB06F2-8-53	41.0bc	43.0b	81.0c	7.0b	3.0b	40.5b	0.6b
2.KAB06F2-8-24	40.0d	42.4bc	82.0c	7.0b	3.0b	39.0c	0.5b
3.KAB06F2-8-78	41.0bc	36.8d	82.0c	7.0b	3.0b	37.5c	0.6b
4.KAB06F2-8-135	43.0a	38.3d	84.0b	6.0c	3.0b	38.2c	0.3c
5.KAB06F2-8-22	42.0ab	40.8bcd	85.0ab	5.0d	3.0b	41.4a	0.4c
6.KAB10F2-8-136	40.0d	38.7cd	80.0d	7.0b	3.0b	40.2b	0.6b
7.KAB06F2-8-13	42.0ab	42.6bc	82.0c	7.0b	3.0b	39.5c	0.6b
8.GLP2	43.0	49.9a	86.0a	8.0a	4.0a	42.0a	0.8a
Mean	41.0	41.6	83.0	7.0	3.0	39.8	0.6
S.E.	0.4	1.3	0.5	0.3	0.1	0.2	0.1
C.V. (%)	14.6	46.8	8.1	54.0	26.0	7.7	128.8
Spac1 (15cm x 40cm)	41.0b	40.4a	83.0a	7.0a	3.0a	39.6b	0.4b
Spac2 (20cm x 40cm)	42.0a	41.9a	83.0a	7.0a	3.0a	40.4a	0.7a
Spac3 (40cm x 40cm)	42.0a	42.4a	83.0a	7.0a	3.0a	39.5a	0.7a
Mean	42.0	41.5	83.0	7.0	3.0	39.8	0.6
S.E.	0.7	2.3	0.8	0.4	0.1	0.4	0.1
C.V. (%)	14.5	47.0	8.1	54.0	25.6	8	127.3
S1: Gisozi	47.0a	19.2c	90.0a	3.0c	3.0a	39.5b	0.1b
S2: Murongwe	43.0b	60.6a	81.0b	10.0a	4.0a	39.6c	1.4a
S3: Moso	35.0c	44.9b	77.0c	7.0b	3.0a	40.4a	0.2b
Mean	42.0	41.6	83.0	7.0	3.3	39.8	0.6
S.E.	0.3	1.1	0.4	0.3	0.1	0.3	0.0
C.V. (%)	7.2	28.1	4.1	35.8	23.3	7.1	70.8

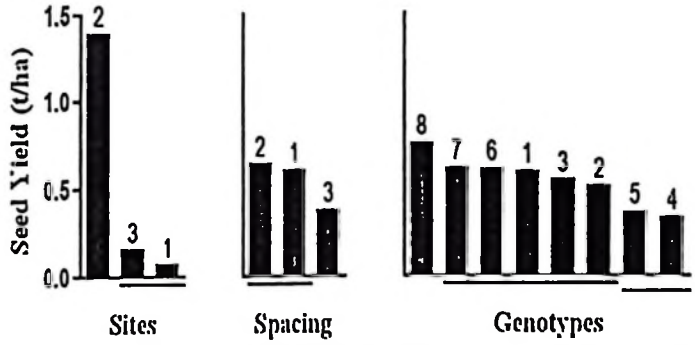

Figure 11: Effect of population (spacings), sites and genotypes on seed yield in combined sites during 2013A season

4.1.4.3 Combined simple correlation coefficient across sites between SY and its components

While DFL had negative and significant correlations with PH, P/P, S/P and 100SW, it was positive and significantly correlated with DPM. Further, PH was positively and significantly associated with P/P, S/P and SY. However, negative and significant correlation was found between PH with DPM. Days to physiological maturity was negatively and significantly correlated with P/P, S/P, HSW and SY. Positive and significant correlations were found among P/P between S/P and SY. Furthermore, positive and significant correlation was observed among S/P and SY. Negative and significant correlations were reported between HSW and SY. The highest correlation coefficient was between DFL and DPM followed by correlations between PH and P/P; PH and SY; P/P and SY (Table 28).

Table 28: Combined simple correlation coefficient between grain yield and yield components across sites during 2013A season

Variables	2	3	4	5	6	7
1.DFL (days)	-0.339***	0.749***	-0.251***	-0.185**	-0.290***	0.070
2.PH (cm)		-0.556***	0.697***	0.438***	0.036	0.690***
3.DPM (days)			-0.494***	-0.281***	-0.195**	-0.193**
4.P/P				0.487***	-0.070	0.660***
5.S/P					0.060	0.380***
6.HSW (g)						-0.280***
7.SY (t/ha)						

4.1.4.4 Influence of yield components on seed yield

Results presented in the Fig. 12 show that most of the variables had positive direct effects on seed yield except 100SW which presented negative direct effect. The PH had the highest positive direct effect on SY followed by P/P and DFL. On the other hand, 100SW showed high and negative direct effect on SY. However, PH displayed a high and positive indirect effect on SY through P/P and S/P (Table 29).

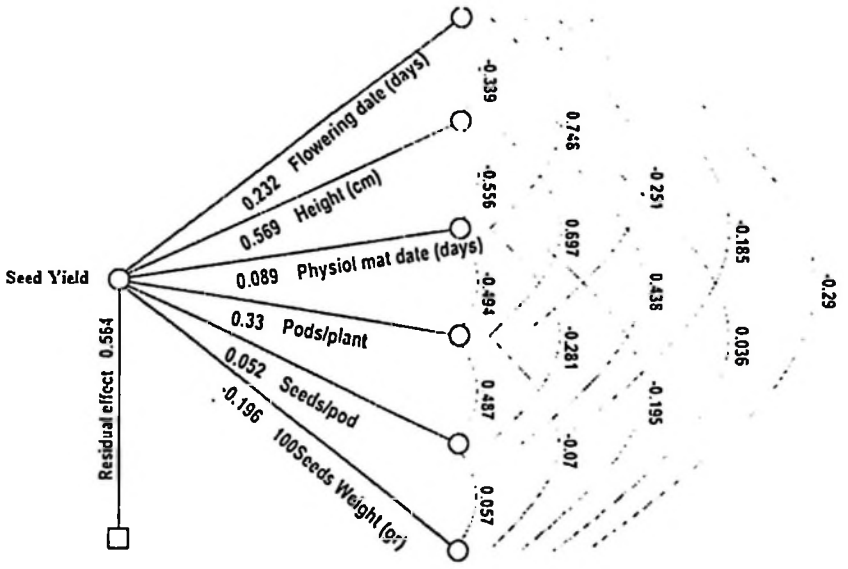

Figure 12: Path diagram indicating the interrelationships among the bean yield with its components in combined sites during 2013A season

Table 29: Path analysis showing direct and indirect effects of different yield components on seed yield in combined sites during 2013A

Variables	1	2	3	4	5	6
1.DFL (days)	0.232	-0.079	0.174	-0.058	-0.043	-0.068
2.Height (cm)	-0.193	0.569	-0.316	0.396	0.249	0.020
3.DPM (days)	0.066	-0.049	0.089	-0.044	-0.025	-0.017
4.P/P	-0.083	0.230	-0.163	0.330	0.161	-0.023
5.S/P	-0.010	0.023	-0.015	0.025	0.052	0.003
6.HSW (gr)	0.057	-0.007	0.038	0.014	-0.011	-0.196
Residual effect (PX7)						0.564

Key: Direct effects are presented in diagonal and indirect effects are presented off diagonal

4.1.5 Combined means of G x E interactions for DFL

The genotypes varied in days to 50% flowering due to G x E interaction. Genotype GLP2 showed similar ranks at Gisozi and Moso expressing.the latest genotype to reach DFL whereas KAB06F2-8-135 was the latest at Murongwe. Genotype KAB10F2-8-136 was presented as the earliest genotype to reach DFL at all of the sites. However, some genotypes reflected similar ranks within sites due to the fact that DFL cannot be decimal number (Table 30).

Table 30: Combined means of G x E interactions for DFL during 2013A season

Genotypes	Gisozi	Rank	Murongwe	Rank	Moso	Rank
KAB06F2-8-53	46	3	42	4	34	3
KAB06F2-8-24	46	3	42	4	33	4
KAB06F2-8-78	46	3	43	3	34	3
KAB06F2-8-135	48	1	45	1	36	2
KAB06F2-8-22	47	2	42	4	36	2
KAB10F2-8-136	46	3	42	4	30	5
KAB06F2-8-13	48	1	42	4	36	2
GLP2	48	1	44	2	37	1
Mean	47		43		35	

Highest rank means early in DFL and lowest rank means late in DFL.

4.1.6 Combined means of G x E interactions for PH (cm)

Genotype GLP2 showed similar rank at Gisozi and Moso expressing the tallest genotype at both sites whereas KAB06F2-8-24 was the tallest at Murongwe. While genotype KAB06F2-8-78 presented similar rank at Gisozi and Murongwe expressing the shortest genotype at these locations, KAB10F2-8-136 was the shortest at Moso (Table 31).

Table 31: Combined means of G x E interactions for PH during 2013A season

Genotypes	Gisozi	Rank	Murongwe	Rank	Moso	Rank
KAB06F2-8-53	21.4	2.0	64.1	3.0	43.4	5.0
KAB06F2-8-24	16.9	6.0	67.6	1.0	42.9	7.0
KAB06F2-8-78	13.3	8.0	53.4	8.0	43.6	4.0
KAB06F2-8-135	17.0	5.0	54.8	7.0	43.1	6.0
KAB06F2-8-22	16.2	7.0	62.7	4.0	43.4	3.0
KAB10F2-8-136	17.2	3.0	57.7	6.0	41.2	8.0
KAB06F2-8-13	17.2	4.0	66.2	2.0	44.2	2.0
GLP2	34.0	1.0	58.2	5.0	57.3	1.0
Mean	19.2		60.6		44.9	

4.1.7 Combined means of G x E interactions for DPM (days)

Even some genotypes presented similar ranks within location, genotype GLP2 showed similar rank at most of the sites signifying the latest genotype to reach maturity. On the other hand, genotype KAB10F2-8-136 presented shorter vegetative cycle at both Murongwe and Moso sites whereas KAB06F2-8-24 and KAB06F2-8-78 were the earliest genotypes at Gisozi (Table 32).

Table 32: Combined means of G x E interactions for DPM during 2013A season

Genotypes	Gisozi	Rank	Murongwe	Rank	Moso	Rank
KAB06F2-8-53	89	4	80	3	75	5
KAB06F2-8-24	87	5	80	3	76	4
KAB06F2-8-78	87	5	80	3	77	3
KAB06F2-8-135	93	1	81	2	78	2
KAB06F2-8-22	91	2	81	2	78	2
KAB10F2-8-136	90	3	79	4	70	6
KAB06F2-8-13	90	3	79	4	76	4
GLP2	93	1	87	1	79	1
Mean	90		81		76.0	

4.1.8 Combined means of G x E interactions for P/P

The genotype GLP2 exhibited similar ranks at Gisozi, Murongwe and Moso site expressing the highest mean number of P/P. However, some genotypes reflected similar ranks within sites due to the fact that P/P cannot be decimal number (Table 33).

Table 33: Combined means of G x E interactions for P/P during 2013A season

Genotypes	Gisozi	Rank	Murongwe	Rank	Moso	Rank
KAB06F2-8-53	3	2	10	2	8	2
KAB06F2-8-24	3	2	11	1	7	3
KAB06F2-8-78	3	2	10	2	7	3
KAB06F2-8-135	3	2	10	2	4	5
KAB06F2-8-22	2	3	10	2	5	4
KAB10F2-8-136	4	1	7	3	7	3
KAB06F2-8-13	3	2	11	1	7	3
GLP2	4	1	11	1	9	1
Mean	3		11		7	

4.1.9 Combined means of G x E interactions for S/P

Even some genotypes reflected similar ranks within sites, results showed that genotype GLP2 had similar ranks at all of the sites expressing the highest mean of S/P (Table 34).

Table 34: Combined means of G x E interactions for S/P during 2013A season

Genotypes	Gisozi	Rank	Murongwe	Rank	Moso	Rank
KAB06F2-8-53	3	1	3	3	3	2
KAB06F2-8-24	3	1	4	2	3	2
KAB06F2-8-78	3	1	4	2	3	2
KAB06F2-8-135	3	1	3	3	3	2
KAB06F2-8-22	3	1	4	2	3	2
KAB10F2-8-136	2	2	3	3	4	1
KAB06F2-8-13	2	2	3	3	3	2
GLP2	3	1	5	1	4	1
Mean	3		4		3	

4.1.10 Combined means of G x E interactions for 100SW (g)

While KAB06F2-8-22 showed the highest weight of 100seeds at Murongwe, GLP2 presented similar ranks at Gisozi and Moso indicating the highest mean weight of 100 seeds. Moreover, KAB06F2-8-78 presented similar ranks at Murongwe and Moso expressing the lowest mean weight of 100 seeds whereas KAB06F2-8-135 showed the lowest mean weight at Gisozi (Table 35).

Table 35: Combined means of G x E interactions for 100SW during 2013A season

Genotypes	Gisozi	Rank	Murongwe	Rank	Moso	Rank
KAB06F2-8-53	39.0	7.0	38.6	4.0	44.0	2.0
KAB06F2-8-24	40.1	4.0	36.1	7.0	41.0	6.0
KAB06F2-8-78	40.0	5.0	36.0	8.0	36.4	8.0
KAB06F2-8-135	33.4	8.0	38.6	5.0	42.7	3.0
KAB06F2-8-22	40.2	3.0	42.6	1.0	41.3	4.0
KAB10F2-8-136	39.3	6.0	40.0	2.0	41.3	5.0
KAB06F2-8-13	40.4	2.0	39.2	3.0	39.0	7.0
GLP2	42.6	1.0	37.3	6.0	46.0	1.0
Mean	39.4		38.5		41.0	

4.1.11 Combined means of G x E interactions for SY (t/ha)

Results presented in Table 36 shows that some genotypes reflected similar ranks within Gisozi site. However, genotype GLP2 showed similar ranks at both sites Gisozi and Murongwe signifying the highest SY whereas KAB06F2-8-78 exhibited the highest mean yield at Moso (Table 36).

Table 36: Combined means of G x E interactions for SY during 2013A season

Genotypes	Gisozi	Rank	Murongwe	Rank	Moso	Rank
KAB06F2-8-53	0.05	4.00	1.54	4.00	0.21	2.00
KAB06F2-8-24	0.05	4.00	1.30	6.00	0.19	3.00
KAB06F2-8-78	0.06	3.00	1.36	5.00	0.24	1.00
KAB06F2-8-135	0.05	4.00	0.86	8.00	0.11	7.00
KAB06F2-8-22	0.04	5.00	0.98	7.00	0.08	8.00
KAB10F2-8-136	0.09	2.00	1.61	3.00	0.14	6.00
KAB06F2-8-13	0.05	4.00	1.65	2.00	0.15	5.00
GLP2	0.22	1.00	1.88	1.00	0.19	4.00
Mean	0.08		1.40		0.16	

4.1.12 Broad sense-heritability parameters estimates of yield and yield components for common bean genotypes studied

Heritability estimates for the various bean traits varied between 0.18 and 0.66. High heritability was observed for DFL, PH, DPM and SY (Table 37). The expected genetic advance was high for PH, PP and SY whereas it was medium for DFL, DPM and S/P. One hundred seeds weight was relatively low on the expected genetic advance. On the other hand, genotypic coefficient of variation and phenotypic coefficient of variation were high for SY (Table 37).

Table 37: Means, variance and estimates of heritability for yield and its components for beans genotypes evaluated across three sites during 2013A season

Variable	Mean	δ^2e	δ^2g	GCV (%)	δ^2ph	PCV (%)	$h^2(b)$	EGA (%)
DFL (days)	41.45	3.63	26.56	12.43	40.19	15.29	0.66	26.68
PH (cm)	41.55	153.54	257.54	38.62	411.08	48.80	0.63	80.71
DPM (days)	82.70	16.71	31.80	6.82	48.50	8.42	0.66	14.57
P/P	6.83	7.87	7.03	38.84	14.91	56.54	0.47	70.43
S/P	3.19	0.59	0.13	11.45	0.73	26.73	0.18	12.96
HSW (g)	39.80	7.76	2.25	3.76	10.01	7.95	0.22	4.71
SY (t/ha)	0.54	0.24	0.30	100.33	0.54	134.00	0.55	196.843

Key: δ^2e = Component of variance due to environments, δ^2g = Component of variance due to genotypes, GCV (%) = Genotypic coefficient of variation, δ^2ph = Component of variance due to phenotypes, PCV (%) = Phenotypic coefficient of variation, $h^2(b)$ = heritability in broad sense, EGA (%) = Expected genetic advance as mean at 1%

4.1.7 Relationship among stability parameters with seed yield and its components

Yield is one of the most desirable traits if a genotype has to be used for a wide cultivation. Adaptability of genotypes to environmental fluctuation is important for the stable crop production over the environments. Bean breeders always aimed at identifying high yielding and stable genotypes. Some cultivars are well adapted to a particular environment whereas other cultivars are widely adapted under diverse environmental conditions. Therefore, a variety considered as stable and widely adapted should meet the criteria of high mean performance; with regression coefficient (bi) non-significantly different from one (1) and deviation from the regression (S^2di) approaching zero (0) (Bahrami *et al.*, 2008; Nath *et al.*, 2013). Finlay and Wilkinson, (1963) stated that

genotypes possessing bi value > 1.00 show adaptability in high yielding environments and genotypes having bi values < 1.00 exhibit adaptability in low yielding environments.

4.1.7.1 Relationship among stability parameters with P/P

Genotype KAB06F2-8-22 (E) presented bi below 1, low mean P/P and high S^2di whereas KAB06F2-8-78 (D) presented bi below 1, low mean P/P and high S^2di. Furthermore, genotype GLP2 (H) showed bi below 1, high mean P/P and low S^2di while KAB06F2-8-78 (C) presented bi-value approximately equal to 1; high mean P/P and high S^2di. Also, genotypes KAB06F2-8-24 (B) and KAB06F2-8-13 (G) showed high bi, low mean P/P and high S^2di. While the genotype KAB06F2-8-53 (A) had bi-value approximately equal to 1, high mean P/P and low S^2di, the genotype KAB10F2-8-136 (F) presented high bi, high mean P/P and low S^2di (Fig. 13).

