GENOTYPE X ENVIRONMENT INTERACTIONS, SHELF-LIFE AND SEED PRODUCTION IN COMMON ONIONS (*Allium cepa*)

BY

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A thesis submitted in partial fulfilment of the requirements
for the degree of

MASTER OF SCIENCE

IN

PLANT BREEDING

DEPARTMENT OF CROP SCIENCE
FACULTY OF AGRICULTURE
UNIVERSITY OF NAIROBI

1992

DECLARATION

This thesis is my original work and has not been submitted for a degree in any other University .

Date 26/6/92

This thesis has been submitted for examination with our approval as University Supervisors.

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PROF. V. K. GUPTA

DEDICATION

Dedicated to my parents

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ACKNOWLEDGEMENTS

I wish to express my sincere gratitude and appreciation to my first supervisor Dr. P.M. Kimani for his guidance and encouragement throughout the course of the study. Appreciation is also extended to my second supervisor Prof. V.K. Gupta for going through the manuscript and making useful criticism and suggestions. I would also like to thank the Onion Project, Department of Crop Science, for availing the plant materials and financial support.

I owe thanks to the officers in charge of Oljorok and Marigat K.A.R.I. stations, Njabini Farmers Training Centre and Kibirigwi Irrigation Scheme, for providing the experimental sites. Thanks also goes to members of the Onion Project for the technical assistance they offered.

Appreciation also goes to Messrs: Thuranira and Owiti of N.A.L., Kamau and Chege of the Department of Crop Science, for doing the data analysis.

I would also like to convey my gratitude to the University of Nairobi for the financial support of my postgraduate study.

Finally, thanks goes to Ms. Jane N. Mbugua for typing the final draft of this manuscript.

ABSTRACT

Eight introduced and three existing onion cultivars were evaluated at four locations for two seasons to determine genotype-environment interactions and stability for bulb yield, and other agronomic characters. The cultivars were then evaluated for their shelf-life. They were also vernalized at four temperature regimes (5°C, 10°C, Njabini 2530 m and Kabete 1820 m room temperature) to induce flowering and seed production. Experimental design for GxE and storage experiments was randomised complete block design with five and three replicates, respectively. Seed production trial was in a split plot design with three replicates.

Genotypic effects were highly significant for all traits except days to maturity. Genotype - environment interactions were highly significant for all traits. The nature of genotype x environment interactions and stability analysis were investigated by regression analysis technique of Eberhart and Russell (1966). Results showed a considerable portion of genotype x environment interactions for bulb yield and shape could be attributed to the linear regressions. The significant GxE (linear) variance indicated that there were genetic differences among the cultivars for their regression on the environmental index.

All exotic cultivars had better bulb yield than the

existing ones. Cultivar KON2 had good adaptation and stability but had below average bulb yield. Cultivar KON4 had high bulb yield and general adaptability but lacked stability for this trait. The exotic cultivars did not have a great advantage over existing cultivars for maturity. Cultivar KON5 was the earliest while KON8 was the latest to mature. All cultivars except KON3 and Bombay Red were not stable for duration to maturity. Cultivar KON6 was early maturing, widely adapted but not stable for maturity.

Combined analysis for shelf-life indicated that location and cultivar effects and their interactions were significant. The exotic cultivars stored better than the existing ones. Best storing exotic cultivars were KON1 and KON4 with 27.2 and 35.6% storage loss ,respectively, after four months of storage at Kabete. The existing cultivars and KON6 had 75% storage loss in four months.

Location, varietal and storage temperature effects were highly significant for all traits considered in seed production trial except percentage germination. Only varietal effects were significant for percentage germination. All interactions were also significant for all traits except germination. Var. x Temp. was significant for germination. Bulbs stored at 10°C flowered earlier and had higher seed yield than those stored at 5°C, Njabini and Kabete room temperature. Bulbs that were naturally vernalised at Njabini had successful flowering in all locations. The exotic cultivars had higher seed yield than the existing ones. The highest seed yielding cultivars were KON7 and KON1. Marigat was the most favourable location for seed production.

CHAPTER I

INTRODUCTION

The common onion (*Allium cepa L.*) is one of the major and widely cultivated vegetables in Kenya. It is a biennial crop grown as an annual and used in cooking not only by itself but also as a basis for soups, salads and stews. It is a rich source of vitamin C and calcium (Tindall, 1985).

Onions in Kenya are grown in a wide range of climatic conditions which vary from relatively hot and dry to fairly cool and humid areas stretching from the Coast to high altitude zones. Of the onions delivered to Horticultural Crops Development Authority (H.C.D.A) Nairobi godowns in 1990, 38% was from Narok, 37% from Perkerra and 16% from Loitokitok while the rest came from other producing areas such as Taveta, Bungoma, Eldoret, Kericho, Naivasha, Nanyuki, Kisii and Kirinyaga district (H.C.D.A, 1991). Most of the onions are produced under rainfed conditions except in Perkerra, Naivasha, Loitokitok, Narosura (Narok) and Garissa, where they are grown under irrigation. Onions in Kenya are valued as a source of income to small scale farmers. It is the principal cash crop in Perkerra irrigation scheme in Baringo district (Irea, 1979).

Inspite of the economic importance of the crop in

Kenya, the yields are low compared to other producing countries. The average yield for most farmers in Kenya is approximately 10 tonnes/ha (H.C.D.A, 1991) compared to 45.5 tons/ha in Japan, 42.5 tons/ha in U.S.A, 39.1 tons/ha in Spain and 14.9 tons/ha in China (Pike, 1986). Post harvest losses are high due to lack of improved high yielding cultivars with resistance to diseases and having long shelf-life (Kimani *et al.*, 1991). Moreover, very little onion breeding work has been done in Kenya largely because research has been concentrated on staple cereals and cash crops for export. Although the area cropped, production and yields vary between seasons, demand for onions has increased steadily with population growth and urban migration.

Onions fall into two major types, known as short-day and long-day onions (Pike, 1986).Those that bulb when the daylength exceeds approximately 11.5 hours fall into the short day group, and those that require 14 hours or more to bulb fall into the long day group. In Kenya, daylength is approximately 12 hours with minor variations depending on location and time of the year (Kimani *et al.*, 1991). Consequently, only short-day onions should be considered for breeding purposes.