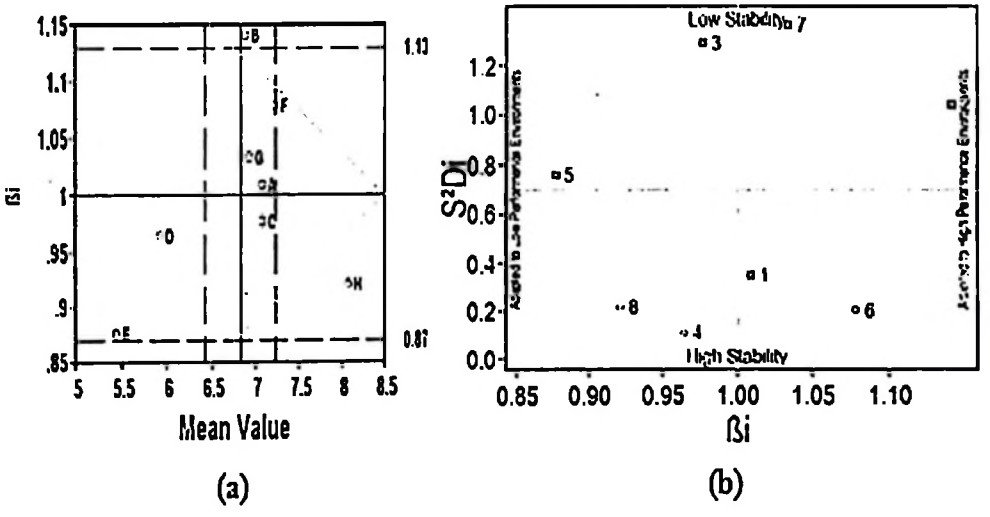

Figure 13: b-value plotted against mean P/P (a) and S^2d plotted against b-value for P/P (b) during 2013A season

Key: A=1. KAB06F2-8-53 B=2. KAB06F2-8-24 C=3. KAB06F2-8-78
D=4. KAB06F2-135 E=5. KAB06F2-8-22 F=6. KAB10F2-8-136
G=7. KAB06F2-8-13 F=8. GLP2

4.1.7.2 Relationship among stability parameters with S/P

Genotype GLP2 (H) presented high bi, high mean S/P, and high S^2di whereas genotype KAB06F2-8-22 (E) presented bi-value approximately equal to 1, low mean S/P and high S^2di. On the other hand, while genotypes KAB06F2-8-78 (C) and KAB06F2-8-135 (D) presented bi below 1, low mean S/P and high S^2di, genotype KAB06F2-8-53 (A) presented bi below 1, low mean S/P and S^2di approximately equal to zero (0). While genotype KAB06F2-8-13 (G) showed high bi, low mean S/P and high S^2di, genotypes KAB06F2-8-24 (B) and KAB10F2-8-136 (F) presented high bi, high mean S/P and low S^2di (Fig.14).

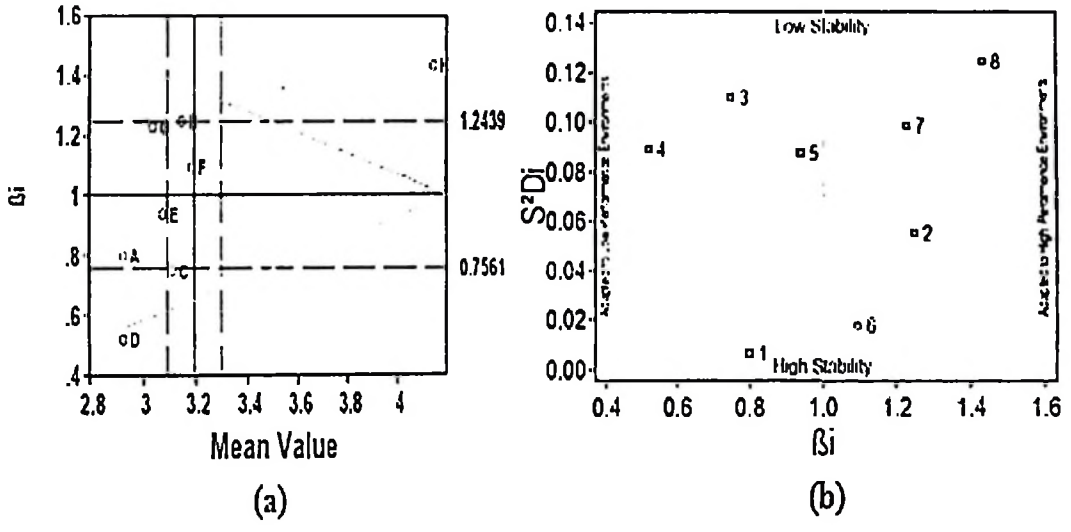

Figure 14: b-value plotted against mean S/P (a) and S^2d plotted against b-value for S/P during 2013A season

4.1.7.3 Relationship among stability parameters with 100SW

Genotypes KAB06F2-8-53 (A) and GLP2 (H) presented high bi, high mean 100SW and low S^2di. On the other hand, genotypes KAB06F2-8-22 (E) and KABO6F2-8-136 (F) presented bi below 1, high mean 100SW and low S^2di. While genotype KAB06F2-8-13 (G) presented bi below 1, low mean 100SW and low S^2di, genotype KAB06F2-8-78 (C)

exhibited bi below 1, low mean 100SW and high S^2di. Furthermore, KAB06F2-8-24 (B) showed high bi, low mean 100SW and low S^2di whereas genotype KAB06F2-8-135 (4) presented high bi, low mean 100SW and high S^2di (Fig 15).

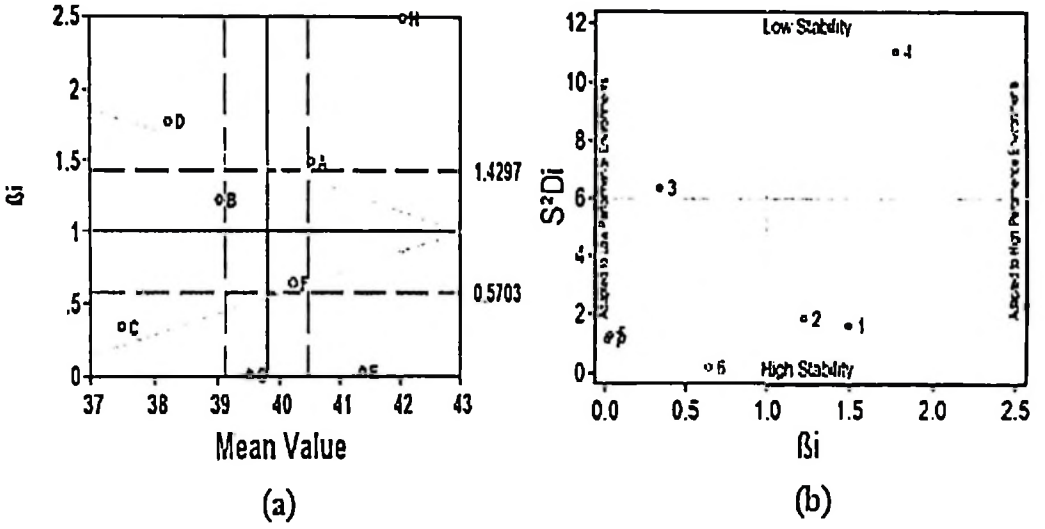

Figure 15: b-value plotted against mean of 100SW (a) and S^2d plotted against b-value for 100SW (b) during 2013A season

4.1.7.4 Relationship among stability parameters with SY

Results presented in Fig. 16 show that genotypes KABO6F2-8-136 (F).and GLP2 (H) presented high bi, high mean SY and high S^2di. On the other side, genotypes KAB06F2-8-53 (A) and KAB06F2-8-13 (G) exhibited high bi, high mean SY and low S^2di. While, genotypes KAB06F2-8-135 (D) and KAB06F2-8-22 (E) presented bi below 1, low mean SY and low S^2di, genotype KAB06F2-8-78 (C) and KAB06F2-8-24 (B) presented bi below 1, high mean SY and low S^2di.

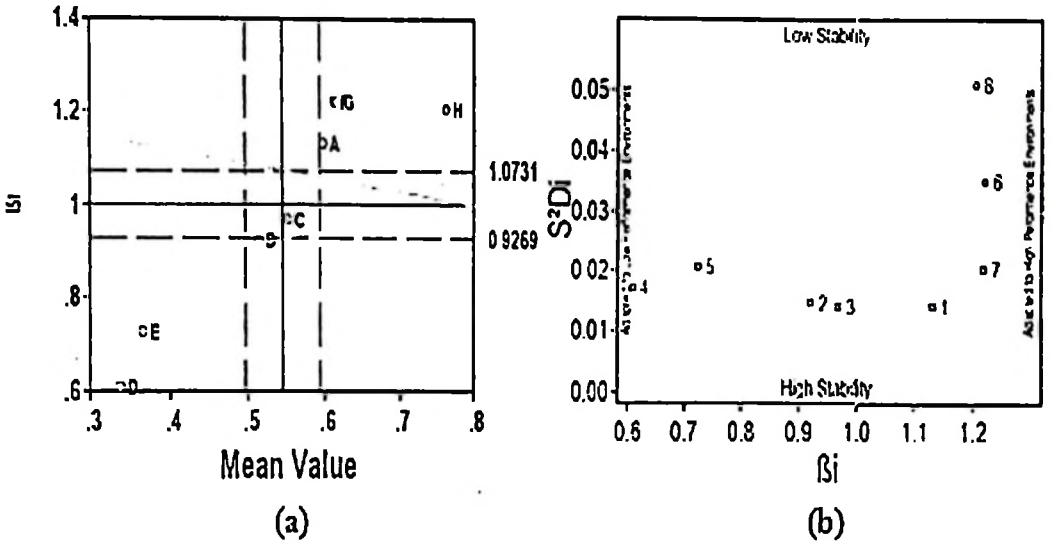

Figure 16: b-value plotted against the mean SY (a) and S^2d plotted against b-value (b) for SY during 2013A season

4.2 Results from the Second Cropping Season (2013B)

4.2.1 Gisozi site

4.2.1.1 ANOVA for different variables studied during 2013B season

Results for ANOVA are presented in Table 38. Highly significant differences ($P \leq 0.001$) were observed among plant population densities for CBB, DPM and SY whereas high significant differences ($P \leq 0.01$) were presented for TPH. Among genotypes, significant differences at different levels of significance were observed for PG, DFL, Anthracnose, ALS, BR, Rust, DFL, TPH and DPM. The interaction between genotypes and plant population densities also presented significant effects ($P \leq 0.05$) for BCMV and CBB diseases whereas highly significant effects ($P \leq 0.001$) were observed for DPM.

Table 38: ANOVA summary for different variables studied at GISOZI during 2013B season

Source of Variation	DF	Mean Squares													
		PG	DFL	ANTR	ALS	BCMV	BR	CBB	RU	TPH	DPM	P/P	S/P	HSW	SY
lication	2	120.10*	0.68	20.60***	3.60***	1.01	3.88	0.389	1.10	121.51	0.43	40.04	5.85	10.76	0.35
Spacing	2	0.39	0.10	5.18	0.35	1.10	0.50	2.18***	0.68	229.85**	9.85***	45.54	2.51	4.39	2.531***
Error (A)	4	28.29	0.97	2.26	0.18	1.06	1.88	0.24	0.45	41.39	0.806	14.71	2.22	3.79	0.25
Genotype	7	22.98*	34.63***	7.63***	2.74***	0.44	0.89**	0.75	3.01*	449.08***	91.20***	7.33	2.73	117.14	0.33
Spac*Geno	14	4.21	0.38	1.37	0.13	0.67 *	0.48	0.78*	0.82	110.29	8.47***	6.03	2.07	4.80	0.31
Error (B)	42	9.81	0.72	1.28	0.18	0.31	0.26	0.34	1.29	71.54	0.728	5.66	2.37	7.78	0.19
Total	71	13.89	3.99	2.63	0.52	0.48	0.56	0.52	1.30	120.57	11.43	8.50	2.44	17.74	0.30
CV (%)		3.34	1.66	34.96	10.54	13.86	12.65	16.01	65.31	20.67	0.94	27.19	45.40	7.12	22.98

4.2.1.2 Effect of genotypes and spacings on germination

Plant population densities were not statistically different and presented the same percentage of PG while genotypes were significantly different with genotype KAB06F2-8-78 presenting the highest mean of PG (Table 39). Fig. 17 presents development stage of different genotypes showing good plant stand at Gisozi site during the second cropping season.

Table 39: Plant germination (%) of eight bean genotypes at three plant spacing at Gisozi sites during 2013B season

Genotypes	Spac.1 (15cmx40cm)	Spac.2 (20cmx40cm)	Spac.3 (40cmx40cm)	Mean
KAB06F2-8-53	94	92	93.333	93bc
KAB06F2-8-24	96	93	92	94abc
KAB06F2-8-78	95	96	98	96a
KAB06F2-8-135	93	93	93	93bc
KAB06F2-8-22	95	94	96	95ab
KAB10F2-8-136	96	95	95	95ab
KAB06F2-8-13	92	94	91	92bc
GLP2	90	92	92	91c
Mean	94a	94a	94a	94
SE	1.06	0.57	0.58	0.74
CV (%)	5.55	2.99	3.00	3.85

Figure 17: Development stage of different bean genotypes at Gisozi in 2013B season showing good plant stand

4.2.1.3 Effect of genotypes and spacings on diseases

According to the standard system for evaluation of common bean germplasm, genotypes showed resistance to intermediate reaction to ALS, Anthracnose, BR, CBB and Rust diseases. Moreover, there were slight differences between different plant populations (Table 40).

Table 40: Disease reaction of eight bean genotypes at three plant spacings at Gisozi site during 2013B season

Genotypes	15cm x 40cm					20cm x 40cm					40cm x 40cm					Mean				
	ALS	ANTR	BR	CBB	RU	ALS	ANTR	BR	CBB	RU	ALS	ANTR	BR	CBB	RU	ALS	ANTR	BR	CBB	RU
KAB06F2-8-53	3	2	4	4	2	4	3	4	3	1	3	5	4	3	2	3d	3ab	4a	3b	1c
KAB06F2-8-24	5	3	4	4	1	5	4	4	4	1	4	4	4	3	1	5a	4a	4a	4a	1c
KAB06F2-8-78	4	2	4	3	3	4	4	4	3	2	4	3	4	4	2	4bc	3ab	4a	4a	2b
KAB06F2-8-135	4	4	5	3	2	4	3	4	4	3	4	3	4	3	2	4bc	3ab	4a	4a	2b
KAB06F2-8-22	4	3	5	4	3	4	5	4	5	2	4	4	4	3	2	4bc	4ab	4a	4a	3a
KAB10F2-8-136	5	3	3	5	2	5	5	4	4	1	5	5	4	3	2	5a	4a	4a	4a	2b
KAB06F2-8-13	4	3	5	4	3	4	3	4	4	1	4	4	4	3	2	4bc	3ab	4a	4a	2b
GLP2	3	1	3	3	1	3	1	4	3	1	3	2	3	3	1	3d	1b	3b	3b	1c
Mean	4a	3a	4a	4a	2a	4a	3a	4a	4a	2a	4a	4a	4a	3b	2a	4	3	4	4	2
SE	0.2	0.3	0.2	0.2	0.3	0.2	0.3	0.1	0.1	0.2	0.1	0.3	0.2	0.1	0.2	0.2	0.3	0.2	0.1	0.2
CV (%)	19.8	60.1	20.3	20.5	66.9	18.0	47.2	12.6	18.3	58.6	16.7	43.5	21.6	16.7	70.0	18.2	50.3	18.2	18.5	65.2

4.2.1.4 Seed yield (t/ha) and yield components

Genotype KAB06F2-8-13 was earliest to reach DFL whereas GLP2 was the latest. Plant population densities were not statistically different and presented the same period to reach DFL. On the other hand, while genotype KAB06F2-8-24 was the earliest to reach DPM, GLP2 was the latest (Table 41).

Table 41: Mean DFL and DPM for eight genotypes at Gisozi during 2013B season

Genotypes	Days to 50% Flowering				Days to Physiological Maturity			
	Spac.1	Spac.2	Spac.3	Mean	Spac.1	Spac.2	Spac.3	Mean
KAB06F2-8-53	40.0	39.0	39.0	39.0bc	90.0	90.0	88.0	89.0bc
KAB06F2-8-24	40.0	40.0	40.0	40.0b	88.0	88.0	87.0	88.0d
KAB06F2-8-78	39.0	39.0	39.0	39.0bc	89.0	88.0	90.0	89.0bc
KAB06F2-8-135	39.0	40.0	39.0	39.0bc	90.0	90.0	90.0	90.0b
KAB06F2-8-22	40.0	40.0	40.0	40.0b	89.0	90.0	89.0	89.0bc
KAB10F2-8-136	39.0	39.0	39.0	39.0bc	90.0	90.0	90.0	90.0b
KAB06F2-8-13	38.0	39.0	38.0	38.0c	90.0	90.0	90.0	90.0b
GLP2	45.0	44.0	45.0	45.0a	98.0	98.0	98.0	98.0a
Mean	40.0a	40.0a	40.0a	40.0	91.0a	91.0a	90.0b	90.0
SE	0.4	0.4	0.4	0.4	0.6	0.6	0.8	0.7
CV (%)	5.2	4.6	5.3	5.0	4.6	5.3	4.3	3.7

Further, the highest mean weight of 100 seeds was found for the genotypes under spacing 40cm x 40cm. The genotype KAB06F2-8-78 exhibited the lowest weight whereas the genotype GLP2 presented the highest mean weight (Table 42).

Regarding plant height, the tallest genotypes were found under spacing 40cm x 40cm and GLP2 was the tallest followed by KAB06F2-8-53 whereas KAB06F2-8-78 was the shortest. Furthermore, genotype KAB06F2-8-78 presented a high mean SY followed by KAB06F2-8-24 and KAB06F2-8-22. Plants under spacing 15cm x 40cm resulted in highest seed yield compared to other two spacings (Table 43, Fig. 18).

Table 42: Mean 100SW for eight genotypes at Gisozi during 2013B season

Genotypes	Spacing 1 (15cm x 40cm)	Spacing 2 (20cm x 40cm)	Spacing 3 (40cm x 40cm)	Mean
KAB06F2-8-53	40.0	38.7	41.7	40.1bc
KAB06F2-8-24	36.7	37.7	35.7	36.7d
KAB06F2-8-78	33.3	34.3	33.3	33.7e
KAB06F2-8-135	36.7	38.0	40.7	38.4cd
KAB06F2-8-22	41.3	42.7	43.7	42.6b
KAB10F2-8-136	41.3	39.0	37.0	37.8cd
KAB06F2-8-13	38.7	38.3	38.7	38.6cd
GLP2	46.3	43.7	46.3	45.4a
Mean	38.8a	39.0a	39.6a	39.2
SE	0.9	0.7	1.0	2.6
CV (%)	11.0	8.5	12.7	12.7

Table 43: Mean PH (cm) and SY (t/ha) for eight genotypes at Gisozi during 2013B season

Genotypes	Plant Height (cm)				Seed Yield (t/ha)			
	Spac.1	Spac.2	Spac.3	Mean	Spac.1	Spac.2	Spac.3	Mean
KAB06F2-8-53	35.67	40.00	44.67	40.11a	2.69	1.06	1.76	1.84ab
KAB06F2-8-24	29.67	44.00	40.00	37.89ab	2.34	2.24	1.45	2.01a
KAB06F2-8-78	31.67	35.33	28.67	31.89b	2.51	2.22	1.65	2.13a
KAB06F2-8-135	46.67	34.00	41.33	40.67a	1.81	2.04	1.96	1.93ab
KAB06F2-8-22	36.67	37.33	36.33	36.78ab	2.37	2.01	1.90	1.94a
KAB10F2-8-136	36.67	31.67	55.00	41.11a	1.80	1.60	1.29	1.56b
KAB06F2-8-13	42.33	36.67	49.00	42.67a	2.31	1.88	1.59	1.93ab
GLP2	52.67	55.33	61.00	56.33a	2.20	1.67	1.29	1.72ab
Mean	39.00b	39.29b	44.50a	40.93	2.25a	1.84b	1.61b	1.9
SE	2.0	1.9	2.7	2.2	38.3	44.0	36.6	39.6
CV (%)	24.9	23.8	29.3	26	20.8	29.3	27.8	26.0

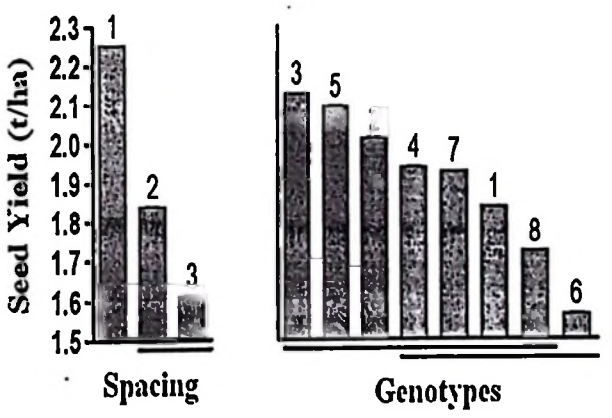

Figure 18: Effect of population (spacings) and genotypes on seed yield at Gisozi during 2013B season

4.2.1.5 Simple correlation coefficients between SY and its component

Positive and significant correlations were found between DFL and PH, DPM and 100SW. Also, positive and significant correlations were found between PH and DPM. The same trend was observed between PH and 100SW. Furthermore, positive and significant correlations were observed between DPM and 100SW. The highest correlation coefficient was observed between DFL and DPM (Table 44).

Table 44: Simple correlation coefficient between yield and yield components at Gisozi site during 2013B season

Variables	2	3	4	5	6	7
1. DFL (days)	0.466***	0.673***	0.076	0.074	0.626***	0.004
2. PH (cm)		0.509***	0.074	-0.070	0.353**	-0.207
3. DPM (days)			0.098	0.044	0.588***	-0.163
4. P/P				0.059	-0.026	0.156
5. S/P					0.004	0.153
6. HSW (g)						-0.051
7. SY (t/ha)						

4.2.1.6 Influence of yield components on seed yield

Path analysis of effective traits on SY showed that most of the variables had positive direct effect to SY except PH and DPM which presented negative direct effect. Days to 50% flowering had the highest positive direct effect to SY followed by P/P. However, DPM showed high and negative direct effect on SY (Fig. 19). On the other hand, DFL provided high and positive indirect effect to SY via DPM (Table 45).

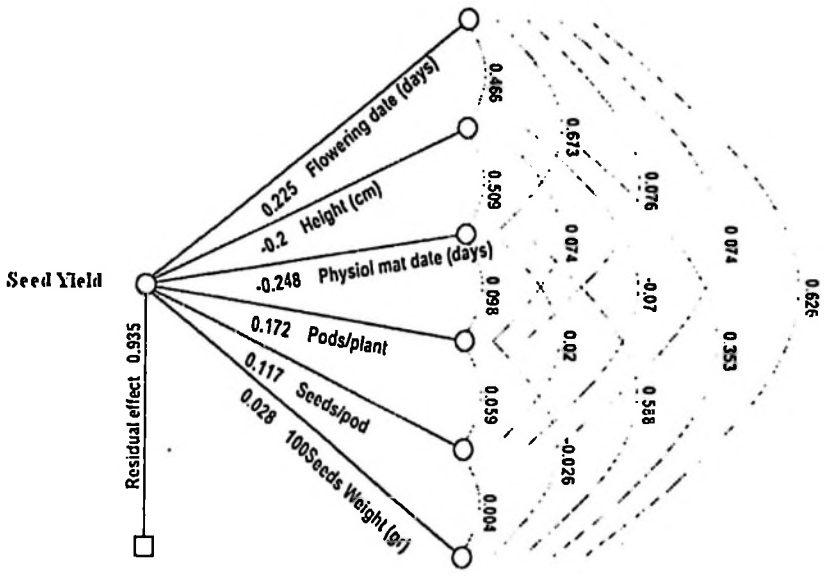

Figure 19: Path diagram indicating the interrelationships among the bean yield with its components at Gisozi site during 2013B season

Table 45: Path analysis showing direct (diagonal) and indirect (off diagonal) effects of different yield components on seed yield at Gisozi site during 2013B

Variables	1	2	3	4	5	6
1.DFL (days)	0.225	0.105	0.151	0.017	0.017	0.141
2. Height (cm)	-0.093	-0.200	-0.102	-0.015	0.014	-0.071
3. DPM (Days)	-0.167	-0.126	-0.248	-0.024	-0.005	-0.146
4. P/P	0.013	0.013	0.017	0.172	0.010	-0.004
5. S/P	0.009	-0.008	0.002	0.007	0.117	0.000
6. HSW (gr)	0.018	0.010	0.017	-0.001	0.000	0.028
Residual effect (PX7)						0.935

Key: Direct effects are presented in diagonal and indirect effects are presented off diagonal

4.2.2 Murongwe site

4.2.2.1 ANOVA for different variables studied

Highly significant differences (P≤0.001) were presented between plant population density for DFL, CBB and P/P whereas high significant differences (P≤0.01) were observed for PG and 100SW. While highly significant differences (P≤0.001) were showed for DFL, ALS, RU, DPM, S/P, 100SW and SY among genotypes, high significant differences (P≤0.01) were observed for PH and P/P. Furthermore, high significant interaction (P ≤0.01) was exhibited between genotypes and plant population densities for 100SW (Table 46).

Table 46: ANOVA summary for different variables studied at Murongwe during 2013B season

Source of Variation	DF	Mean Squares													
		PG	DFL	ALS	ASCO	BCMV	BR	CBB	RU	PH	DPM	P/P	S/P	HSW	SY
Replication	2	5.54	0.04	1.01**	1.26***	0.17	2.51**	1.79**	0.17	434.59*	18.06***	4.39	0.06	89.02***	3.92***
Spacing	2	104.17**	0.29***	0.18	0.06	0.54	0.68	3.17***	0.54	219.39	2.51	21.10***	0.18	49.48**	0.82
Error (A)	4	13.02	0.02	0.18	0.10	0.58	0.45	0.33	0.40	95.81	0.83	2.16	0.14	0.90	0.38
Genotype	7	7.43	21.65***	1.20***	0.32	0.41	0.14	0.33	4.030***	467.36**	65.55***	10.19**	1.45***	115.64***	1.52***
Spacing*Genotype	14	7.02	0.18	0.23	0.25	0.45*	0.38	0.42	0.45	96.52	0.29	3.59	0.20	5.645**	0.11
Error (B)	42	3.67	0.12	0.22	0.22	0.21	0.28	0.30	0.32	110.98	0.49	3.00	0.22	2.18	0.34
Total	71	8.11	2.25	0.34	0.25	0.30	0.37	0.45	0.72	154.58	7.44	4.33	0.33	17.76	0.53
CV (%)		2.01	0.88	13.46	13.50	17.58	18.29	18.91	34.78	16.50	0.92	20.11	14.26	3.33	23.05

4.2.2.2 Effect of genotypes and spacings on germination

Most of the genotypes except KAB06F2-8-22 and KAB10F2-8-136 presented high mean PG and were not statistically different. Moreover, genotypes under spacing 40cm x 40cm exhibited highest mean of PG followed by genotypes under spacing 20cm x 40cm (Table 47). Figure 20 shows the development stage of different bean genotypes showing good performance at Murongwe site during 2013B.

Table 47: Plant germination (%) of eight bean genotypes at three plant spacings at Murongwe site during 2013A season

Genotypes	Spacing 1 (15cm x 40cm)	Spacing 2 (20cm x 40cm)	Spacing 3 (40cm x 40cm)	Mean
KAB06F2-8-53	95	95	96	95ab
KAB06F2-8-24	94	94	99	96a
KAB06F2-8-78	92	95	100	95ab
KAB06F2-8-135	93	95	98	96a
KAB06F2-8-22	91	96	96	94ab
KAB10F2-8-136	90	95	96	94ab
KAB06F2-8-13	94	97	98	96a
GLP2	96	96	97	96a
Mean	93b	95ab	97a	95
SE	0.6	0.3	0.4	0.4
CV (%)	3.2	1.7	2.2	2.4

Figure 20: Development stage of different bean genotypes at Murongwe in 2013B season

4.2.2.3 Effect of genotypes and spacings on diseases

In overall disease reaction was moderate for most of the diseases ranging from 1 - 4. Therefore, according to the standard system for evaluation of bean germplasm, genotypes exhibited intermediate reaction to ALS, Anthracnose, BR, CBB and Rust diseases. Further, plant population densities did not have effect on diseases reaction (Table 48).

Table 48: Disease reaction of 8 bean genotypes at three plant spacings at Murongwe site during 2013B season

	15cm x 40cm				20cm x 40cm				40cm x 40cm				Mean			
Genotypes	ALS	RU	CBB	BCMV	ALS	RU	CBB	BCMV	ALS	Ru	CBB	BCMV	ALS	Ru	CBB	BCMV
KAB06F2-8-53	4	2	3	3	4	1	3	1	4	1	3	2	4ab	1c	3a	2b
KAB06F2-8-24	4	1	3	3	3	1	3	1	4	1	2	2	4ab	1c	3a	3a
KAB06F2-8-78	4	2	3	2	4	2	3	1	4	1	3	3	4ab	2b	3a	2b
KAB06F2-8-135	3	1	3	2	4	2	3	1	3	1	2	2	3b	1c	3a	2b
KAB06F2-8-22	3	3	3	3	3	4	3	3	3	3	2	3	3b	3a	3a	3a
KAB10F2-8-136	4	1	3	3	4	2	3	1	4	1	2	3	4ab	2b	3a	3a
KAB06F2-8-13	4	2	3	2	3	1	3	2	3	2	3	3	3b	2b	3a	3a
GLP2	3	1	3	2	3	1	4	1	3	1	2	3	3b	1c	3a	3a
Mean	4a	2a	3a	3a	3a	2a	3a	1a	3a	1a	2b	3a	3	2	3	3
SE	0.1	0.2	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.2	0.1	0.1
CV (%)	14.0	49.0	18.1	23.1	14.7	56.5	21.8	20.7	21.0	49.4	24.4	19.3	16.6	51.6	18.5	21

4.2.2.4 Yield components and SY (t/ha) performance

The earliest genotype to reach DFL was KAB06F2-8-53. However, genotypes under different levels of spacing presented the same period to reach DFL. On the other hand, genotypes KAB06F2-8-53, KAB06F2-8-24, KAB06F2-8-78, KAB10F2-8-136 and KAB06F2-8-13 were the earliest to reach maturity. Moreover, results revealed that the earliest genotype to reach DFL was the earliest to reach maturity and the latest genotype to reach DFL was the latest to reach maturity (Table 49).

Table 49: Mean DFL and DPM for eight genotypes at Murongwe during 2013B season

Genotypes	Days to 50% Flowering				Days to Physiological Maturity			
	Spac.1	Spac.2	Spac.3	Mean	Spac.1	Spac.2	Spac.3	Mean
KAB06F2-8-53	37	36	37	37c	76	75	75	75c
KAB06F2-8-24	41	40	41	41b	76	75	75	75c
KAB06F2-8-78	40	40	40	40c	76	75	75	75c
KAB06F2-8-135	40	40	40	40c	76	75	76	76b
KAB06F2-8-22	39	39	39	39d	77	76	76	76b
KAB10F2-8-136	40	40	40	40c	75	75	75	75c
KAB06F2-8-13	39	39	39	39d	76	75	76	75c
GLP2	42	42	42	42a	83	83	83	83a
Mean	40a	40a	40a	40	77a	76a	76a	76
SE	0.3	0.3	0.3	0.3	0.6	0.6	0.6	0.6
CV (%)	3.6	3.6	4.0	3.7	3.6	3.6	3.6	3.6

Regarding height of the plants and the number of pods per plant, genotypes under spacing 20cm x 40cm were tallest followed by genotypes under spacing 40cm x 40cm. Among genotypes, GLP2 was the tallest whereas KAB06F2-8-22 was the shortest. While genotypes KAB06F2-8-24 and KAB06F2-8-13 presented highest mean P/P, genotype GLP2 presented the lowest mean. Among plant population densities, genotypes under spacing 40cm x 40cm exhibited the highest mean P/P (Table 50).

Table 50: Mean PH and P/P for eight genotypes at Murongwe during 2013B season

	Plant height (cm)				Pods per plant			
Genotypes	Spac.1	Spac.2	Spac.3	Mean	Spac.1	Spac.2	Spac.3	Mean
KAB06F2-8-53	60.8	67.3	61.8	63.3bc	9.0	9.0	8.0	9.0ab
KAB06F2-8-24	65.9	59.7	69.8	65.2bc	10.0	11.0	10.0	10.0a
KAB06F2-8-78	56.5	57.8	60.9	58.4bc	8.0	9.0	10.0	9.0ab
KAB06F2-8-135	52.9	72.8	69.5	65.1bc	7.0	9.0	9.0	8.0b
KAB06F2-8-22	45.7	62.9	49.7	52.8c	7.0	7.0	9.0	8.0b
KAB10F2-8-136	59.7	64.7	63.3	62.6bc	7.0	9.0	9.0	8.0b
KAB06F2-8-13	66.3	71.6	57.6	65.2bc	8.0	10.0	11.0	10.0a
GLP2	77.7	76.9	79.9	78.2a	5.0	6.0	10.0	7.0c
Mean	60.7a	66.7a	64.1a	63.8	8.0b	9.0ab	10.0a	9.0
SE	2.8	2.3	2.4	2.5	0.4	0.4	0.3	0.4
CV (%)	22.8	16.7	18.6	19.4	26.8	24.4	17.8	23.0

The genotype KAB06F2-8-22 presented highest mean weight of 100 seeds whereas GLP2 exhibited the lowest mean weight. Between plant population densities, genotypes under spacing 40cm x 40cm presented highest mean weight of 100 seeds (Table 51).

Table 51: Mean 100SW for eight genotypes at Murongwe during 2013B season

Genotypes	Spac.1(15cm x 40cm)	Spac.2(20cm x 40cm)	Spac3(40cm x 40cm)	Mean
KAB06F2-8-53	45.8	46.7	49.1	47.2b
KAB06F2-8-24	40.4	43.4	41.6	41.8d
KAB06F2-8-78	39.7	39.8	39.2	39.6e
KAB06F2-8-135	44.9	45.2	49.5	46.5b
KAB06F2-8-22	50.3	48.5	52.5	50.4a
KAB10F2-8-136	43.1	42.4	46.4	43.9c
KAB06F2-8-13	43.3	43.6	46.3	44.4c
GLP2	38.4	41.7	43.4	41.1d
Mean	43.2b	43.9b	46.0a	44.4
SE	0.8	0.7	1.0	0.6
CV (%)	9.5	7.7	10.3	6.9

With regards to S/P and seed yield, the check genotype (GLP2) presented the highest mean S/P and SY. However, the lowest mean SY was observed for KAB06F2-8-22. Among plant population densities, genotypes under different spacing levels were not statistically different and were classified in the same group means (Table 52 and Fig. 21).