The main onion cultivars grown in Kenya include Bombay Red, Tropicana Hybrid and Red Creole. Light skinned varieties like Texas Grano, White Creole and

Yellow Granex are also grown to a l extent for processing (dehydration) especially in vasha. Cook (1963) observed that these imported ivars, which were bred for temperate climates, were y adapted to the Kenyan conditions. Bombay Red is highly susceptible to purple blotch caused by *naria porri*, has a tendency to bolt and has bulbs or keeping quality. Red-Creole is outyielded by cana Hybrid but the latter is not resistant to fun iseases and is inferior in keeping quality (Moh 1977). In addition, Tropicana Hybrid seeds are ver nsive for small scale farmers. The prices for one Tropicana Hybrid, Red Creole and Bombay Red seeds shs. 2791, 1107 and 856, respectively (Simlaw s personal communication, 1991).

In view of this, an onion breedin gramme is essential in Kenya to introduce new imp cultivars and ensure that the potential of existi tivars is realized. The initial objective of suc breeding programme is to select cultivars that a sistently high yielding over a range of environments occur in different onion growing areas and seasons. er, this selection, can be hampered by cultiv ironment interactions (Comstock and Moll, 1963). quently, the existing and new cultivar should be ev d over a wide range of environmental conditio volving locations and seasons prior to further bre ork. As

Yellow Granex are also grown to a small extent for processing (dehydration) especially in Naivasha. Cook (1963) observed that these imported cultivars, which were bred for temperate climates, were poorly adapted to the Kenyan conditions. Bombay Red which is highly susceptible to purple blotch caused by *Alternaria porri*, has a tendency to bolt and has bulbs of poor keeping quality. Red-Creole is outyielded by Tropicana Hybrid but the latter is not resistant to fungal diseases and is inferior in keeping quality (Mohdhar, 1977). In addition, Tropicana Hybrid seeds are very expensive for small scale farmers. The prices for one kg of Tropicana Hybrid, Red Creole and Bombay Red seeds were Kshs. 2791, 1107 and 856, respectively (Simlaw seeds, personal communication, 1991).

In view of this, an onion breeding programme is essential in Kenya to introduce new improved cultivars and ensure that the potential of existing cultivars is realized. The initial objective of such a breeding programme is to select cultivars that are consistently high yielding over a range of environments that occur in different onion growing areas and seasons. However, this selection, can be hampered by cultivar-environment interactions (Comstock and Moll, 1963). Consequently, the existing and new cultivar should be evaluated over a wide range of environmental conditions involving locations and seasons prior to further breeding work. As a preliminary to breeding programme, such an evaluation programme can guide the breeder in screening environments which maximise the expression of important traits such as yield.

In Kenya, onions are mainly produced for fresh market and they have to be transported over long distances to the urban centres and stored for considerable periods for sale during off season period. High humidity and high to moderate temperatures in Kenya, make storage of onions difficult. Cold storage which could extend storage life of these onions is not available to most farmers. Selection for superior genotypes with good shelf-life is necessary to minimise storage losses.

The success of such an onion breeding programme can only be ensured if seeds are produced locally. Several attempts have been made to produce onion seeds in Kenya with little success (Cook, 1963 and Combes, 1982). As a result, all onion seeds used in Kenya are imported. This is because onions are temperate in origin and therefore not successfully adapted to the tropics where they develop a vegetative phase without changing into a reproductive phase. Onions require sufficient low temperature for flower induction. The cost of the imported seeds is prohibitive and a major constraint to increased onion production. Local onion seed production, no doubt will facilitate onion improvement work.

The objectives of the study were therefore:-

(a) To determine the cultivar - environment interaction and stability analysis of bulb yield and related traits for local and exotic onion cultivars.

(b) Evaluate the shelf-life of local and exotic cultivars.

(c) Determine the possibility of local onion seed production.

CHAPTER II

LITERATURE REVIEW

2.1.1 Botany of onions

The common onion belongs to the genus *Allium* of the family Liliaceae. The genus has about 500 recorded species but only seven species are of commercial importance as food crops. They are *Allium cepa* (onion), *A. ampeloprasum* L. var. porrum (leeks), *A. fistalosum* L. (japanese bunching or welsh onions), *A. schoenoprasum* L.) (chives), *A. tuberosum* (chinese chives) *A. ascalonicum l.* (shallots) and *A. sativum l.* (garlic) (George, 1985).

Allium cepa L. is a diploid species (2n = 16) whose origin was West and Central Asia, where it spread to regions as diverse as Scandinavia and Sri Lanka (Currah, 1985). The crop is biennial grown as an annual for its bulb. The bulb is made up of thickened leaf basis attached to a conical stem. The outer layers are thin and fibrous while the inner layers do not have blades. Bulbs may be white, yellow, red or of intermediate colour, depending on cultivars. Varieties differ also in such characters as adaptation to daylength, bulb size, shape, storage ability, firmness and dry matter content.

Onion flowers are borne on a scape (flowerstalk) enclosed by a sheath called the spathe. Terminal umbels produce cymes, each with 5-10 flowers. The fruit is a capsule containing three pairs of seeds, black in colour and angular. Onions are largely outcrossing species resulting in genetically heterogeneous populations with high degree of heterozygosity (Jones and Manns, 1963). This results in a wide plant-to-plant genetic variation. Moreover, there is considerable variation between onion populations.

Development of the onions is highly influenced by environmental factors primarily daylength and temperature. Bulbing is dependent on daylength. A certain daylength has to be attained before bulbing takes place. For good bulbing short-day and long-day cultivars requires more than 11.5 and 14 hours of daylength, respectively. Bulbing occurs at relatively high temperatures, but it is preferable for the vegetative phase to be completed during a relatively cool period with a range of 18-25°C. The more the temperature and daylength exceed the minimum requirements for the variety, the shorter will be the time between the start of bulbing and maturity. When temperature exceed the requirement for bulbing, maturity is hastened and bulbs do not reach their maximum size and consequently yield is reduced (Jones and Manns, 1963). If low temperatures prevail, maturity is delayed resulting in poor storage quality bulbs. When onion cultivars are not adapted to daylength where they are grown, proper bulbing does not occur resulting in thick necked bulbs. Bulbing is thus determined by the interaction of daylength and temperature.

Flower initiation and development in onion is also influenced by environmental factors. Temperatures is the primary factor affecting the flowering process. Exposure to low temperature (vernalization) is required for flower induction. The vernalization requirements for successful flower initiation depends on the cultivar (George, 1985).

2.1.2 Genotype-environment interactions

Phenotype is a result of genotypic and environmental effects. The two effects are not independent (Comstock and Moll, 1963). A specified genotype does not exhibit the same phenotypic characteristics under all the environments and different genotypes respond differently to a specified environment. There is an interplay between genetic and non-genetic effects on phenotypic effects. The interplay between genotypic and non-genetic factors on phenotypic manifestation is referred to as genotypic-environment interactions.

Genotype-environment interactions are of major importance to the plant breeder in developing improved cultivars and their release for production. If there is genotype-environment interaction when different varieties are compared over a series of environments, the relative rankings usually differ. According to Knight (1970) and Nguyen *et al* (1980) changes in ranking make it difficult for the plant breeder to decide which genotypes should be selected. Moreover, progress from selection is also reduced due to the presence of GE interactions masking genotypic effects. Comstock and Moll, (1963), Freeman (1973), Verma and Gill (1975) and Wamatu (1989) noted that the interaction between a genotype and its environment contributes to the total variances, which can be isolated and tested for its significance.

Different attempts have been made to solve problems created by genotype-environment interactions. Horner and Frey (1957) used stratification of environments to reduce genotype-environment interactions in oats. Allard and Bradshaw (1964) coined the terms predictable and unpredictable environments. Predictable environment includes permanent features of the environment, such as climate and soils, as well as those aspects of the environment which fluctuate in a systematic manner, such as daylength. It also includes aspects determined by man, such as sowing dates, sowing density and other agronomic practices. Unpredictable environment includes fluctuations in weather such as amount and distribution of rainfall and temperature. Predictable environmental variations can be reduced by stratification of the environment and allocation of different genotypes to different environments. Limitation of the stratification of environment method is that it is not effective for unpredictable environmental variations (Horner and Frey, 1957). Tai (1971) observed that large interactions of genotypes with locations could still exist in a sub-region and more importantly the genotype-year interaction cannot be reduced by the sub-division of a breeding area.

The use of genetic diversity, either in heterozygotes or heterogeneous population has been suggested as a means to reduce genotype-environment interaction (Sprague and Federer, 1951, Allard and Bradshaw, 1964; Eberhart *et al.*, 1964).

Comstock and Moll (1963) developed the analysis of variance approach to estimate genotype-environment interactions. These estimates provide information on existence and magnitude of genotype-environment interactions. Using data from multilocational trials over a number of seasons, analysis of variance is conducted to calculate the variance due to GE interaction. In the event that this variance is significant, stability analysis can be done.

2.1.3 Stability analysis

Stability in performance is the ability to show a minimum of interaction with the environment. It is one of the most desirable properties of a genotype to be released as a variety for wide cultivation. Several stability parameters have been reviewed by Freeman (1973) and Linn *et al.* (1986).

Lewis (1954) suggested the use of phenotypic stability factor (S.F.) which took into considerations the mean values only in the highest and lowest yielding environments. The maximum phenotypic stability is indicated by S.F. = 1. This is a biased estimate since it does not consider intermediate environments.

Plaisted and Peterson (1959) made an attempt to measure stability of individual cultivars. Their method involved a combined analysis of variance for each pair of cultivars. The average of the estimate for all combinations with a variety in common was considered a measure of the stability of the common variéty. According to Nguyen *et al* (1980) the method is cumbersome when a large number of cultivars is tested.

Wrinkle (1962 and 1966) developed a stability parameter which he termed ecovalence (Wi). Ecovalence is the contribution of a genotype to the genotype-environment interactions sum of squares. Variety with the least ecovalence is considered more stable and varieties with high ecovalence have poor stability. This parameter has a limited use (Fejer, 1967 and 1973; Qualset, 1968) because it does not allow the prediction of performance of genotypes over environments (Verma and Gill, 1975, Kermali, 1981, Wamatu, 1989). Fejer (1967) concluded that this method was superior when the number of environments was limited.

Shukla (1972), suggested a method for deriving a stability variance (Si) based on the residuals in a two-way classification. The variance of a genotype across environments is the stability measure.

Yates and Cochran (1938) showed that a linear regression of yields of the separate varieties, accounted for a large part of the interaction in a set of barley trials in seven environments. In their analysis the mean yield of many genotypes was used as a quantitative measure of the environment. They showed that linear regression of yields of separate genotypes on the mean value of environments accounted for a large part of genotype-environment interaction. The regression coefficients for each genotype was taken as its stability measure. Varieties characterized by regression coefficients (bi) approximately 1.0 have average stability over all environments. Genotypes with bi above 1.0 have below average stability i.e. are more sensitive to environmental changes. Regression values below 1.0 indicate above average stability i.e. are more resistant to environmental changes. On this criteria an ideal genotype was defined as the one with maximum yield potential under the most favourable environment and with the maximum stability.

The regression technique of Finlay and Wilkinson (1963) was improved by Eberhart and Russell (1966) by adding another parameter, namely deviation from regression (£ij) which is a secondary measure of stability. They defined an ideal variety as one which has a high mean yield (μ), unit regression coefficient (bi) = 1.0 and the least deviation from regression (£ij = 0). This method has the advantage of using independent variable, the environmental index. Although Eberhart and Russell (1966) method has been used by many plant breeders (Jowett, 1972; Nguyen *et al*, 1980; Kermali, 1981; Tai, 1971; Wamatu, 1989), it has been questioned by Linn *et al* (1986). The latter doubted whether deviations from regression represent genotypes stability character. They argued that the independent variable (environmental index) cannot be measured prior to the experiment. Consequently, it does not provide a prediction model and therefore lacks a deterministic property that can be associated with the genotypes. The environmental index should be replaced with actual environmental factors, such as temperature or rainfall etc., leading to a prediction model.

Hanson (1970), using data from a set of U.S. regional soybean yield trials defined genotypic stability so that measures represented a combination of information from regression and deviation from regression analysis. The stability measure is similar to Wrinckle's (1962) but takes account of regression.