Table 52: Mean S/P and SY for eight genotypes at Murongwe during 2013B season

	Seeds per pod				Seed Yield (t/ha)			
Genotypes	Spac.1	Spac.2	Spac.3	Mean	Spac.1	Spac.2	Spac.3	Mean
KAB06F2-8-53	3.00	3.00	3.00	3.00b	2.73	2.93	2.71	2.79b
KAB06F2-8-24	3.00	.004	3.00	3.00b	2.59	2.28	2.22	2.37bc
KAB06F2-8-78	3.00	3.00	3.00	3.00b	2.34	2.53	1.97	2.28bc
KAB06F2-8-135	3.00	3.00	3.00	3.00b	2.09	2.40	2.17	2.22c
KAB06F2-8-22	3.00	3.00	3.00	3.00b	2.25	2.19	2.06	2.17c
KAB10F2-8-136	3.00	3.00	4.00	3.00b	2.49	2.60	1.88	2.32bc
KAB06F2-8-13	4.00	3.00	3.00	3.00b	2.83	2.83	2.21	2.63bc
GLP2	4.00	4.00	4.00	4.00a	3.70	3.24	3.23	3.39a
Mean	3.00a	3.00a	3.00a	4.00	2.63a	2.62a	2.31a	2.52
SE	0.10	0.10	0.10	0.10	0.20	0.10	0.20	0.20
CV (%)	18.30	17.00	16.90	17.40	33.60	19.40	31.00	28.00

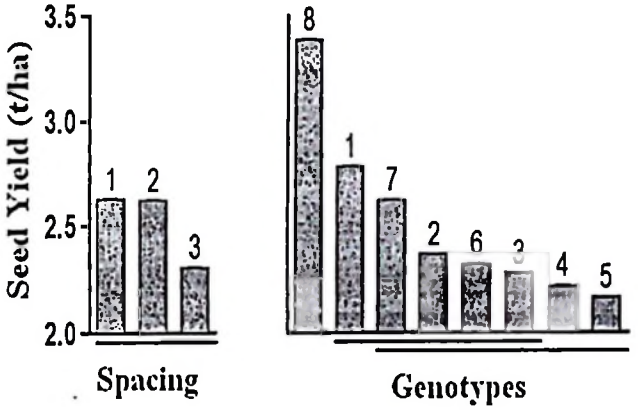

Figure 21: Effect of population (spacings) and genotypes on seed yield at Murongwe site during 2013B season

4.2.2.5 Simple correlation coefficients between SY and its components

Positive and significant correlations at different levels of significance were found between DFL and PH; DPM and S/P. However, negative and significant correlation was determined between DFL and 100SW. While positive correlations were observed between PH and DPM; S/P and SY, significant and negative correlations were observed between PH and 100SW. Days to physiological maturity had positive and significant association with S/P and SY whereas negative and significant association was observed with P/P. Also, positive and significant correlation was found between S/P and SY. However, negative and significant correlations were observed between S/P and 100SW. The same trend was found between 100SW and SY. The highest correlation coefficient was

observed between PH and SY followed by correlations between DFL and DPM (Table 53).

Table 53: Simple correlation coefficient between SY and yield components at Murongwe site during 2013B season

Variables	2	3	4	5	6	7
1.DFL (days)	0.275*	0.544**	-0.060	0.415***	-0.489***	0.112
2. PH (cm)		0.244*	0.130	0.458***	-0.373**	0.648***
3. DPM (days)			-0.357**	0.493***	-0.114	0.252*
4. P/P				0.054	-0.111	-0.021
5. S/P					-0.255*	0.318**
6. HSW (g)						-0.375**
7. SY (t/ha)						

4.2.2.6 Influence of yield components on seed yield

How yield is influenced by various yield components is shown in Fig. 22. Plant height had the highest positive direct effect on SY followed by DPM. However, DFL showed high and negative direct effect on SY. On the other hand, PH provided high and positive indirect effect on SY via S/P (Table 54).

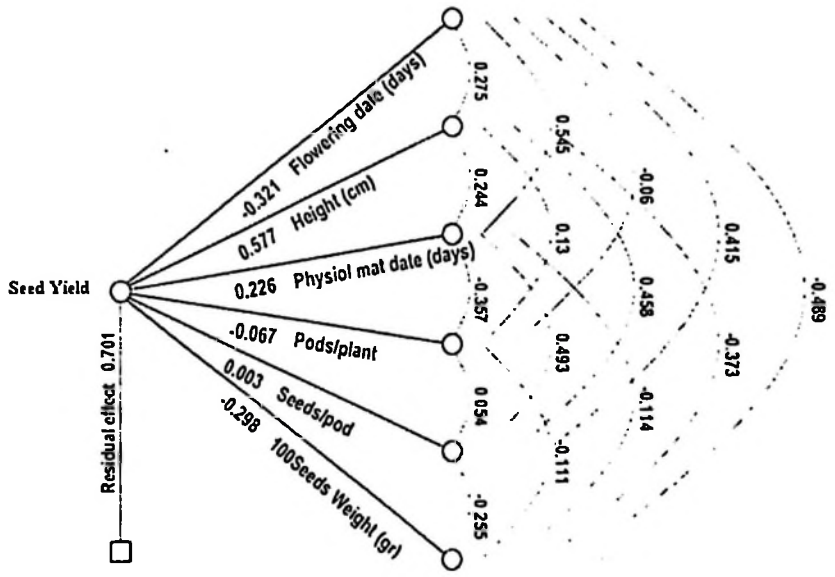

Figure 22: Path diagram indicating the interrelationships among the bean yield with its components at Murongwe site during 2013B season

Table 54: Path analysis showing direct and indirect effects of different yield components on seed yield at Murongwe site during 2013B

Variables	1	2	3	4	5	6
1.DFL (days)	-0.321	-0.088	-0.175	0.019	-0.133	0.157
2. Height (cm)	0.159	0.577	0.141	0.075	0.264	-0.215
3. DPM (Days)	0.123	0.055	0.226	-0.081	0.112	-0.026
4. P/P	0.004	-0.009	0.024	-0.067	-0.004	0.007
5. S/P	0.001	0.002	0.002	0.000	0.003	-0.001
6. HSW (gr)	0.146	0.111	0.034	0.033	0.076	-0.298
Residual effect (PX7)						0.701

Key: Direct effects are presented in diagonal and indirect effects are presented off diagonal

4.2.3 Moso site

4.2.3.1 ANOVA for different variables studied during 2013B season

Significant differences ($P \leq 0.05$) were observed among plant population densities for PG whereas high significant differences ($P \leq 0.01$) were found for 100SW (Table 55). Among genotypes significant effects at different levels of significance were observed for ALS, BCMV, Rust, DFL, PH, DPM, 100SW and SY.

Table 55: ANOVA summary for different variables studied at Moso during 2013B season

Source of Variation	DF	Mean Squares					
		PG	DFL	ALS	ASCO	BCMV	RU
Replication	2	48.76	0.26	0.06	0.06	0.01	0.06
Spacing	2	89.06*	0.01	0.18	0.06	0.01	0.18
Error (A)	4	18.01	0.39	0.14	0.22	0.06	0.39
Genotype	7	9.28	19.57 ***	1.17 ***	1.01	1.97***	4.70 ***
Spacing*Genotype	14	12.09	0.38	0.20	0.44	0.11	0.85
Error (B)	42	11.58	0.59	0.22	0.68	0.07	0.69
Total	71	15.05	2.38	0.30	0.60	0.26	1.07
CV (%)		3.59	2.11	14.26	60.34	9.61	53.42

Table 55: Continued

Source of Variation	DF	Mean Squares					
		PH	DPM	P/P	S/P	HSW	SY
Replication	2	720.88 *	3.18	25.18	5.38	6.43	0.52
Spacing	2	135.27	0.39	80.10	3.50	37.10 **	0.19
Error (A)	4	141.28	4.41	60.87	2.38	4.99	0.85
Genotype	7	364.58 **	86.21 ***	54.63	4.81	36.03 ***	0.18 *
Spacing*Genotype	14	103.91	2.07	21.86	3.04	6.91	0.13
Error (B)	42	111.35	3.10	49.21	3.68	7.33	0.07
Total	71	154.38	11.09	45.20	3.63	10.76	0.15
CV (%)		12.36	2.38	54.78	45.56	6.16	11.92

4.2.3.2 Effect of genotypes and spacings on germination

Genotypes under spacing 40cm x 40cm presented a high mean of germination compared to other spacings. However, genotypes were not statistically different for PG and were classified in one mean group (Table 56). Fig. 23 shows development stage of different genotypes showing good performance at Moso site during 2013B.

Table 56: Plant germination (%) of eight bean genotypes at three plant spacings at Moso site during 2013A season

Genotypes	Spacing 1 (15cmx40cm)	Spacing 2 (20cmx40cm)	Spacing 3 (40cmx40cm)	Mean
KAB06F2-8-53	95.0	96.0	100.0	97.0a
KAB06F2-8-24	97.0	93.0	96.0	94.0a
KAB06F2-8-78	92.0	97.0	97.0	95.0a
KAB06F2-8-135	96.0	96.0	96.0	96.0a
KAB06F2-8-22	94.0	90.0	97.0	94.0a
KAB10F2-8-136	92.0	92.0	97.0	94.0a
KAB06F2-8-13	96.0	92.0	97.0	95.0a
GLP2	91.0	96.0	97.0	95.0a
Mean	94.0b	94.0b	97.0a	95.0
SE	0.7	0.8	0.7	0.7
CV (%)	3.6	4.3	3.4	3.8

Figure 23: Development stage of different genotypes at Moso during 2013B season showing vigorous plants

4.2.3.3 Effect of genotypes and spacings on diseases

According to the standard system for evaluation of bean germplasm, genotypes indicated resistance to intermediate reaction to ALS, BCMV and rust diseases. On the other hand, among plant population densities, genotypes presented resistance reaction to the diseases studied (Table 57).

Table 57: Disease reaction of eight bean genotypes at three plant spacings at Moso site during 2013B season

Genotypes	15cm x 40cm			20cmx40cm			40cmx40cm			Mean		
	ALS	BCMV	RU	ALS	BCMV	RU	ALS	BCMV	RU	ALS	BCMV	RU
KAB06F2-8-53	3.0	2.0	1.0	3.0	2.0	1.0	3.0	3.0	1.0	3.0ab	2.0b	1.0
KAB06F2-8-24	3.0	2.0	1.0	4.0	2.0	1.0	4.0	2.0	1.0	4.0a	2.0b	1.0
KAB06F2-8-78	4.0	3.0	2.0	4.0	3.0	1.0	4.0	3.0	2.0	4.0a	3.0a	2.0
KAB06F2-8-135	3.0	3.0	2.0	3.0	4.0	1.0	3.0	3.0	2.0	3.0ab	3.0a	2.0
KAB06F2-8-22	3.0	3.0	3.0	3.0	3.0	4.0	3.0	3.0	2.0	3.0ab	3.0a	3.0
KAB10F2-8-136	3.0	3.0	2.0	3.0	3.0	2.0	4.0	3.0	2.0	3.0ab	3.0a	2.0
KAB06F2-8-13	4.0	3.0	1.0	4.0	3.0	1.0	3.0	3.0	1.0	4.0a	3.0a	1.0
GLP2	3.0	3.0	1.0	3.0	3.0	1.0	3.0	3.0	1.0	3.0ab	3.0a	1.0
Mean	3.0a	3.0a	2.0a	3.0a	3.0a	1.a	3.0a	3.0a	2.0a	3	3.0	2.0
SE	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.2
CV (%)	20.5	21.1	67.0	14.5	20.0	72.8	14.7	13.4	62.4	16.6	18.2	67.4

4.2.3.4 Yield components and seed yield (t/ha) performance

Genotypes KAB06F2-8-24, KAB06F2-8-78 and KAB10F2-8-136 presented the shortest period to reach DFL. Similarly, genotypes KAB06F2-8-53, KAB06F2-8-78, KAB10F2-8-136 and KAB06F2-8-13 were the earliest to reach maturity whereas GLP2 was the latest. However, plants in different population densities were not statistically different for both DFL and DPM (Table 58).

Table 58: Mean DFL and DPM for eight genotypes at Moso during 2013B season

Genotypes	Days to 50% Flowering				Days to Physiological Maturity			
	Spac.1	Spac.2	Spac.3	Mean	Spac.1	Spac.2	Spac.3	Mean
KAB06F2-8-53	36.0	36.0	35.0	36.0dc	72.0	73.0	72.0	72.0c
KAB06F2-8-24	36.0	35.0	35.0	35.0c	74.0	74.0	73.0	74.0b
KAB06F2-8-78	35.0	35.0	35.0	35.0c	72.0	73.0	72.0	72.0c
KAB06F2-8-135	36.0	36.0	36.0	36.0bc	73.0	73.0	76.0	74.0b
KAB06F2-8-22	35.0	36.0	36.0	36.0cd	74.0	73.0	73.0	74.0b
KAB10F2-8-136	35.0	35.0	36.0	35.0c	72.0	72.0	72.0	72.0c
KAB06F2-8-13	37.0	37.0	37.0	37.0b	72.0	72.0	72.0	72.0c
GLP2	40.0	40.0	39.0	40.0a	81.0	81.0	81.0	81.0a
Mean	36.0a	36.0a	36.0a	36.0	74.0a	74.0a	74.0a	74.0
SE	0.3	0.3	0.3	0.3	0.6	0.6	0.8	0.7
CV (%)	4.5	4.5	3.9	4.3	4.3	4.2	5.2	4.6

Genotype KAB06F2-8-22 showed highest mean of 100SW followed by KAB06F2-8-53, KAB06F2-8-135 and GLP2. Among plant population densities, genotypes under spacing 40cm x 40cm exhibited the highest mean weight of 100 seeds (Table 59). The tallest genotype was KAB06F2-8-53 followed by KAB06F2-8-13 whereas the shortest was KAB06F2-8-78. Among plant population densities, genotypes under spacing 20cm x 40cm were the tallest followed by genotypes under spacing 40cm x 40cm. Most of genotypes studied except KAB06F2-8-22 were not statistically different despite high means seeds yields observed (Table 60). Between plant population densities, genotypes under spacing 15cm x 40cm exhibited the highest mean SY though not statistically different from the other spacings (Fig. 24).

Table 59: Mean 100SW for eight genotypes at Moso during 2013B season

Genotypes	Spacing 1 (15cm x 40cm)	Spacing 2 (20cm x 40cm)	Spacing 3 (40cm x 40cm)	Mean
KAB06F2-8-53	46.0	44.7	48.0	46.2ab
KAB06F2-8-24	40.0	40.3	42.0	40.8d
KAB06F2-8-78	43.0	40.3	42.0	41.8cd
KAB06F2-8-135	46.0	43.3	44.7	44.7ab
KAB06F2-8-22	45.3	46.3	48.3	46.7a
KAB10F2-8-136	43.0	44.3	43.7	43.7bc
KAB06F2-8-13	42.0	43.0	46.0	43.7bc
GLP2	41.3	42.7	48.3	44.1abc
Mean	43.3b	43.1b	45.4a	43.9
SE	0.6	0.6	0.7	0.6
CV (%)	7.1	6.7	7.7	7.2

Table 60: Mean PH and SY for eight genotypes at Moso during 2013B season

	Plant Height (cm)				Seed Yield (t/ha)			
Genotypes	Spac.1	Spac.2	Spac.3	Mean	Spac.1	Spac.2	Spac.3	Mean
KAB06F2-8-53	85.2	104.1	93.7	94.3a	2.48	2.35	2.09	2.31a
KAB06F2-8-24	87.9	82.1	83.7	84.6abc	2.26	2.11	2.24	2.20a
KAB06F2-8-78	79.5	79.2	70.2	76.3c	2.23	2.04	2.29	2.19a
KAB06F2-8-135	84.2	90.0	81.0	85.1abc	2.25	2.41	2.11	2.25a
KAB06F2-8-22	92.9	85.2	90.7	89.6ab	1.98	2.01	1.76	1.92b
KAB10F2-8-136	70.8	83.1	88.7	80.9bc	2.67	1.91	1.98	2.18a
KAB06F2-8-13	90.7	93.3	93.3	92.4a	2.49	2.19	2.22	2.30a
GLP2	73.0	85.1	80.9	79.7bc	2.14	2.63	2.38	2.38a
Mean	83.0a	87.8a	85.3a	85.4	2.31a	2.21a	2.14a	2.22
SE	2.3	2.4	2.9	2.5	0.10	0.07	0.06	0.08
CV (%)	13.8	13.4	16.4	14.5	21.73	15.38	13.68	16.93

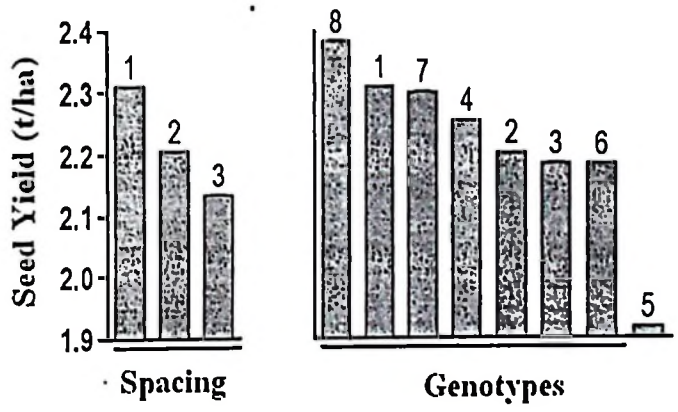

Figure 24: Effect of population on yield and mean performance of different genotypes at Moso site during 2013B season

4.2.3.5 Simple correlation coefficients between seeds yield and its components

Positive and significant correlations were observed between DFL and DPM. Number of P/P had positive and significant relationship with S/P. The highest correlation coefficient was observed between DFL and DPM (Table 61).

Table 61: Simple correlation coefficient between SY and yield components at Moso site during 2013B season

Variables	2	3	4	5	6	7
1.DFL (days)	-0.1248	0.7438***	-0.080	0.199	-0.0002	0.145
2.PH (cm)		-0.119	-0.019	-0.036	0.0557	-0.100
3.DPM (days)			-0.159	0.149	0.0016	0.019
4.P/P				0.5682***	-0.052	0.150
5.S/P					-0.088	0.088
6.HSW (g)						-0.179
7.SY (t/ha)						

4.2.3.6 Influence of yield components on seed yield

How yield is influenced by various yield components is shown in Fig. 25. Days to 50% flowering presented the highest positive direct effect on SY followed by P/P. The weight of 100 seeds showed high and negative direct effect on SY. However, DFL displayed a high and positive indirect effect on SY through DPM (Table 62).