Tai (1971) proposed a procedure to determine the stability of potato varieties based on the principle of structural relationship analysis. The method is a special form of that of Eberhart and Russell analysis (1966), when the environmental index is assumed to be random. The genotype-environment interaction is partitioned into linear response to environmental effects (α) and the deviation from the linear response (λ). A stable variety has $(\alpha, \lambda) = (-1, 1)$ and a variety with average stability has $(\alpha, \lambda) = (0, 1)$.

2.1.4 Adaptability and Stability Parameters

The parameters proposed by Eberhart and Russell (1966) for adaptability and stability are regression coefficients (b_i) and deviations from regression (s^2_{di}). A stable cultivar is also more desirable if it has a high mean performance. A variety with regression coefficients (b_i) approximately equal to unity and above-average performance has general adaptabiilty. On the other hand, if $b_i = 1$ and below average performance, such a cultivar has poor adaptability. Varieties with regression coefficients b>1 have low stability and are specifically adapted to high-yielding environments. b<1 indicates high stability and specific adaptation to low yielding environment. According to Eberhart and Russell (1966) and Breese (1969), deviation from regression are a measure of genotypic stability. A stable genotype has deviations that are not significantly different from zero.

Finlay and Wilkinson (1963) defined (b_i) as a quantitative measure of phenotypic stability. Perkins and Jinks (1968) defined β_i, obtained by regressing genotype-environmental interactions (g_{ij}) on the environment (e_j), as a measure of genotypic stability. In Eberhart and Russell Model (1966), (e_j + g_{ij}) is regressed on e_j. The regression of e_j on e_j being one, and regression of g_{ij} on e_{ij} being β_{ij}, the b_i value of Eberhart and Russell model is thus:

$$b_i = 1 + \beta_i$$

$$b_i - 1 = \beta_i$$

A stable genotype will have ($1+\beta_i$) value of 1.00 and β_i value of zero. Unstable genotype has ($1+\beta_i$) value greater than 1.00 and has a β_i value greater than zero.

2.1.5 Genotype-environment interaction in onions

Little work has been published on genotype-environment interactions in onions. Dowker and Fennel

(1974b) in a series of field trials using varieties Rijnsburger and Zittan types, inbreds derived from the varieties, and two F_1 hybrids, determined the interactions of these genotypes with important agronomic practices with respect to yield, bulb shape, bulb marketability and bulb qualities. The agronomic practices used were time of sowing and harvesting, and plant density.

In the time of sowing trial, three varieties Rijnsburger, Cambridge No. 10 and N.V.R.S. hybrid, AC 64008 were sown on six successive dates at fortnightly intervals. Analysis was done on yield and storage qualities. Significant genotypic effects were detected for yield, storage qualities and sowing dates. There were significant varietal and time-of-sowing effects for yield and shape ratio. Only variety effects were significant for storage qualities. There was no evidence of genotype x environment interaction for all the characters considered.

In the time of harvest trial, two varieties namely, Mustang (An American F_1 hybrid) and Rijnsburger, were used for two years and each variety harvested on ten successive weekly occasions. Maturity and storage qualities were considered in the analysis. Years and time of harvests were significant for both traits. No varietal differences were detected for storage quality.

Genotype x harvest x year interactions were shown to occur for yield and percentage of sprouted bulbs, and also a genotype x year interaction with the latter trait.

Two sets of density trials were carried out. One of the density trial was done with varieties Rijnsburger, Rola and Zittan, sown at three densities, 32, 97 and 231 plants/m^2 for three years. Maturity and storage qualities were the characters considered. Varietal and density effects were detected for maturity but not for storage qualities. Years x density interactions were significant for both traits. Years x varieties interaction were significant for storage qualities but not for maturity. No other genotype-environment interactions were detected for both traits.

Another plant density trial involved inbred lines grown at densities 16, 32, 65 and 129 plants/m^2 for one year. Characters considered were yield, bullnecks (thick-necks), double and storage qualities. Density effects were only significant for doubles and bullnecks. Varietal differences were detected in all the traits except storage qualities. Variety x density interactions were significant for all traits except bullnecks.

Fennell and Salter (1977) evaluated onion cultivars of Japanese and European origin at six sites over two seasons. Other variables were plant density (86 and 130 plants/m^2) and two sowing dates. Characters considered were winter-kill, bolting, maturity and yield. Where significant genotype-environment interactions were detected joint-regression approach, developed by Perkins and Jinks (1968), was used for further investigations. Within each season genotypic differences were detected for all traits but from combined analysis over seasons genotypic differences were detected for percentage winter-kill. Environmental effects were important with differences between seasons, sites and sowings recorded for winter-kill and bolting. For maturity and yield, year x site, sowings and year x site x sowings were most important in that order. Plant density was significant for maturity time. Higher density had earlier maturity. Genotype-environment interactions were found for winter-kill, bolting and maturity. For bolting year x genotype was most important.

Hosfied *et al.* (1977) used a diallel analysis to estimate combining ability of several traits in onibns and evaluated the importance of interaction of general combining ability (G.C.A.) and specific combining ability (S.C.A.) with locations and years. All possible crosses among seven-inbred lines were tested for 2 years at three locations for yield, maturity, bulb traits and storage quality. They found significant but small GCA x year and GCA x year x location interactions for centres/bulbs as well as GCA x location and GCA x year x location interactions for yield. For maturity and % of storage loss, the SCA x year x location component was larger than the SCA component. They also reported that correlations of GCA effects between environments suggested that significant interactions of GCA were sometimes due to, change in rank of effects from environment to environment and a change in rank and change in variance.

2.2 SEED PRODUCTION IN ONIONS

2.2.1 Flowering and flower development

The basic requirement for seed crops is that the plant must flower. Consequently, in onion seed production practices, an understanding of the factors that affect flower induction is essential. However, Currah and Proctor (1990) reported that these factors have not been well understood in the tropics.

Onions are biennual plants, producing a bulb in one year and seed in the next. However, bolting can occur in the season of bulb production (Jones and Manns, 1963). Flowering during the seed production season is of interest because seed yields are directly dependent on the amount of flowering.

The onion flowers are borne on umbels (Plate 1). Each umbel consists of a few to more than 2000 flowers.

The flower stalk (scape) is an extension of the stem without nodes and internodes and it ceases to grow when its umbel starts to flower (Pike, 1986). George (1985), observed that the duration of anthesis is approximately four weeks on individual umbels and that of a whole plant may be longer. Currah (1981) reported that there is a tendency for flowering to start at the top of the umbel and proceed downwards rather than the flower opening in a regular pattern.

2.2.2 Pollination

The prerequisites for seed set and development are pollination and subsequent fertilization of the onion flowers. All anthers of a given flower, shed their pollen before the style reaches its final length (Currah and Ockendon, 1978; Ali *et al.*, 1984). Due to this delayed female maturity (protandry) self pollination within an individual flower is prevented. Consequently, onions are largely cross-pollinated by bees, flies and other insects. Currah and Ockendon (1983) observed that the pollinating insects may visit many flowers before leaving for another plant, thus self-pollination between flowers of a single genotype may occur.

2.2.3 Factors affecting flowering and seed production

Flowering of the onion is initiated by environmental factors. Temperature is the principal

Plate: 1 An onion umbel with good seed set, Kabete ,1991 factor affecting both inflorescence initiation and development (Brewster, 1977; Pike, 1986 and Currah and Proctor,1990). Brewster (1982) observed that inflorescence development in onions has three successive phases namely, the 'thermo-phase', the 'competition phase' and the 'completion-phase'. The first phase requires sufficient low temperature exposure for floral initiation. Factors favouring bulbing suppresse inflorescence emergence in the 'competition phase', and in the last phase, inflorescnece growth is favoured by high temperatures and longer days.

Temperature

According to Brewster (1977 and 1982), floral initiation requires low temperature. Tropical climates do not experience low temperatures sufficient to induce flowering in onions. Consequently, artificial vernalization has to be used to induce flowering. Storage temperature and duration must be optimum to ensure that stored bulbs receive sufficient cold stimulus for flower induction.

The effect of bulb storage temperature on floral initiation and subsequent development have been studied. Holdsworth and Heath (1950) observed that flower initiation did not occur above 17°C in all the varieties used. Jones and Manns (1963) reported that temperature varying from 11.5 to 14°C, with an optimum of 11-12°C are the best for flower induction. They observed that temperatures of 3.6 and 30°C inhibited or delayed the formation of flower primordia. Brewster (1977) and Currah (1981) reported that the most favourable temperature for floral initiation is 9-13°C.

Time required for floral initiation is minimised when temperatures are in the range of 5 to 12°C and longer periods are required under both lower or higher temperatures (Ali *et al*,1984).Brewster (1982) cautioned that the duration and temperature of the 'thermo-phase' must be sufficient to ensure that inflorescence development is not supppressed by competition for bulb development when temperatures are increased to accelerate inflorescence emergence. He compared the response of a number of genotypes and noted that 7 to 13°C was optimal for flower induction.

Brewster (1977) and Currah (1981) reported that after floral initiation, high temperatures of 28 to 30°C could revert floral to a vegetative phase. Currah (1981) observed that temperatures above 30°C in cultivar Rijnsburger resulted in flower abortion due to competition for assimilates between bulbing and flower scape. High temperature (>28°C), therefore, adversely affects flowering by decreasing inflorescence initiation and promoting bulbing. Cultivar variation has been observed in response to storage temperatures. Sinnadurai

(1970) noted a Nigerian cultivar which would flower satisfactorily without low temperature treatments. Prevailing ambient temperatures were 15 to 21°C, a temperature range which could inhibit flower induction in some varieties.

Demille and Vest (1975) investigated the effects of storage temperature treatments on flowering date of open-pollinated cultivars. They reported that storage temperatures of 7°C resulted in earlier flowering, a large number of umbels and a higher seed yield than that of bulbs stored at a temperature regime of 2°C the first half and 7°C the last half of the storage period.

Bulb storage temperature also affects other seed yield components. Demille and Vest (1976) reported that storage temperature of 7°C followed by a cooler temperature of 2°C had a higher, seed weight plant^{-1}, stalk height and number of leaves plant^{-1} than 7°C treatment alone. The number of umbels plant^{-1} was not affected by temperature treatment. Hesse *et al* (1979) noted that onion inbred lines stored at 10°C for 24 weeks had earlier flowering, a higher number of florets bulb^{-1}, than inbred lines stored at 2°C for the same duration.

Optimal duration for vernalization has been variable among workers. In Taiwan, Chang *et al* (1987), using cultivars, Taiwan No. 1, Granex, Texas Early Grano 502, Red Creole and White Creole, achieved 80% flowering after a 4-week storage period at 9°C. They observed that an optimum of 8 weeks of storage at 9°C was sufficient to induce flower bud initiation. Pike (1986) had earlier reported that a temperature of 40°F (4.5°C) or below for 1 week was enough to induce flowering. Currah and Proctor (1990) reviewed a series of experiments to determine the optimum temperature and duration of storage of bulbs for seed production. They reported that 15 days of cold treatment at 7-8°C, no onion flowered and most cultivars responded to increase in cold storage duration from 30 to 75 days with increase in seed yield. At storage temperatures of 8-10°C, 75% flowering was achieved at an optimum storage duration of 90 days. Artificial cold treatment for 45 to 60 days at 7-11°C induced flowering only in some varieties.

Daylength

De Mille (1975), Hesse and Vest (1975) and Ali *et al* (1984) observed that daylength did not affect floral initiation. However, Brewster *et al* (1980) reported that use of extended daylength coupled with low temperatures (10-15°C) can accelerate inflorescence emergence. Holdsworth and Heath (1950) had earlier observed that daylength did not directly affect floral initiation but that under cool temperatures, long days favoured emergence of flowers and elongation of flower stalk. At temperatures high enough to promote bulbing (>28°C) long days suppressed inflorescence emergence (Jones and Manns, 1963).