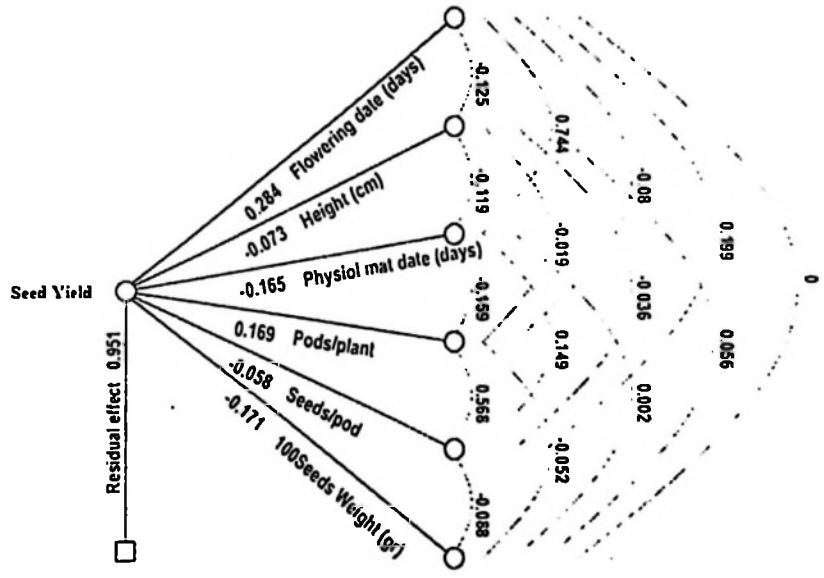

Figure 25: Path diagram indicating the interrelationships among the bean yield with its components at Moso site during 2013B season

Table 62: Path analysis showing direct (diagonal) and indirect (off diagonal) effects of different yield components on seed yield at Moso site during 2013B

Variables	1	2	3	4	5	6
1.DFL (days)	0.284	-0.035	0.211	-0.023	0.056	0.000
2.Height (cm)	0.009	-0.073	0.009	0.001	0.003	-0.004
3.DPM (Days)	-0.123	0.020	-0.165	0.026	-0.025	0.000
4.P/P	-0.014	-0.003	-0.027	0.169	0.096	-0.009
5.S/P	-0.012	0.002	-0.009	-0.033	-0.058	0.005
6.HSW (gr)	0.000	-0.010	0.000	0.009	0.015	-0.171
Residual effect (PX7)						0.951

Key: Direct effects are presented in diagonal and indirect effects are presented off diagonal

4.2.4 Combined sites

4.2.4.1 ANOVA for different variables studied

Significant differences at different levels of significance were observed among sites for most of variables except for PG, rust diseases and SY. Among plant population densities, significant differences at different levels of significance were found for PG, CBB, PH, P/P, 100SW and SY. Moreover, significant effects ($P \leq 0.05$) were observed in the interaction between site and plant population densities for Anthracnose and 100SW whereas high significant differences ($P \leq 0.01$) were showed for CBB. Among genotypes highly significant effects ($P \leq 0.001$) were presented for DFL, Anthracnose, ALS, BCMV, Rust, PH, DPM and 100SW whereas high significant differences ($P \leq 0.01$) were observed for BR and SY.

While high significant effects ($P \leq 0.001$) were observed in the interaction between genotypes and sites for DFL, Anthracnose, ALS, BCMV, PH, DPM, 100SW and SY; significant effects ($P \leq 0.05$) were found for PG and CBB. Furthermore, highly significant effects ($P \leq 0.001$) were presented in the interaction of Plants population densities x Sites x Genotypes for BCMV and CBB diseases whereas significant effect ($P \leq 0.05$) was observed for BR (Table 63).

Table 63: ANOVA summary for different variables studied in combined sites during 2013B season

Source of Variation	DF	Sum Squares					
		PG	DFL	ANTR	ALS	ASCO	BCMV
Replicates	2	82.57	0.22	4.89	0.69	0.3	0.23
Site	2	49.17	298.10***	115.70***	8.95*	202.64***	43.23***
Error (A)	4	45.91	0.38	8.1	1.99	0.6	0.48
Spacing	2	127.91**	0.18	0.84	0.12	0.52	0.91
Site*Spacing	4	32.85	0.11	2.42*	0.3	0.24	0.37
Error (B)	12	19.77	0.46	0.92	0.17	0.22	0.57
Genotype	7	6.58	57.76***	2.67***	3.64***	0.3	1.16***
Site*Genotype	14	16.56*	9.05***	2.59***	0.74***	0.62	0.83***
Spac*Genotype	14	6.34	0.29	0.58	0.14	0.27	0.3
Site*Spac*Geno	28	8.49	0.33	0.5	0.2	0.32	0.46***
Error (C)	126	8.35	0.48	0.5	0.21	0.36	0.2
Total	215	12.69	5.62	2.03	0.47	2.24	0.75
CV (%)		3.05	1.79	39.80	12.64	18.90	14.12

Table 63: (continued)

Source of Variation	DF	Sum Squares					
		HB	BR	CBB	WB	RU	PH
Replicates	2	0.06	1.28	1.14	0.02	0.26	170.25
Site	2	195.45***	165.89***	132.76***	65.56***	0.6	35542.92***
Error (A)	4	0.37	2.55	0.52	0.02	0.53	553.36
Spacing	2	0.23	0.03	3.53***	0.02	0.38	328.095*
Site*Spacing	4	0.2	0.57	0.91**	0.02	0.51	128.2
Error (B)	12	0.27	0.78	0.19	0.16	0.41	92.83
Genotype	7	0.48	0.53**	0.17	0.39	10.03***	620.88***
Site*Genotype	14	0.32	0.25	0.458 *	0.39	0.86	330.07***
Spac*Genotype	14	0.32	0.28	0.2	0.11	0.73	78.41
Site*Spac*Geno	28	0.24	0.29*	0.50***	0.11	0.69	116.16
Error (C)	126	0.28	0.18	0.21	0.23	0.77	97.96
Total	215	2.1	1.85	1.55	0.82	1.02	472.48
CV (%)		20.197	16.071	18.368	31.066	53.375	15.617

Table 63:Continued

Source of Variation	DF	Mean Squares				
		DPM	P/P	S/P	HSW	SY
Replicates	2	9.04	4.76	1.2	12.62	0.17
Site	2	6018.67***	408.72***	17.92 *	605.38**	6.85
Error (A)	4	6.27	32.42	5.04	46.79	2.3
Spacing	2	3.60	124.22 **	0.64	75.18**	2.61 **
Site*Spacing	4	4.58	11.26	2.78	7.89*	0.47
Error (B)	12	2.01	25.91	1.58	3.23	0.49
Genotype	7	224.74***	32.59	3.87	183.78***	0.63**
Site*Genotype	14	9.11***	19.78	2.56	42.52***	0.67***
Spac*Genotype	14	3.17*	12.21	1.55	6.97	0.15
Site*Spac*Geno	28	3.83***	9.64	1.88	5.19	0.2
Error (C)	126	1.44	19.29	2.09	5.76	0.2
Total	215	65.88	22.96	2.28	20.91	0.39
CV (%)		1.49	43.677	39.766	5.65	20.181

4.2.4.2 Yield components (t/ha) and seed yield performance

Results on yield components and seed yield are presented in Table 64. While most of the genotypes except KAB06F2-8-24 and GLP2 presented the shortest period to reach DFL, among plant population densities, genotypes were not statistically different and presented the same period to reach DFL. Between sites, genotypes planted at Moso exhibited the shortest period to reach DFL. On the other hand, the tallest genotype was GLP2 followed by KAB06F2-8-13. In addition, among sites genotypes planted at Moso were the tallest followed by genotypes grown at Murongwe. However, between plant population densities, genotypes under spacing 20cm x 40cm and 40cm x 40cm were not statistically different and were the tallest.

Furthermore, most of the genotypes except GLP2 presented the shortest vegetative period to reach maturity. Between plant population densities, genotypes were not statistically different and had the same period to reach DPM. However, among sites genotypes planted at Moso were the earliest to reach maturity followed by genotypes grown at Murongwe. Among genotypes, KAB06F2-8-78 presented a high mean P/P followed by KAB06F2-8-53 and KAB06F2-8-24. However, among plant population densities, genotypes under spacing 40cm x 40cm presented the highest mean P/P followed by genotypes in plant population densities 20cm x 40cm.

The highest mean S/P was observed for genotypes KAB06F2-8-78, KAB06F2-8-135 and GLP2. On the other side, genotype KAB06F2-8-22 showed the highest weight of 100 seeds and genotypes under spacing 40cm x 40cm presented the highest mean weight. Between sites, the highest mean weight of 100 seeds was found at Murongwe and Moso. Regarding seed yield, GLP2 presented highest mean SY followed by KAB06F2-8-53 and KAB06F2-8-13. Among plant population densities, genotypes at spacing 15cm x 40cm

were not statistically different to genotypes at spacing 20cm x 40cm and were highest. Between sites, genotypes planted at Murongwe exhibited the highest mean SY compared to other sites though they did not differ significantly (Fig. 26).

Table 64: Main effect of genotype on yield and yields components in combined sites during 2013B season

Genotypes	PG	DFL	PH	DPM	P/P	S/P	HSW	SY
KAB06F2-8-53	95.0a	38.0bc	65.9b	79.0b	11.0ab	3.0b	44.5b	2.3ab
KAB06F2-8-24	95.0a	39.0b	62.5bc	79.0b	11.0ab	3.0b	39.8c	2.2cde
KAB06F2-8-78	96.0a	38.0bc	55.5d	79.0b	12.0a	4.0a	38.3c	2.2cde
KAB06F2-8-135	95.0a	38.0bc	63.6bc	79.0b	10.0ab	4.0a	43.2cd	2.1cde
KAB06F2-8-22	94.0a	38.0bc	59.7cd	79.0b	9.0b	3.0b	46.6a	2.1de
KAB10F2-8-136	94.0a	38.0bc	61.5bc	79.0b	9.0b	3.0b	41.8de	2.0e
KAB06F2-8-13	94.0a	38.0bc	66.8ab	79.0b	10.0ab	3.0b	42.2cde	2.3abc
GLP2	94.0a	42.0a	71.4a	87.0a	9.0b	4.0a	43.6bc	2.5a
Mean	95.0	39.0	63.4	80.0	10.0	4.0	42.5	2.2
S.E.	0.2	0.1	1.5	0.9	0.3	0.1	0.3	0.0
C.V. (%)	3.8	6.2	34.3	15.8	47.7	41.5	10.8	28.1
Spac1 (15cmx40cm)	94.0b	39.0a	60.9b	80.0a	9.0b	4.0a	41.8b	2.4a
Spac2 (20cmx40cm)	94.0b	39.0a	64.6a	80.0a	10.0b	4.0a	42.0b	2.2ab
Spac3 (40cmx40cm)	96.0a	39.0a	64.6a	81.0a	12.0a	4.0a	43.7a	2.0b
Mean	95.0	39	63.4	80.0	10.0	4.0	42.5	2.2
S.E.	0.4	0.3	2.6	1.0	0.5	0.2	0.5	0.1
C.V. (%)	3.6	6.2	34.4	10.1	49.5	38.9	10.5	27.3
S1: Gisozi	94.0a	40.0a	40.9c	91.0a	9.0b	3.0a	39.2b	1.9a
S2: Murongwe	95.0a	40.0a	63.8b	77.0b	9.0b	3.0	44.4a	2.5a
S3: Moso	95.0a	36.0b	85.4a	74.0c	13.0a	4.0a	43.9a	2.2a
Mean	95.0	42.0	63.4	81.0	10.0	3.0	42.4	2.2
S.E.	0.4	0.2	1.4	0.4	0.5	0.2	0.5	0.1
C.V. (%)	3.7	4.4	20.3	3.9	36.7	36.2	9.2	25.1

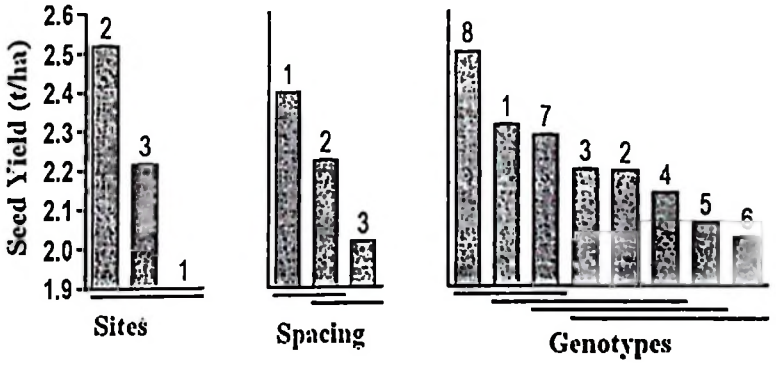

Figure 26: Effect of population on yield and mean performance of different genotypes in combined sites during 2013B season

4.2.4.3 Combined simple correlation coefficient across sites between SY and its components for the second cropping season

While DFL had negative and significant correlations with PH and P/P, it was positively and significantly correlated with DPM. Further, PH had positive and significant correlations with P/P, S/P, 100SW and SY. However, negative and significant correlation was found between PH and DPM. Negative and significant correlations were realised between DPM and P/P, 100SW and SY. Moreover, positive and significant correlations were observed between P/P and S/P. The highest correlation coefficient was reported between DFL and DPM followed by correlations between P/P and S/P (Table 65).

Table 65: Combined simple correlation coefficients between SY and yield components across sites during 2013B season

Variables	2	3	4	5	6	7
1.DFL (days)	-0.433***	0.606***	-0.302***	-0.081	-0.106	0.032
2.PH (cm)		-0.680***	0.300***	0.196**	0.360***	0.278***
3.DPM (days)			-0.264***	-0.100	-0.404***	-0.281**
4.P/P				0.457***	0.050	0.065
5.S/P					-0.005	0.108
6.HSW (g)						0.017
7.SY (t/ha)						

4.2.4.4 Influence of yield components on seed yield

The number of DFL had the highest positive direct effect on SY followed by PH. DPM presented high and negative direct effect on SY (Fig. 27). On the other hand, DPM displayed a high and positive indirect effect on SY through PH. The same trend was observed for DFL via DPM (Table 66).

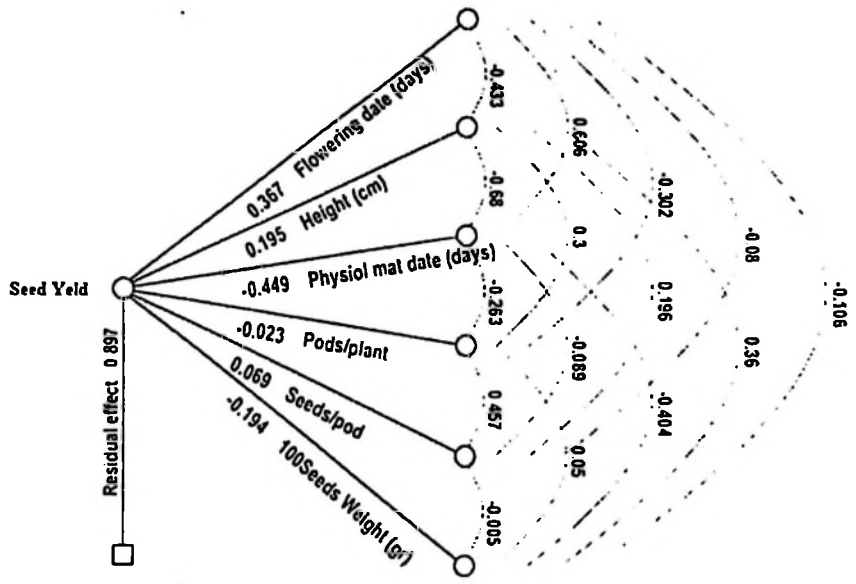

Figure 27: Path diagram indicating the interrelationships among the bean yield with its components in combined sites during 2013B season

Table 66: Path analysis showing direct (diagonal) and indirect (off diagonal) effects of different yield components on seed yield in combined sites (t/ha) during 2013B

Variables	1	2	3	4	5	6
1.DFL (days)	0.367	-0.159	0.222	-0.111	-0.030	-0.039
2.Height (cm)	-0.084	0.195	-0.133	0.058	0.038	0.070
3.DPM (Days)	-0.272	0.306	-0.449	0.118	0.040	0.182
4.P/P	0.007	-0.007	0.006	-0.023	-0.011	-0.001
5.S/P	-0.006	0.013	-0.006	0.031	0.069	0.000
6.HSW (gr)	0.021	-0.070	0.078	-0.010	0.001	-0.194
Residual effect (PX7)						0.897

Key: Direct effects are presented in diagonal and indirect effects are presented off diagonal

4.2.5 Combined means of G x E interactions for DFL

Genotype GLP2 showed similar ranks across sites expressing the latest genotype to reach DFL. However, due to the fact that DFL cannot be decimal number, similar ranks within sites were observed between genotypes (Table 67).

Table 67: Combined means of G x E interactions for DFL during 2013B season

Genotypes	Gisozi	Rank	Murongwe	Rank	Moso	Rank
KAB06F2-8-53	39	3	37	5	36	3
KAB06F2-8-24	40	2	41	2	36	3
KAB06F2-8-78	39	3	40	3	35	4
KAB06F2-8-135	39	3	40	3	36	3
KAB06F2-8-22	40	2	39	4	35	4
KAB10F2-8-136	39	3	40	3	35	4
KAB06F2-8-13	38	4	39	4	37	2
GLP2	45	1	42	1	40	1
Mean	40		40		36	

4.2.6 Combined means of G x E interactions for PH

Genotype GLP2 showed similar ranks at Gisozi and Murongwe expressing the tallest genotype at both sites whereas KAB06F2-8-53 was the tallest at Moso. On the other hand, genotype KAB06F2-8-78 also exhibited similar ranks at Gisozi and Moso expressing the shortest genotype at both locations whereas KAB06F2-8-22 was presented as the shortest at Murongwe (Table 68).

Table 68: Combined means of G x E interactions for PH during 2013B season

Genotypes	Gisozi	Rank	Murongwe	Rank	Moso	Rank
KAB06F2-8-53	40.1	5.0	63.3	5.0	94.3	1.0
KAB06F2-8-24	38.0	6.0	65.2	3.0	84.6	4.0
KAB06F2-8-78	32.0	8.0	58.4	7.0	76.3	8.0
KAB06F2-8-135	41.0	4.0	65.1	4.0	85.1	5.0
KAB06F2-8-22	36.8	7.0	52.8	8.0	89.6	3.0
KAB10F2-8-136	41.1	3.0	62.6	6.0	80.9	6.0
KAB06F2-8-13	42.7	2.0	65.2	2.0	92.4	2.0
GLP2	56.3	1.0	78.2	1.0	79.7	7.0
Mean	40.9		63.8		85.4	

4.2.7 Combined means of G x E interactions for DPM

Results presented in Table 61 highlighted similar ranks within sites between genotypes. Genotype GLP2 exhibited similar ranks at Gisozi, Murongwe and Moso site expressing the longest cycle to reach maturity (Table 69).

Table 69: Combined means of G x E interaction for DPM during 2013B season

Genotypes	Gisozi	Rank	Murongwe	Rank	Moso	Rank
KAB06F2-8-53	89	3	75	3	72	3
KAB06F2-8-24	88	4	75	3	74	2
KAB06F2-8-78	89	3	75	3	72	3
KAB06F2-8-135	90	2	76	2	74	2
KAB06F2-8-22	89	3	76	2	74	2
KAB10F2-8-136	90	2	75	3	72	3
KAB06F2-8-13	90	2	75	3	72	3
GLP2	98	1	83	1	81	1
Mean	90		76		74	

4.2.8 Combined means of G x E interaction for P/P

The genotype KAB06F2-8-24 presented similar ranks at both Gisozi and Murongwe sites expressing the highest mean of P/P whereas KAB06F2-8-78 showed the highest mean at Moso. However, due to the fact that the number of P/P cannot be expressed by decimal numbers, similar ranks within sites were presented between genotypes (Table 70).

Table 70: Combined means of G x E interaction for P/P during 2013B season

Genotypes	Gisozi	Rank	Murongwe	Rank	Moso	Rank
KAB06F2-8-53	9	2	9	2	15	2
KAB06F2-8-24	10	1	10	1	13	3
KAB06F2-8-78	9	2	9	2	18	1
KAB06F2-8-135	10	1	8	3	13	3
KAB06F2-8-22	9	2	8	3	10	5
KAB10F2-8-136	7	3	8	3	13	3
KAB06F2-8-13	9	2	10	1	11	4
GLP2	9	2	7	4	11	4
Mean	9		9		13	

4.2.9 Combined means of G x E interactions for S/P

Results presented in Table 71 showed that some genotypes reflected similar ranks within sites. Genotype GLP2 was the first to be ranked at both sites Murongwe and Moso. It was also the second to be ranked at Gisozi showing that it consistently had high number of S/P.

Table 71: Combined means of G x E interaction for S/P during 2013B season

Genotypes	Gisozi	Rank	Murongwe	Rank	Moso	Rank
KAB06F2-8-53	3	3	3	2	4	2
KAB06F2-8-24	3	3	3	2	4	2
KAB06F2-8-78	3	3	3	2	5	1
KAB06F2-8-135	5	1	3	2	4	2
KAB06F2-8-22	3	3	3	2	4	2
KAB10F2-8-136	3	3	3	2	4	2
KAB06F2-8-13	3	3	3	2	4	2
GLP2	4	2	4	1	5	1
Mean	3		3		4	

4.2.10 Combined means of G x E interaction for 100SW(g)

The genotype KAB06F2-8-22 presented similar ranks at Murongwe and Moso signifying the highest weight of 100 seeds whereas GLP2 presented the highest mean weight at Gisozi (Table 72).

Table 72: Combined means of G x E interaction for 100SW during 2013B season

Genotypes	Gisozi	Rank	Murongwe	Rank	Moso	Rank
KAB06F2-8-53	40.1	3.0	47.2	2.0	46.2	2.0
KAB06F2-8-24	36.7	7.0	41.8	6.0	40.8	8.0
KAB06F2-8-78	33.7	8.0	39.6	8.0	41.8	6.0
KAB06F2-8-135	38.4	5.0	46.5	3.0	44.7	3.0
KAB06F2-8-22	42.6	2.0	50.4	1.0	46.7	1.0
KAB10F2-8-136	37.8	6.0	43.9	5.0	43.7	4.0
KAB06F2-8-13	38.6	4.0	44.4	4.0	43.7	5.0
GLP2	45.4	1.0	41.1	7.0	44.1	7.0
Mean	39.2		44.4		43.9	

4.2.11 Combined means of G x E interaction for SY (t/ha)

The genotype GLP2 presented similar ranks at Murongwe and Moso indicating the highest mean SY while KAB06F2-8-78 exhibited the highest mean at Gisozi. Moreover, KAB10F2-8-136 showed similar ranks at Gisozi and Moso expressing the lowest SY whereas KAB06F2-8-22 presented the lowest mean at Murongwe (Table 73).

Table 73: Combined means of G x E interactions for SY (t/ha) during 2013B

Genotypes	Gisozi	Rank	Murongwe	Rank	Moso	Rank
KAB06F2-8-53	1.84	6.00	2.79	2.00	2.31	2.00
KAB06F2-8-24	2.01	2.00	2.37	4.00	2.20	5.00
KAB06F2-8-78	2.13	1.00	2.28	6.00	2.19	7.00
KAB06F2-8-135	1.93	4.00	2.22	7.00	2.25	4.00
KAB06F2-8-22	1.94	3.00	2.17	8.00	1.92	6.00
KAB10F2-8-136	1.56	8.00	2.32	5.00	2.18	8.00
KAB06F2-8-13	1.92	5.00	2.63	3.00	2.30	3.00
GLP2	1.72	7.00	3.39	1.00	2.38	1.00
Mean	1.90		2.52		2.22	

4.2.12 Broad sense-heritability parameters estimates of yield and yield components for the common bean genotypes studied during 2013B

Heritability estimates for the various bean traits ranked between 0.07 and 0.75. High heritability was observed for PH and DPM. The expected genetic advance was high especially for PH, DPM and P/P. On the other hand, genotypic and phenotypic variations were high for PH and DPM. Moreover, phenotypic variations also were high for P/P and 100SW. Furthermore, phenotypic and genotypic coefficients of variation were low in case of most of the traits. Variation due to environment was high for PH (Table 74).

Table 74: Means and estimates of heritability parameters for growth characteristics, yield and yield components for bean genotypes evaluated across three sites during 2013B season

Variable	Mean	δ^2e	δ^2g	GCV (%)	δ^2ph	PCV (%)	$h^2(b)$	EGA (%)
DFL (days)	38.58	3.73	2.39	4.00	6.12	6.41	0.39	6.60
PH (cm)	63.37	150.30	358.43	29.87	508.73	35.59	0.70	66.20
DPM (days)	84.24	18.82	55.06	9.23	73.88	10.70	0.75	21.04
P/P	10.06	18.72	4.73	21.63	23.45	48.15	0.20	25.64
S/P	3.63	2.17	0.16	11.00	2.33	41.99	0.07	7.60
HSW (g)	42.49	15.74	6.54	6.02	22.28	11.11	0.29	8.61
SY (t/ha)	2.21	0.36	0.05	10.01	0.40	28.75	0.12	9.19

4.2.13 Relationship among stability parameters with seed yield and its components

4.2.13.1 Relationship among stability parameters with P/P

Genotypes KAB06F2-8-22 (E) and GLP2 (H) presented low bi, low mean P/P and high S^2di whereas genotype KAB06F2-8- 24 (B) presented low bi, high mean P/P and high S^2di. Furthermore, genotype KAB06F2-8-78 (C) presented high regression coefficient,

high mean P/P and low S^2di while KAB06F2-8-53 (A) showed high bi, high mean P/P and high S^2di.

On the other hand, while genotype KAB06F2-8-78 (D) presented bi-value approximately equal to 1, high mean P/P and high S^2di, genotype KAB10F2-8-136 (F) exhibited bi-value approximately equal to 1, low mean P/P and high S^2di. Moreover, genotype KAB06F2-8-13 (G) presented bi-value approximately equal to 1, high mean P/P and low S^2di (Fig. 28)

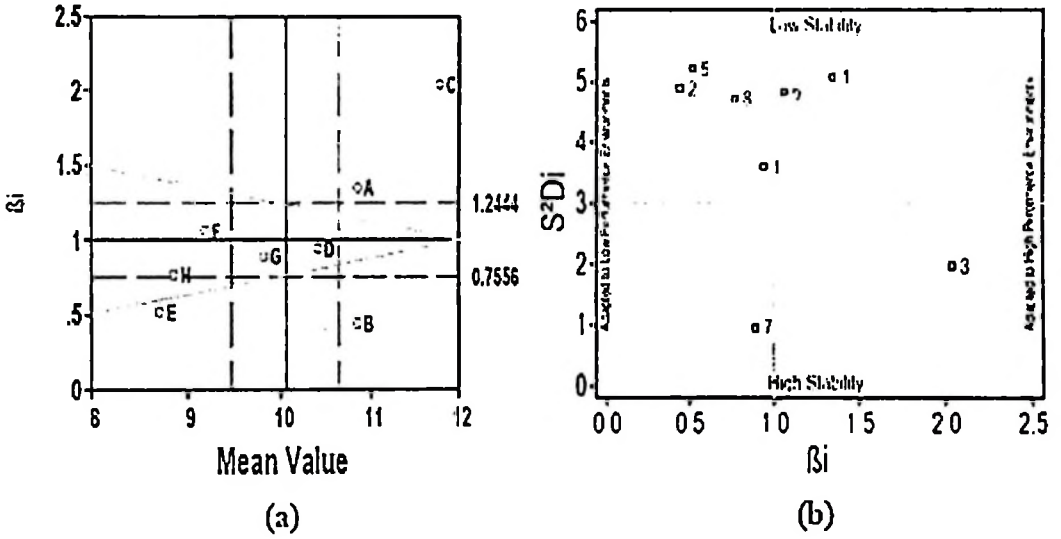

Figure 28: b-value plotted against mean P/P (a) and S^2d plotted against b-value for P/P (b) during 2013B

Key: A=1. KAB06F2-8-53 B=2. KAB06F2-8-24 C=3. KAB06F2-8-78
D=4. KAB06F2-135 E=5. KAB06F2-8-22 F=6. KAB10F2-8-136
G=7. KAB06F2-8-13 F=8. GLP2

4.2.13.2 Relationship among stability parameters with S/P

Genotypes KAB06F2-8-78 (C) and GLP2 (H) presented high bi, high mean S/P and low S^2di. On the other hand genotypes KAB06F2-8-53 (A), KAB06F2-8-24 (B), KAB06F2-8-22 (E), KAB10F2-8-136 and KAB06F2-8-13 (G) presented low bi, low mean S/P and low S^2di. Furthermore, KAB06F2-8-135 (D) showed bi-value approximately equal to 1, high mean S/P and high S^2di (Fig.29).

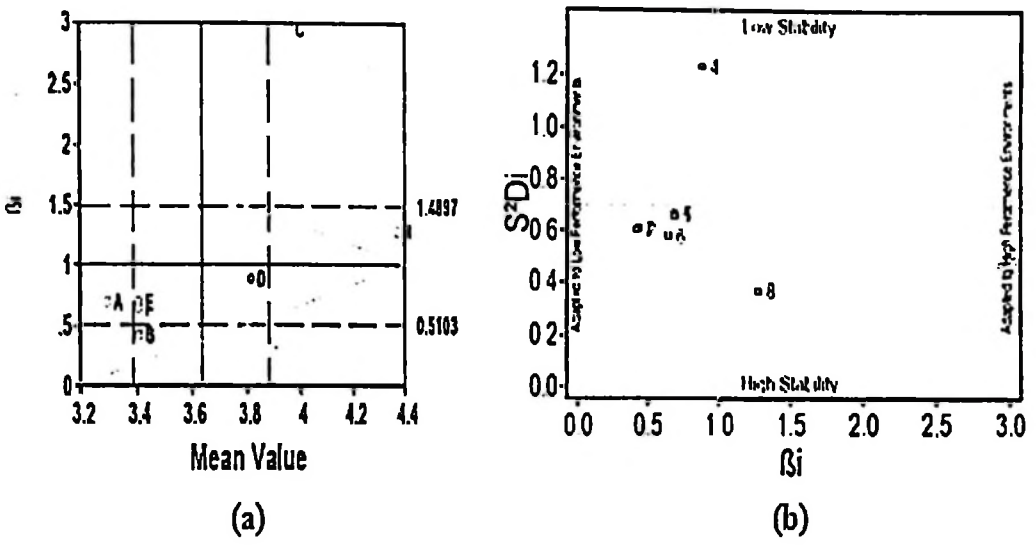

Figure 29: b-value plotted against mean S/P (a) and S^2d plotted against b-value for S/P (b) during 2013B

4.2.13.3 Relationship among stability parameters with 100SW

Genotypes KAB06F2-8-78 (C), KAB10F2-8-136 (F), KAB06F2-8-13 (G) presented high bi and low mean 100SW and low S^2di. On the other hand, genotypes KAB06F2-8-53 (A) and KAB06F2-8-22 (E) exhibited high bi, high mean 100SW and low S^2di. Furthermore, genotype KAB06F2-8-24 (B) had low bi, low mean 100SW and low S^2di whereas KAB06F2-8-135 (D) presented high bi, high mean 100SW and S^2di approximately equal to zero. The GLP2 (H) genotype presented low bi, high mean 100SW and high S^2di (Fig.30).

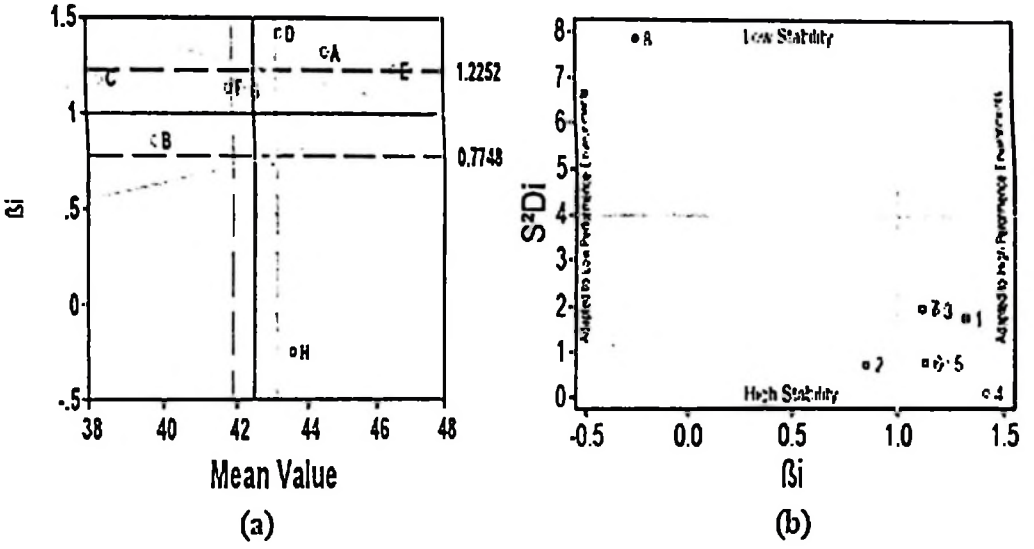

Figure 30: b-value plotted against mean of 100SW (a) and S^2d plotted against b-value for 100SW (b) during 2013B

4.2.13.4 Similarity among stability parameters with SY

Results presented in the Fig. 38 show that genotypes KAB06F2-8-24 (B), KAB06F2-8-135 (D) and KAB06F2-8-22 (E) presented low bi, low mean SY and high S^2di. On the other side, KAB06F2-8-53 (A) and GLP2 (H) exhibited high bi, high mean SY and low S^2di. While genotypes KAB10F2-8-136 (F) presented high bi, low mean SY and low S^2di, genotype KAB06F2-8-78 (C) exhibited low bi, low mean SY and low S^2di. Moreover, KAB06F2-8-13 (G) genotype presented high bi, high mean SY and high S^2di

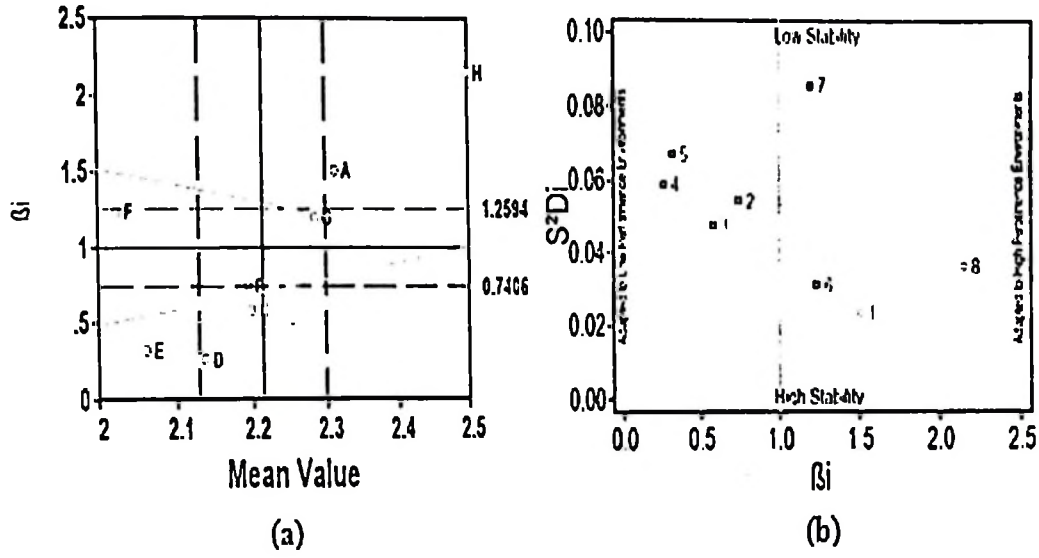

Figure 31: b-value plotted against the mean SY (a) and S^2d plotted against b-value (b) for SY (b) during 2013B

CHAPTER FIVE

5.0 DISCUSSION

5.1 Yield Components and Yield Perfomance

In both cropping seasons, G x E interaction was significant showing variable performance of the genotypes in the various environments. G x E interactions were highly significant ($P \leq 0.001$) for PH, DPM and HSW indicating differential genotypic responses of yield and yield components across environments. Hence, the three traits varied from location to location, implying that selection for these traits has to be done at each location. This observation also indicates that the relative ranking of genotypes differs across locations and this can make evaluation and selection of genotypes more complicated and difficult which implies that final selection for seed yield has to be done at each location. Similar results of environmental influences on common bean performance were reported by De Ron *et al.* (2004). There were tremendous changes in yield ranks of the genotypes across locations. Pham and Kang (1988) indicated that a G x E interaction minimizes the usefulness of genotypes by confounding their yield performance.