Bulb size

Bulb size affects umbel and seed number (Currah, 1981). Bulbs weighing 80-85g were noted to produce almost twice as much seed per bulb as those weighing 20-25g. She also reported an experiment using 3 lines of Rijnsburger onions with bulbs of equal sizes where one selection produced more flower stalks and a higher seed yield than the others. Flower stalk number was directly related to bulb size within each line. Chang *et al* (1987) reported that a positive correlation exists between bulb size and number of flower stalks produced per bulb. They found that bulbs of cultivar Taiwan No. 1 weighing 100-150g, 150-200g and 200-250g had an average number of flower stalks per bulb of 2.3, 2.8 and 3.5, respectively. Peters (1990) noted that larger bulbs gave a higher seed yield per plant and allowed easier selection for bulb-shape and bolt-resistance than smaller ones. However, large bulbs have inferior shelf-life (Stow, 1975b). Thus medium sized bulbs should be used for seed production. Peters (1990) reported that the diameter of bulbs commonly used for seed production is 4 to 6 cms.

Plant growth regulators

Attempts to promote flowering using growth regulating chemicals has been made. In Israel, Naamni *et* *al* (1980) investigated the effect of treating mother bulbs with gibberellic acid (GA_3) when the first flower stems were emerging. A single application of GA_3 at 50 ppm reduced the time to 80% floral stem emergence by half and improved the uniformity of seed stalk height. They also reported 30% increase in seed yield. Levy *et al* (1972) and Corgan (1975) showed that spraying ethephon on plants which were coming to flower reduced overall seed stalk height and decreased the amount of lodging. Best timings and application rates, however, have to be ascertained because ethephon can cause reduction of the number of flower stalks. In Mexico, Corgan and Montano (1975) observed that application of GA_3 at 1000 ppm onto the onion plants increased flowering percentage and seed yields. Maleic hydrazide suppresses flowering by inhibition of the terminal meristems (Naamni *et al*, 1980), thus cannot be used in onion seed production.

2.2.4 **Methods of onion seed production**

Two methods, seed-to-seed and bulb-to-seed, can be used in onion seed production (George, 1985 and Peters, 1990). In the seed-to-seed method, onion bulbs get their chilling requirements in the field during winter. Unfortunately, in the tropics we do not have sufficient low temperatures to induce flowering. Consequently, only bulb-to-seed method, which requires artificial vernalization can be used. Currah and Proctor (1990) and

Peters (1990) noted that bulb-to-seed method allows selection for quality and storage ability.

2.2.5 Prospects of onion·seed production in Kenya.

Until recently little attention had been paid to onion seed production in Kenya. With increased demand for vegetable crops, onions have assumed a lot of importance in both rural and urban centres.

Cook (1963) identified the lack of locally produced onion seed as a major constraint to onion production in Kenya. He described the various attempts that were made to produce onion seeds, such as cutting back the tops and use of immature bulbs, with little success. He concluded that onion breeding in Kenya will depend on development of a method to induce flowering in onion plants.

Combes (1982), attributed vegetable crops vernalization requirement to induce flowering as one of the major reasons hampering self-sufficiency in vegetable seed-production in Kenya. He suggested that the solution to this problem depends on a long-term selection programme to provide varieties which would flower more readily under local conditions and still retain the desirable fresh vegetable characteristics.

2.3 SHELF-LIFE IN ONIONS

2.3.1 Cultivar selection for better shelf-life

Jones and Manns (1963) reported that under all storage conditions, onion bulbs continually lose water and dry matter, but the most serious losses arise from storage rots, sprouts and rooting. Warm and humid conditions prevail in the tropics making storage of onions difficult.

The onion bulb is delicate and perishable, thus must be adapted to the poor storage conditions in the tropics. Selection for better storing cultivars, therefore, is essential for consumption and seed production. The only method of screening for better shelf-life is with storage trials (Pike, 1986). This is because storage life of onion is influenced by many factors.

To improve storage quality in onion bulbs, cultural practices, chemical and physical methods of minimizing bulb loss should be studied. However, the most successful method of minimizing storage loss is by cultivar selection and improvement. In Israel Peters *et al* (1989) reported that continuous selection for better shelf-life has resulted in the release of short-day cultivars with improved storage quality both under tropical and temperate conditions.

2.3.2 Factors affecting shelf-life in onions.

Cultural factors and harvesting

Excessive nitrogen application and late irrigation in the growing season produces thick necked bulbs with high levels of neck rot in store (Jones and Manns, 1963 and Currah and Proctor, 1990). Sypien *et al* (1971) observed that high doses of N application (300 kg N/ha) resulted in a lot of bottle-neck onions. Small doses of N caused small number of bottle neck onions in the yield. Kale *et al* (1990b) reported that high levels of irrigation and late irrigation in the growing season resulted in significant increase in bulbs that sprouted or rotted in store. Irrigation should be stopped 2-3 weeks prior to harvesting.

Many workers have suggested use of growth regulators such as maleic hydrazide and ethrel for increasing the shelf-life of onions (Thompson, 1982, Chang *et al.*, 1987; Currah and Proctor, 1990; Dutta *et al* 1990). Maleic hydrazide is the one commonly used though Chang *et al* (1987) indicated that it can only be used on bulbs for commercial production and not bulbs intended for seed production. It is used as a foliar spray in the field prior to harvesting. Ward and Turker (1976) reported that maleic hydrazide not only reduces sprouting but also further reduces respiration rates.

Harvesting should be done when the 'neck' of the bulbs is tight and leaves fallen over. The tight 'neck' forms a neck which prevents entry of pathogen. Ward (1979), Tucker and Drew (1982) observed that delayed harvesting led to increased sprouting and rotting in store.

Curing

Chang *et al* (1987) and Thompson (1982) reported that curing reduces loss through rotting by removing excess moisture from the outer skin and neck of the onions. Kale *et al* (1990b) observed that cured bulbs had less storage losses than uncured bulbs. Field curing (2-3 weeks) and artificial curing (14-17 days at 16-27°C with >65% RH) are the recommended methods of curing (Salunkhe and Desai, 1984).

Storage conditions

Storage conditions are also very crucial in influencing shelf-life of onions. Karmarkar and Joshi (1941) investigated the effects of different temperatures on the storage behaviour of onions. They noted that sprouting and root growth increased with increase in storage temperature from 0°C to 10°C. Stow (1975 a and b) noted that high temperatures (>25°C) minimised storage losses through sprouting. Sprouting increased with increase in temperature reaching maximum at 15°C and decreased with subsequent increase in temperature (Ward, 1976). The little sprouting at temperatures above 25°C is due to respiration or water loss. Low temperature (-1 to 2°C) and high temperature (>25°C) keep onion bulbs dormant and prolong shelf-life. (Brewster, 1977).