Besides genetic effects, season effects also played an important role in expression of SY. This trait varied from one location to another, indicating that choice of location and season is important for maximizing SY. Our results are in agreement with the findings reported in pear millet hybrids by Yahaya *et al.* (2006). Variation in SY during the first cropping season was attributed to the environmental factors such as climatic variation among sites, seasons and soil factors. Similar results had been reported by Misangu, (1982). Accordingly, high rainfall was observed after planting in November 2012 (156.2mm) and in December 2012 (190.3mm) at Gisozi and Moso sites, respectively (Appendices 2, 3 and 4). This resulted into seed decaying before germination, poor

germination and poor vegetative growth. Our results are in agreement with Godderis (1993) who reported that a mean monthly rainfall which is above 140mm during the first month after sowing is a limiting factor for *Phaseolus vulgaris*. In addition, during the vegetative growth and development stages genotypes received 630.8mm and 630.6mm at Gisozi and Moso sites respectively which had been the limitant factor to bean production during 2013A (Appendices 2, 3 and 4). Our results are also in consonance with the findings of Broughton *et al.* (2003) who reported that the crop requires between 200 and 400mm of rainfall during growth and development. Therefore, yield performance at Murongwe was better than other sites due to the fact that rainfall was well distributed (426.6mm) during growth and development stages. Rainfall differences among the three sites had a profound influence on environmental variation and ultimately on individual genotype performance. Our results correspond to the findings on bean landraces reported by Mukandala (2010).

On the other hand, the second cropping season resulted into high yields compared to the first cropping season. Genotypes exhibited significant differences across environments and high performance genotypes were found. This is justified by the fact that the second cropping season received favourable rainfalls for common bean development which were 416.2mm, 398.8mm and 350mm at Moso, Murongwe and Gisozi sites respectively (Appendices 2, 3 and 4). In addition, the seeds used during 2013B cropping season resulted from the previous seeds harvested during 2013A cropping.

The effect of genotypes, sites and G x E interaction was significant for DFL in both cropping seasons and DFL were short, medium and long at Moso, Murongwe and Gisozi respectively. This implies that the differences among genotypes for duration to 50% flowering were caused by environmental factors. These results are in consonnance with

the findings of Mukandala (2010) who reported that duration to flowering is highly affected by environments factors and thus differences in the environment such as altitudes to which genotypes are growing, influence flowering duration among genotypes. These results are in conformity with the findings reported by Yan and Hunt (2001) who stated that low temperature and high temperature influence crop growth. Indeed, the effect of genotypes, sites and G x E interaction was significant for DFL and DPM in both cropping seasons due to environmental and genotypic factors. Days to 50% flowering and DPM were short at Moso due to high temperature, medium at Murongwe due to its moderate temperature and cool temperature delaying the time to 50% flowering and DPM at Gisozi (Appendices 2, 3 and 4). These results explain how environment effect interacted with genotypes. Comparable results were reported by Shrivastava *et al.* (2012) who stated that high temperature stress is one of the most important environmental factors influencing crop growth, development, and yield processes.

On the other hand, the significant variations among genotypes within locations and seasons on plant height was due to genetic differences, site and G x E interaction. The significance of the G x E interaction indicated that genotypes varied in their adaptations to the environments (soil fertility and low ambient temperature) where they were tested. Moreover, the variations of genotypes across the locations on these variables could be attributed to a larger extend to differences in available moisture as indicated by amount of rainfall recorded at each location during the experimental period (Appendeces 2, 3 and 4). Soil characteristic differences among the locations could have also influenced plant characters such as height of the genotype at each location (Appendix 5, 6 and 7). These can be justified by the fact that genotypes was tall at Murongwe and Moso while they were shortest at Gisozi. Both Murongwe and Moso sites had high mean monthly temperatures (23^0C and 20^0C at Moso and Murongwe respectively) and good soil ferility

with low exchangeable aluminium. Thus, high temperature and soil fertility influenced plant growth in both sites Moso and Murongwe compared to genotypes grown at Gisozi site. These results are in concordance with the findings in bean landrace reported by Mukandala (2010) who stated that environmental conditions such as rainfall, temperatures, relative humidity and soils have greater influence on bean growth.

The significant variation among genotypes within locations and seasons on P/P was due to genetic differences and environmental factors. Results showed the average of 3 P/P in 2013A season and 9 P/P in 2013B. The relative magnitude of the environmental effect was much greater than for the genotypic effect. Therefore, soil and climatic factors were probably important factors which caused variations in both cropping seasons. Soils at Murongwe and Moso were fertile with low acidity whereas soil acidity was medium at Gisozi (Appendices 5, 6 and 7). Moreover, the heavy rainfall received at flowering stage in December 2012 destroyed some flowers at Gisozi hence was the most limiting factor for this trait. Also, during pod filling stage in May 2013 a short drought spell appeared and a number of pods were not filled. Similar results had been reported by Rosales-Serna *et al.* (2000) who stated that common bean yields are drastically reduced when dry spells and erratic rainfall occurs in a growing season. Therefore, reproductive stages such as flowering and pod filling are very critical in water requirements such that total crop loss can result from this water shortage.

The significant variations among genotypes within locations and seasons on S/P was due to genetic differences and environmental factors. The weather variable such as rainfall, drought could have reduced the photosynthetic activities of the bean plant and consequently affecting the pods filling potential of most genotypes evaluated. However, in November and December, sites received heavy rainfall (151.2 and 143.3mm, 156.2 and

262mm at Murongwe and Gisozi respectively in the two respective cropping seasons) which were limitant factor for pod filling. The same bean plant received low amount of rainfall in May 2013 which also affected the pod filling stage (45mm, 16mm and 58.5mm at Moso, Murongwe and Moso respectively) (Appendix 2, 3 and 4). These results are in consonance with the findings of Mwale *et al.* (2008) who reported that low moisture during flowering and pod filling levels affect bush beans production.

The significant variations among genotypes within locations and seasons on 100SW was due to genetic differences, site and G x E interaction. Soil characteristic differences among the locations could have also influenced plant characters such as weight of the genotype at each location. Moreover, the absence of sufficient rainfall in May 2013 influenced the grain size during the 2013B season to be smaller than expected.

5.2 Diseases Reaction

In both seasons, results showed significant differences at different levels of significance on diseases incidence such as ALS, Ascochyta, BR, BCMV, Anthracnose, WB, HB, CBB and Rust. The differential responses of genotypes on disease incidences over location indicated that environmental factors were not the same. One of the most important factors that contributed to the variation was perhaps differences in their altitude, genetic, climatic and edaphic factors. This observation is in agreement with Van-Schoonhoven and Pastor-Corrales (1987) who reported that beans are generally characterized by their instable yields resulting from biological, climatic and edaphic factors which affect plant growth and productivity.

Most of the genotypes showed low to moderate reaction to diseases studied i.e resistant to intermediate reaction in both cropping seasons (with score rating ranking between 1-5).

This means that from these genotypes source of resistance to diseases can be obtained. According to Van-Schoonhoven and Pastor-Corrales (1987), resistant genotypes (score: 1-3) may be useful as parents or commercial varieties while intermediate genotypes (score: 4-6) shall be used as commercial varieties or as source of resistance to certain diseases. The check genotype (GLP2) showed suceptilbility to Ascochyta and Halo blight (with score=6) at Gisozi site during 2013A season. However, some significant variations of diseases reaction among genotypes in the three sites suggest possible differences in levels of diseases susceptibility regardless on diseases pressure. These results are in conformity with the findings on snap beans reported by Michael (2005).

5.3 Effect on Plant Germination

Results indicated that PG differed among genotypes, environment and among plant population densities due to the presence of G x E interaction. Indeed in 2013A cropping season, the absence of rainfall after sowing time at Moso site and heavy rainfall at Gisozi site since sowing time influenced highly low germination of genotypes studied. The existence of G x E interaction indicated instability of the PG with change of environnement during both cropping seasons. Results revealed that low PG affected seriously bean production in the actual study. Therefore, low PG contributed to low SY resulted during the first cropping season. These results are in agreement with the findings of Smittle (1976), Crothers and Westermann (1976) who reported that grain yield is increased with a high plant population per unit area.

5.4 Plant Population Densities

Genotypes at spacing 20cm x 40cm and 40cm x 40cm had the highest weight of 100 seeds during 2013A and 2013B seasons respectively perhaps due to greater available space and minimal competition for soil nutrients as reported by Crothers and Westermann

(1976) resulting into accumulation of assimilates in the seeds. The effect of spacing for SY and other traits was not highly significant and genotypes planted at spacing 15cm x 40cm and at spacing 20cm x 40cm were not statistically different in their perfomance. Therefore, spacing 20cm x 40cm can be retained for use since it contributed to the increase of SY whereas intermediate quantity of seeds was used. Previous studies have also reported comparable results that weigh support to this observed trend on increasing SY (Mureithi *et al.*, 2012).

5.5 Heritability Estimates

Heritability estimates have been understood to be useful in indicating the relative value of selection based on phenotypic expression of different characters. The partitioning of variance components showed low, moderate and high heritability estimates in the broad sense for the characters. This implies that it is possible to improve these traits through breeding and selection. Our results are in agreement with the findings reported by Alan and Geren (2007); Okonkwo and Idahosa (2013).

From the study it was shown that the estimates genetic variances (δ^2g) were relatively small for each of the variables as compared to the corresponding phenotypic variances (δ^2ph). This signifies that there was an environmental influence in determining phenotypic expression which means that improvement for these traits through selection will be slow. When estimates of genetic variance are high for a particular trait, heritability estimate is also expected to be high indicating less involvement of environmental influence (Raffi and Nath, 2004). High phenotypic variances for the trait imply that environmental factors played a major role on the phenotypic expression of the trait.

High heritability was found for PH and DPM in both cropping seasons. This indicates that traits were expressing the presence of genetic effects for possible improvement and hence cannot be influenced by environmental factors. High heritability value for PH has previously reported by Mukandala (2010). The impact of an environmental factor on different genotypes may vary implying that the productivity of a crop may also vary from one environment to another (Bondari, 2003). For this reason, bean improvement plans may focus on the G x E interaction to select the best genotype suitable for a targeted environment.

Moreover, low heritability estimates were found for S/P, P/P and 100SW in both 2013A and 2013B seasons. In addition, low heritability was observed for P/P and SY in 2013B cropping season. This means that those variables were influenced by non-heritable factors and therefore direct selection for improvement of these characters may not be feasible. These results are in conformity with the findings reported by Shenkut and Brick (2003) who reported that the low heritability estimates for seed yield point out the difficulty in making progress to improve seed yield across diverse environments if selection for seed yield alone is used as the sole selection criterion.

Genetic advance was also high in case of PH for both 2013A and 2013B cropping seasons. This means that the trait was highly influenced by genetic factors and selection can be effective for improvement. Thus, heritability and genetic advance are important aspects to be considered during selection in breeding programmes for this trait (Kashif *et al.*, 2003; Dursum, 2007; Mukandala, 2010 and Sofi *et al.*, 2011). These parameters including high mean, high coefficient of variation, heritability and genetic advance are efficient indicators of the nature of variability for economic traits and the possible breeding progress expected under selection. The low genetic advance observed in some of

the studied traits of common beans means that in order to make improvement of these traits, several cycles of selection would be necessary and the final selection could be done during late stages.

5.6 Simple Correlation

Knowledge of relationship among yield and the other agronomic characters is important in plant breeding, especially for the individual plant selection. Correlation analysis for both cropping seasons described the mutual relationship between different pairs of characters. However, the extent of correlation varied in sites and seasons due to G x E interaction. Significant and negative correlations revealed from combined analysis in both cropping seasons between DFL and PH; DFL and P/P signified that the plants height and pods per plant decreased were the unsuitable weather conditions as heavy rainfall recorded during reproductive stage at all sites (Appendices 2, 3 and 4). Negative and significant correlation between days to flowering and plant height was in agreement with Yucel (2004). The highest significant and positive correlations observed between DFL and DPM; between PH and SY; P/P and SY imply that importance should be given for the above traits while selecting plants as these traits have high significant positive association. The results were in agreement with the results reported by Sivaprasad (2008).

Combined analysis revealed significant negative correlation between PH and DPM; DPM and SY; 100SW and SY which implies that PH increased because of warm and rainy weather conditions in the growing period in the second experiment year and so plants tend to lodge. This caused the yield and yield components to decrease. These results were in harmony with the studies carried out on narbon bean by Yucel (2004).

Significant and positive correlations were observed between P/P and SY implying that P/P increased positively SY regardless of the growing environments. Similar results have been reported by Westerman and Crothers (1977), Karasu and Oz (2010). Highly significant positive correlations observed between P/P and S/P indicates that the plant with more number of pods tend olso to have more number of seeds. These results are in agreement with the findings of various authors (Dursun, 2007, Sofi *et al.*, 2011, Cokkizgin *et al.*, 2013, and Padmavathi *et al.*, 2013). In the breeding of dry bean, generally highly positive correlations between seed yield and pods per plant and seeds per pod are expected and desired (Karasu and Oz, 2010). The highest negative and significant correlation observed between PH and DPM in both cropping seasons indicates that effort should be made in selecting for tall plants.

5.7 Path Coeficient Analysis

Simple correlation does not provide the actual contribution of the characters towards the yield. Therefore, path coefficient analysis appeared to provide a clue to the contribution of various components of yield to over all seed yield in the genotypes under study.

During 2013A, PH had the highest positive direct effect on SY followed by P/P and DFL in combined sites whereas in 2013B, DFL had the highest positive direct effect on SY followed by PH. This provides that across seasons, tall genotypes produced more flowers, more pods per plant and consequently more SY taking into consideration factors prevalent during the reproductive stage. In addition, the high yielding in bean could be obtained by selecting pods per plants and plant height. Therefore, direct and indirect selection for higher seed yield may be effective for improving these traits. Similar results were reported by other researchers (Singh *et al.*, 2009; Karasu and Oz, 2010; Okonkwo and Idahosa, 2013). Moreover, high and positive indirect effects on SY observed in

relationship of DFL via DPM; PH via P/P and S/P; S/P via DPM; P/P via DFL; DPM via PH indicate that improvement based on these characters will increase seed yield. In a similar research, Faisal *et al.* (2007); Karasu and Oz (2010); Hossein *et al.* (2012) reported that attention should be paid to these traits for augmentation of seed yield and these traits could be used as selection criterion in common bean breeding programs.

5.8 Genotype Stability in Performance

Number of Pods per plant (P/P): From the results, genotype GLP2 in 2013A season and genotypes KAB06F2-8-24, KAB06F2-8-78 and KAB06F2-8-22 in 2013B exhibited significant coefficients of regression (b- values) implying that these genotypes were responsive with changing environments (Appendices 8 and 12). The genotype KAB06F2-8-78 was found poorly adapted to all environments, because it showed bi-value approximately equal to 1; high mean value of P/P and high S^2di. The genotypes KAB06F2-8-22 (E), GLP2 (H) had bi less to 1 with mean performance below the grand mean and high S^2di, hence these genotypes were relatively better adapted to low yielding environments. However, in both cropping seasons, genotypes performed differently for adaptability to high yielding environments and stability.

Number of seeds per pod (S/P): During 2013B season, genotypes KAB06F2-8-24, KAB06F2-8-78 and KAB06F2-8-13 exhibited significant coefficients of regression (b- values) whereas KAB06F2-8-135 indicated significant variance of deviation from regression (S^2d) implying that these genotypes were responsive with changing environments (Appendices 9 and 13). The genotype GLP2 exhibited high bi with high mean performance and was found to have adaptability to high yielding environments. Similar results were reported by AL-Aysh (2013). The genotype KAB06F2-8-53 (A) had low bi, with mean performance below the grand mean, hence it was relatively adapted to

low yielding environment. On the other side, genotypes presented different responses for poor adaptability.

One hundred seeds weight (100SW): In 2013A season, genotypes KAB06F2-8-22, KAB06F2-8-13 and GLP2 presented significant coefficients of regression (b- values) implying that these genotypes were responsive with changing environments. The same trend was observed in 2013B season for genotypes KAB06F2-8-53 and GLP2. Moreover, during 2013A season most of the genotypes except KAB10F2-8-136 showed significant deviation from regression (S^2d) implying that these genotypes were less stable (Appendices 10 and 14). Therefore, in both cropping seasons, genotypes KAB06F2-8-53 and KAB06F2-8-135 had regression coefficients significantly greater than one; they have, therefore, adaptability to high yielding environments and all of them recorded very near or higher performance than the grand mean. However, genotypes showed different responses for adaptability to low yielding environment.

Seed yield (SY): During 2013A cropping season, genotypes KAB06F2-8-53, KAB06F2-8-135, KAB06F2-8-22 and KAB06F2-8-13 revealed significant coefficients of regression which were also observed for KAB06F2-8-135, KAB06F2-8-22 and GLP2 during 2013B season implying that genotypes were responsive with changing environments. The same trend on significant deviation from regression (S^2d) was observed for genotypes KAB10F2-8-136 and GLP2 during 2013A cropping season (Appendices 11 and 15). Therefore, genotypes KAB06F2-8-53, KAB06F2-8-136, KAB06F2-8-13 and GLP2 had regression coefficients significantly greater than one and higher yields and are expected to give good yields under high yielding environments thus, may be suitable for farmers who can afford better growing environments or in areas with favourable natural conditions (e.g, soil fertility and moisture).

On the other hand, KAB06F2-8-24 (B), KAB06F2-8-78 (C), KAB06F2-8-135 (D) and KAB06F2-8-22 (E) presented regression coefficients below the unit values and low mean yields, hence were adapted poorly to low yielding environments or unfavourable environmental conditions. These genotypes could be very suitable under small scale farmers who entirely depend on natural environments with poor soils and unreliable rainfall. These results support the findings on faba bean reported by Karadavut *et al.* (2010) and AL-Aysh (2013); who found smaller values of regression coefficients.

Even though no genotype was found suitable across wider environments, results showed that genotypes KAB06F2-8-24, KAB06F2-8-78, KAB06F2-8-53 and KAB06F2-8-13 had good yields in both seasons regardless of the sites.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMANDATIONS

6.1 Conclusion

Differences in genotypes performance were influenced by environmental conditions, such as amount of rainfall differences which played an important role in phenotypic expression of SY and yield components (DFL, DPM, PH, P/P, S/P and 100SW) of common bean genotype evaluated. Its presence altered the relative rank of the common bean genotypes and the relationships between yield and its components. G x E interaction for diseases recorded was not statistically significant during both crop seasons and most of the genotypes evaluated showed resistance to intermediate reaction to diseases.

Genotypes at spacing 20cm x 40cm were not statistically different to genotypes at spacing 15cm x 40cm on SY. Therefore, spacing 20cm x 40cm is retained for use since it contributed to the increase of SY where intermediate quantity of seeds was used. In fact of using high population density, farmers in Burundi will benefit the use of intermediate quantity of seeds in bean production with respect to the use of adequate agronomic practices. This will help farmers to sow wider area of land due to seed availability and hence bean production will increase.

In both cropping seasons, estimates of heritability for seed yield were not different from zero and the magnitudes of the GE interactions were high. Environmental factors highly influenced phenotypic expression in some traits studied. Low heritability estimates observed may also be attributed to the lack of genetic variation for seed yield among lines used in this study. High heritability estimates were obtained for plant height and days to physiological maturity and selection for these traits could be effective for genetic improvement in common bean. Similarly, combined correlation analysis over locations

and seasons indicated that DFL was highly correlated with DPM, thus importance should be given for the above traits while selecting bean crop. As results, the path coefficient analysis showed that plant height was the most important characteristics in determining seed yield. This could be used as a selection criterion in dry bean breeding for high yield.

No genotype was found to be stable in wider environment for seed yield in this study. However, genotypes KAB06F2-8-53, KAB06F2-8-136, KAB06F2-8-13 and GLP2 are expected to give good yields under high yielding environments whereas KAB06F2-8-24, KAB06F2-8-78, KAB06F2-8-135 and KAB06F2-8-22 showed to have adaptability to low yielding environments or unfavourable environmental conditions.

6.2 Recommendations

From this study, the following recommendations are suggested:

i. Genotypes KAB06F2-8-24, KAB06F2-8-78, KAB06F2-8-53 and KAB06F2-8-13 are recommended for confirmation trials on farmer conditions before recommendation for release and adoption by farmers;

ii. Genotypes KAB06F2-8-24, KAB06F2-8-78 are recommended for confirmation on farmer conditions in high altitudes such as Mugamba region;

iii. KAB06F2-8-53 and KAB06F2-8-13 are recommended for confirmation on farmer conditions in low and middle altitudes such as Moso, Bugesera and Kirimiro;

iv. In order to get the best estimate of future yields by increasing precision and reducing experimental errors, future studies should focus on more seasons and locations in different agro-ecological zones. However, researchers can manipulate the combination of these factors based on the availability of resources and time.

v. Plant population of 20cm x 40cm is recommended for bush bean production in Burundi.

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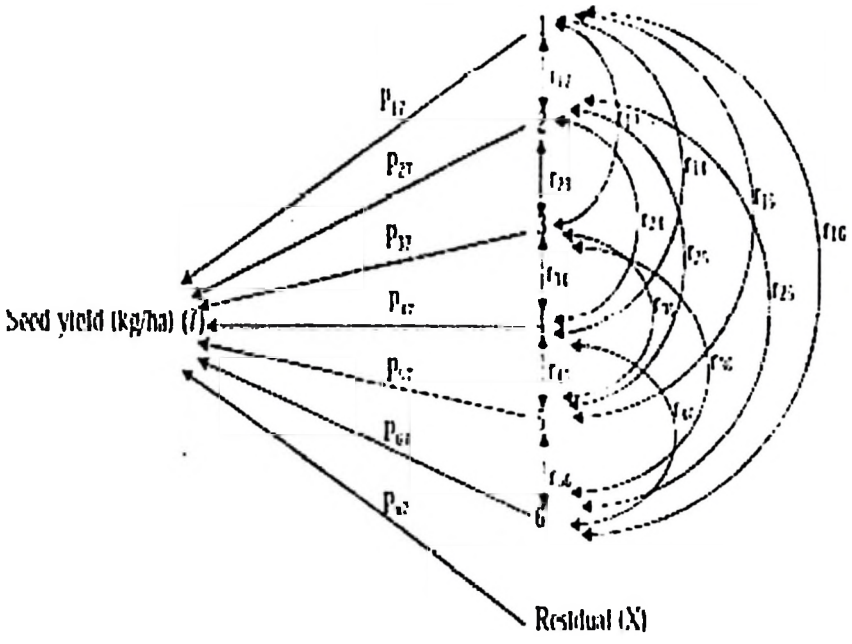
APPENDICES

Appendix 1: Path diagram showing causal relationships between yield and yield components



Appendix 2: Mean monthly temperature and total rainfall during the experimental period October 2012-June 2013 at Moso site

Month	Year	Max Temp (° C)	Min Temp (°C)	Mean Temp (°C)	Total monthly rainfall (mm)	Max. Relat Humid (%)	Min. Relat Humid (%)	Mean. Relat Humid (%)
December	2012	27.7	17	22.35	190.3	98	64	81
January	2013	29.2	17.2	23.2	198.6	97	59	78
February	2013	29.6	16.3	22.95	241.9	98	56	77
Total 1		86.5	50.5	68.5	630.8	293	179	236
Total mean 1		29	17	23	210	98	60	79
March	2013	28.5	17.6	23.05	247.5	97	61	79
April	2013	27.8	17.6	22.7	262.9	98	64	81
May	2013	28.4	16.5	22.45	45.8	96	56	76
Total 2		84.7	51.7	68.2	556.2	291	181	236
Total mean 2		28	17	23	185	97	60	79

Source: IGEBU (2012-2013)

Appendix 3: Mean monthly temperature and total rainfall during the experimental period October 2012-June 2013 at Murongwe site

Month	Year	Max Temp (° C)	Min Temp (°C)	Mean Temp (°C)	Total monthly rainfall (mm)	Max Relat Humid (%)	Min Relat Humi d (%)	Mean Relat Humid (%)
October	2012	26.8	14.6	20.7	77.7	96	49	72.5
November	2012	24.8	14.3	19.55	151.2	99	61	80
December	2012	25	14.4	19.7	143.3	99	62	80.5
January	2013	27.1	15.1	21.1	54.4	98	53	75.5
Total 1		103.7	58.4	81.05	426.6	392	225	308.5
Total mean 1		26	15	20	107	98	56	77
March	2013	26.2	15.2	20.7	154.7	97	56	76.5
April	2013	25.4	15.5	20.45	227	99	61	80
May	2013	25.2	14.3	19.75	16.5	96	54	75
Total 2		76.8	45	60.9	398.2	292	171	231.5
Total mean 2		26	15	20	133	97	57	77

Source: IGEBU (2012-2013)

Appendix 4: Mean monthly temperature and total rainfall during the experimental period October 2012-June 2013 at Gisozi site

Month	Year	Max Temp (° C)	Min Temp (°C)	Mean Temp (°C)	Total monthly rainfall (mm)	Max Relat Humid (%)	Min Relat humid (%)	Mean Relat humid (%)
October	2012	22.8	11.4	17.2	80	96	58	77
November	2012	21	11.6	16.1	156.2	97	67	82
December	2012	21.2	11.2	16.4	262	97	68	82.5
January	2013	22.8	11.6	16.7	132.4	97	60	78.5
Total 1		87.8	45.8	66.4	630.6	387	253	320
Total mean 1		22	11	17	158	97	63	80
March	2013	22.1	11.8	17.05	84.6	98	66	82
April	2013	21.6	12	16.2	207.2	98	69	83.5
May	2013	21.1	10.8	10.55	58.5	95	64	79.5
June	2013	21.8	7.1	14.45	0	92	47	69.5
Total 2		86.6	41.7	58.25	350.3	383	246	314.5
Total mean 2		22	10	15	88	96	62	79

Source: IGEBU (2012-2013)

Appendix 5: Physical and chemical characteristics of the soil at Gisozi site

Characteristics	Measurements	1st season (2013A)		2nd season (2013B)	
		Rating	Interpretation	Rating	Interpretation
Soil pH (H2O)	pH (H2O)	4.7	Very Strong acidity	5.23	moderately acid
pH KCl	pH KCl	4.26		4.51	
Organic Carbon (%)	C	2.05	Low	4.77	Medium
Total Nitrogen (%)	N	0.35	Medium	0.58	High
PA (mg/kg)	P	85	High	27	Medium
EB(meq/100g)	K^+	0.16	Low	0.69	Very high
	Na+	0.03	Low	0.02	Low
	Ca^{2+}	2.13	Low	1.27	Low
	Mg^{2+}	0.35	Low	0.93	Medium
CEC (meq/100g)		12	Low	10.53	Low
PSG	Clay (%)	32.2	Low	31.1	Low
	Silt (%) L.G	4.32	Sand-sand loam	4.45	High
	L.F	4.25	Sand-sand loam	6.97	High
	Sand (%) 1000µ	0.79	Moderate	1.1	High
	500µ	4.87	High	5.18	High
	250µ	10.56	High	9.29	High
	100µ	0.98	Moderate	0.74	Moderate
	50µ	5.04	High	8.17	High
Al3+		0.95	Medium	0	Low
H+		0.23	Low	0.49	Medium
TEA (meq/100g)		1.18	Medium	0.49	Medium

Appendix 6: Physical and chemical characteristics of the soil at Murongwe site

Characteristic	Measurement	1st season 2013A)		2nd season (2013B)	
		Rating	Interpretation	Rating	Interpretation
Soil pH (H2O)	pH (H2O)	4.74	Very strong acidity	5.93	Moderately acid
pH KCl	pH KCl	4.24		4.59	
Organic Carbon (%)	C	1.88	Very low	1.87	Very low
Total Nitrogen (%)	N	0.24	Medium	0.23	Medium
PA (mg/kg)	P	73	High	33	Medium
EB (meq/100g)	K'	0.21	Medium	0.25	Medium
	Na+	0.08	Low	0.03	Low
	Ca^{2+}	2.54	Low	5.78	Medium
	Mg^{2+}	0.77	Medium	3.74	High
CEC (meq/100g)		10.5	Low	14.03	Medium
PSD	Clay (%)	33.72	Low	50.09	High
	Silt (%) L.G	15.43	Silt-loam	10.8	High
	L.F	10.56	Silt-loam	10.68	High
	Sand (%) 1000µ	0.58	Moderate	0.44	Low
	500µ	2.59	High	1.01	High
	250µ	8.76	High	2.99	High
	100µ	0.37	Low	0.21	Low
	50µ	27.99	High	23.78	High
Al3+		0.45	Low	0	Low
H+		0.3	Low	0.1	Low
TEA (meq/100g)		0.75	Low	0.1	Low

Appendix 7: Physical and chemical characteristics of the soil at Moso site

Characteristic	Measurement	1st season 2013A)		2nd season (2013B)	
		Rating	Interpretation	Rating	Interpretation
Soil pH (H2O)	pH (H2O)	5.45	moderately acid	5.66	Moderately acid
pH KCl	pH KCl	5.09		5.14	
Organic Carbon (%)	C	1.94	Very low	1.87	Very low
Total Nitrogen (%)	N	0.19	Low	0.24	Low
PA (mg/kg)	P	8	Very low	17	Low
EB (meq/100g)	K^+	0.76	Very high	0.92	Very high
	Na+	0.05	Low	0.02	Low
	Ca^{2+}	12.95	High	4.25	Low
	Mg^{2+}	4.05	High	7.14	High
CEC (meq/100g)		22.2	Medium	16.43	Medium
PSD	Clay (%)	79.69	High	64.75	High
	Silt (%) L.G	1.89	Sand-sand loam	6.31	High
	L.F	17.5	Silt loam-loam	24.25	High
	Sand (%) 1000µ	0.02	Low	0.24	Low
	500µ	0.16	Low	0.5	Moderate
	250µ	0.17	Low	1.04	High
	100µ	0.06	Low	0.78	Moderate
	50µ	0.51	Moderate	2.13	High
Al3+		0	Low	0	Low
H+		0.08	Low	0.07	Low
TEA (meq/100g)		0.08	Low	0.07	Low

Key: PSD=Particle Size Distribution, TEA= Total Exchangeable Acidity, PA=Phosphorus available, EB= Exchangeable Bases, L.G=Limon Grossier, L.F= Limon Fin

Appendix 8: Regression of P/P for each genotype across locations during 2013A

Genotypes	Code	Mean	βi	Rank	S^2d	Rank	R^2
KAB06F2-8-53	A	7	1.01	1	-0.356	4	0.883
KAB06F2-8-24	B	7	1.14	8	-1.043	6	0.948
KAB06F2-8-78	C	7	0.98	2	-1.293	7	0.953
KAB06F2-8-135	D	6	1.0	4	0.110	1	0.839
KAB06F2-8-22	E	5	0.88	7	-0.76	5	0.888
KAB10F2-8-136	F	7	1.08	5	0.20	2	0.861
KAB06F2-8-13	G	7	1.03	3	-1.37	8	0.964
GLP2	H	8	0.92	6	0.218	3	0.818

Appendix 9: Regression of S/P for each genotype across locations during 2013A

Genotypes	Code	Mean	βi	Rank	S^2d	Rank	R^2
KAB06F2-8-53	A	3	0.80	3	-0.006	1	0.469
KAB06F2-8-24	B	3	1.25	5	-0.055	3	0.762
KAB06F2-8-78	C	3	0.75	6	-0.110	7	0.720
KAB06F2-8-135	D	3	0.5	8	-0.089	5	0.457
KAB06F2-8-22	E	3	0.94	1	-0.09	4	0.729
KAB10F2-8-136	F	3	1.09	2	0.02	2	0.588
KAB06F2-8-13	G	3	1.23	4	-0.10	6	0.846
GLP2	H	4	1.430*	7	-0.125	8	0.933

Appendix 10: Regression of 100SW (g) for each genotype across locations during 2013A

Genotypes	Code	Mean	βi	Rank	S^2d	Rank	R^2
KAB06F2-8-53	A	40.52	1.49	3	1.55***	4	0.76
KAB06F2-8-24	B	39.04	1.22	1	1.81***	5	0.652
KAB06F2-8-78	C	37.48	0.34	4	6.34***	7	0.045
KAB06F2-8-135	D	38.22	1.8	5	11.01***	8	0.436
KAB06F2-8-22	E	41.37	0.029*	6	1.24***	3	0.001
KAB10F2-8-136	F	40.22	0.64	2	0.16	1	0.666
KAB06F2-8-13	G	39.52	0.011*	7	1.10**	2	0
GLP2	H	42.04	2.485*	8	2.35***	6	0.862

Appendix 11: Regression of SY (t/ha) for each genotype across locations during 2013A

Genotypes	Code	Mean	βi	Rank	S^2d	Rank	R^2
KAB06F2-8-53	A	0.6	1.131*	3	-0.014	2	0.99
KAB06F2-8-24	B	0.51	0.92	2	-0.015	3	0.986
KAB06F2-8-78	C	0.55	0.97	1	-0.014	1	0.986
KAB06F2-8-135	D	0.34	0.609*	8	-0.017	4	0.98
KAB06F2-8-22	E	0.37	0.725*	7	-0.02	6	0.999
KAB10F2-8-136	F	0.61	1.22	6	0.0350*	7	0.932
KAB06F2-8-13	G	0.62	1.218*	5	-0.02	5	0.999
GLP2	H	0.76	1.21	4	0.0511**	8	0.912

Appendix 12: Regression of P/P for each genotype across locations during 2013B

Genotypes	Code	Mean	βi	Rank	S^2d	Rank	R^2
KAB06F2-8-53	A	11	1.35	5	-5.07	7	0.88
KAB06F2-8-24	B	11	0.44*	7	-4.89	6	0.42
KAB06F2-8-78	C	12	2.04*	8	-1.96	2	0.85
KAB06F2-8-135	D	10	0.9	1	-3.60	3	0.66
KAB06F2-8-22	E	9	0.52*	6	-5.21	8	0.55
KAB10F2-8-136	F	9	1.06	2	-4.83	5	0.80
KAB06F2-8-13	G	10	0.89	3	-0.95	1	0.48
GLP2	H	9	0.77	4	-4.723	4	0.67

Appendix 13: Regression of S/P for each genotype across locations during 2013B

Genotypes	Code	Mean	βi	Rank	S^2d	Rank	R^2
KAB06F2-8-53	A	3	0.69	4	-0.67	7	0.797
KAB06F2-8-24	B	3	0.44*	6	-0.61	5	0.365
KAB06F2-8-78	C	4	2.95*	8	0.47	2	0.68
KAB06F2-8-135	D	4	0.9	1	1.23*	8	0.104
KAB06F2-8-22	E	3	0.7	3	-0.66	6	0.756
KAB10F2-8-136	F	3	0.65	5	-0.58	3	0.486
KAB06F2-8-13	G	3	0.42*	7	-0.6	4	0.332
GLP2	H	4	1.28	2	-0.366	1	0.58

Appendix 14: Regression 100SW (g) for each genotype across locations during 2013B

Genotypes	Code	Mean	βi	Rank	S^2d	Rank	R^2
KAB06F2-8-53	A	44.52	1.32*	6	-1.75	5	0.966
KAB06F2-8-24	B	39.75	0.85	3	-0.67	2	0.794
KAB06F2-8-78	C	38.33	1.18	4	1.89	6	0.735
KAB06F2-8-135	D	43.22	1.4	7	0.08	1	0.877
KAB06F2-8-22	E	46.55	1.23	5	0.74	3	0.807
KAB10F2-8-136	F	41.8	1.13	2	-0.74	4	0.875
KAB06F2-8-13	G	42.2	1.12	1	-1.94	7	0.97
GLP2	H	43.57	-0.25*	8	7.85***	8	0.048

Appendix 15: Regression of SY (t/ha) for each genotype across locations during 2013B

Genotypes	Code	Mean	βi	Rank	S^2d	Rank	R^2
KAB06F2-8-53	A	2.31	1.2	3	0.024	1	0.706
KAB06F2-8-24	B	2.19	0.74	5	-0.055	5	0.634
KAB06F2-8-78	C	2.2	0.58	4	-0.048	4	0.473
KAB06F2-8-135	D	2.14	0.262*	7	-0.059	6	0.195
KAB06F2-8-22	E	2.06	0.318*	6	-0.07	7	0.318
KAB10F2-8-136	F	2.02	1.18	2	-0.03	2	0.751
KAB06F2-8-13	G	2.28	1.2	1	-0.09	8	0.956
GLP2	H	2.5	2.153*	8	0.036	3	0.815