According to Jones and Manns (1963) relative humidity ranks second to choice of cultivars in influencing bulb keeping quality. High humidity reduces loss through dessication but increases fungal rotting (Stow 1975a). Low humidity results in water loss and sound skins are essential to prevent dessication.

Thompson *et al* (1972) recommended onion storage conditions of 0 °C with 70-75% relative humidity whereas Stow (1975a) recommended 30 °C and relative humidity at 50-80%.

Genetic Factors.

Cultivars

Keeping quality of onions in storage varies greatly between different cultivars (Foskett and Peterson, 1950; Stow, 1975b; Kale *et al*, 1990a). Although shelf-life of onions is affected by cultural factors, Jones and Manns (1963) and Thompson (1982) observed that different cultivars tend to assume the same relative position for storage quality regardless of how they have been grown or stored. Cultivar variation may be attributed to differences in biochemical constituents, bulb size or even dormancy. The latter varies between cultivars (Jones and Manns, 1963 and Thompson, 1982). Stow (1976) and Brewster (1977) observed that dormancy of an onion bulb is determined by its hormonal balance and it can be extended by very low temperatures (-1 to 2°C) or high temperatures (>25°C).

Dry Matter Content

Dry matter content of bulbs differ greatly between cultivars (Brewster, 1977). Foskett and Peterson (1950) had earlier done correlation studies between dry matter content and shelf-life in some onion varieties and hybrids. They noted that the onion bulbs with high dry matter had better shelf-life. Recently a number of workers have associated high dry matter content with good shelf-life (McCollum, 1968; Chang *et al.* 1987; Currah and Proctor, 1990). Dry matter content in bulb varies between low levels of 7-10% to high levels of 15-20% (Currah and Proctor, 1990).

Bulb Size

Bulb size has also been correlated with shelf-life in onion bulbs. This trait can be genetic or it can be controlled by varying plant density or amount of nitrogen fertilizer. Karmarkar and Joshi (1941) observed that sprouting was higher in large sized onions than the small sized ones. Stow (1975b) working on cultivars Wijbo and Rijnsburger reported that rotting of bulbs was more prevalent in large ones. Tucker and Morris (1984) using two cultivars of the Rijnsburger group (Bola and Robusta) noted that the best cultivar for storage was the one which bulbed early resulting in small sized bulbs. Kale *et al* (1990a) while screening the keeping quality of some tropical onion varieties, observed that total storage losses were positively correlated with the neck-thickness and bulb size.

Pungency

Pungency in onions is caused by volatile flavour compounds, mainly pyruvates, released when onion tissues are damaged. Bajaj *et al* (1990) reported that pyruvic acid content and pungency are correlated. Chang *et al* (1987), Currah and Proctor(1990) associated good shelf-life with onion bulbs with high pungency and high pyruvic acid content.

Skin quality and colour

Skin splitting and physical injury reveals the fleshy scales underneath the dry protective scales. Physical injury results in undesirable softening of the damaged tissues thus enhancing decaying. It also provides an avenue for microorganism attack. Apeland (1971) demonstrated that the loss of skin doubles the rate of weight loss in store due to dessication and also promoted sprouting. In Nigeria, Amans and Kadams (1990) associated bulb colour with shelf-life. They reported that red-skinned bulb onions had better shelf-life than light skinned ones. In India, Bajaj *et al* (1990) observed that red varieties with high dry matter content and low total soluble solids are desirable for storage. However, Bleasdale *et al* (1969), Tucker and Drew (1982) had earlier reported that skin colour had no effect on storage performance.

CHAPTER III

MATERIALS AND METHODS

3.0 Experiment 1 - Genotype-environment interaction

3.1.1 Plant materials

Eight new and three existing cultivars were used in the study. They differed in yield, maturity, shape, bulb colour and shelf-life. The new cultivars were received from the onion breeding program at Hebrew University of Jerusalem, Rehovot and Hazera research department, Hazera (1939) Ltd, SdehGat, Israel.

New Cultivars

KON1 - (Arad)

An Israel hybrid released in 1986 by Hazera Seed Company. The variety is light brown in colour with a thick, tight adhering skin. It is a flattened globe and medium maturing variety (174 days).

KON2 -(H-710)

An early maturing hybrid (169 days) with yellow/brown delicate skin. It has a long shelf-life.

KON3 - (Granex)

A medium maturing hybrid (172 days) with large bulbs. The skin is yellow and delicate.

KON4- (Sivan)

A large reddish brown skinned and early maturing hybrid (169 days). It is flattened globe in shape with a shelf-life of 6-7 months.

KON5 -(H-508)

An early (167 days), high yielding hybrid with mild firm fresh. The rounded top bulbs are medium large and yellow skinned, which store well under ambient conditions for 4-5 months.

KON6 - (Early Red)

Bright red bulbs which are globe shaped with mild flavour. Early maturing (169 days) open pollinated variety.

KON7 - (Grano no. 4)

A medium early maturing (175 days) variety with large straw yellow bulbs. High yielding with shelf-life of 4-5 months.

KON8 - (Red Synthetic)

A medium to late (181 days) maturing open pollinated variety. Has a dark red, thick tight adhering skin. Moderately pungent and firm fresh.

Existing Cultivars

Bombay Red (BR)

A small to medium sized, globe-shaped, purplish cultivar. It was developed in the Indian sub-continent. The variety is suitable for dry and warmer condition with a maturing duration of 173 days.

Red-Creole (RC)

A popular variety in Kenya that is resistant to purple blotch. It is red skinned, flat-round in shape and pungent in taste. Has good keeping quality and maturing period of about 178 days.

Tropicana Hybrid (HT)

A high yielding F_1 hybrid with large, red, thick-flat onion bulbs and firm pungent fresh. The cultivar matured in 177 days.

3.1.2 Location

The experiment was conducted for two seasons during the 1990 long rains and 1990 short rains. During the long rains, the eleven cultivars were grown at three sites, namely Kabete field station (Nairobi district), Kibirigwi Irrigation Scheme (Kirinyaga district) and Oljorok (Nyandarua district). In the short rains, the experiment was conducted at four locations: Kabete (Nairobi-district), Kibirigwi (Kirinyaga district), Oljorok (Nyandarua district) and Marigat (Baringo district). All the four locations are in different agroecological zones differing in soils, temperatures, rainfall and relative humidity. They are all in onion growing areas in Kenya.

Marigat is situated 100 km from Nakuru. It is in agroecological zone (AEZ) IL6 at an altitude of 1065 meters above sea level. It lies between latitude 0.5° North and longitude 36° East. The area has semi-arid climatic conditions with an annual rainfall of 652 mm and an annual mean maximum and minimum temperature of 31°C and 24°C, respectively. Weather conditions during the period of study are given in appendix VII. Soils are well drained, very deep, brown to greyish brown, calcareous, saline and often sodic, firm, fine sandy loam to clay loam (Jaetzold and Schmidt, 1983).

Kabete is on latitude 11 4'20"S longitude 36°45'E and at an altitude of 1820 metres above sea level. The average annual rainfall for Kabete is 1046 mm. The area has a mean maximum temperature of 23°C and minimum of 12°C (K.M.D., 1985). Details of weather data during period of study are shown in Appendix VIII. The dorminant soils are well drained, very deep, dark reddish brown, friable clay (Siderius, 1976).

Oljorok almost lies on the equator at a latitude of 0°25'S and longitude of 36° 2'E. It is in AEZ Upper

Highland (UH_3) at an altitude of 2371 metres above sea level. The station has an annual rainfall of 977 mm and an annual mean temperature of maximum 21.2°C and minimum of 6.8 °C. Weather data for period of study is shown in Appendix IX. The soils are well drained, deep to very deep, very dark greyish brown to dark brown, friable and slightly smeary clay loam (Jaetzold and Schmidt, 1983).

Kibirigwi irrigation scheme is at an altitude of 1400 metres above sea level between latitude 0^0 30'S and longtitude 37° 30'E. The area has a bimodal rain pattern. The annual average rainfall is 1100 mm with a mean annual temperature of 21.3°C. Weather data during period of study is given in appendix X. The soils are ferrisols with dark brown to dark reddish brown friable clay to clay loams, which are fertile, very deep and well drained (Ministry of Agriculture,Project proposal,1980).

Njabini Farmers Training Centre is in Nyandarua district in AEZ UH_2 at an altitude of 2530 metres above sea level. The site has a mean annual temperature of 12-14°C and an average rainfall of 1219 mm (Fertiliser Use Reccommendation Project,F.U.R.P,1987). Weather data for period of study is shown in Appendix XI. The soils are moderately deep to deep, yellowish red to dark reddish brown in colour, and consists of friable and slightly smeary clay with a thick humic top soil (F.U.R.P., 1987).

3.1.3 Culture and Experimental Design

The seeds for all the cultivars were sown in nursery beds at the University Farm, Kabete, Nairobi on February 18, 1990 and fertilized with CAN at a rate of 100 kg ha^{-1}. The seedlings were transplanted when they were approximately 50 days. Seedlings for the first sowing were transplanted to fields in three locations, Kabete, Kibirigwi and Oljorok on April 9, 11 and 14, respectively. Seeds for the second season were sown on July 25 and transplanted to four locations; Kibirigwi, Marigat, Kabete and Oljorok on October 9, 10, 11 and 14, respectively.

At each location the experiment was laid out in a randomized complete block design with five replicates. Plots were 0.9 m wide and 3 m long. Seedlings were transplanted at a spacing of 8 cm within rows and 30 cm between rows, a plant density of 56 plants/m^2. Three guard rows were planted around the experimental plot. Diammonium phosphate (D.A.P) was applied at 200 kg ha^{-1}.

To control purple blotch, the crop was sprayed with dithane M-45 at a rate of 50 g in 20 litres of water at 7 days intervals. Ridomil was sprayed to control downy mildew at a rate of 3.5 kg/ha at 14 days intervals. Thrips were controlled by spraying rogor L40 at a rate of 1.5 l/ha as necessary The crop was kept weed-free and irrigated when necessary. Irrigation was stopped three weeks before harvesting.

Harvesting was done when more than 50 percent of the tops had fallen.

3.1.4 Data Collection

Data was collected on the following traits:

(a) **Maturity**

The date when more than 50% of the tops had fallen. Expressed as the number of days from the date seeds were sown in the nursery.

(b) **Bulb yield**

The total weight of bulbs harvested from 0.9 x 3.0 m^2 plot expressed in tons ha^{-1}. Weight of bulbs from the three guard rows was not considered.

(c) **Bulb weight**

Ten bulbs were randomly selected and weighed in each plot. The mean of all the bulbs was taken to give weight of individual bulb in grams.

(d) **Bulb shape**

Expressed as shape index, is the ratio of diameter to height in cms. Height was measured as the vertical distance from the base plate to the neck constriction at a point where curvature changes from convex to concave. Diameter was recorded as the greatest bulb diameter on a horizontal plane. Measurements were made with a vernier calipers.

(e) **Dry-matter content**

A hand-held refractometer (HRN-32 model) manufactured by KrÜss,Tokyo,Japan, was used to determine soluble solids, which provides a good estimate of dry matter (Foskett and Peterson, 1950; Pike, 1986; and Currah and Proctor , 1990). Ten bulbs were randomly selected and a single drop of juice squeezed out of each bulb onto the glass plate of the refractometer. The refractometer reading gave percentage dry matter.

3.2 Experiment II: Shelf-life studies.

3.2.1 Materials

Bulbs of the eight new and three existing cultivars grown at Kabete, Kibirigwi, Oljorok and Marigat during the 1990 - long rains and 1990-91 short rains, were used in this study.

3.2.2 Methods

Storage trials were used to assess the shelf-life of the cultivars in the field station, Kabete. The first storage trial was initiated on October 1, 1990 using bulbs harvested from Kabete, Kibirigwi and Oljorok sites during the 1990 long rains. The second storage trial, was begun on March 23, 1991 and May 2, 1991 using bulbs harvested from Kabete, Marigat, Kibirigwi and Oljorok, respectively. The cultivars were assessed for their keeping quality for a duration of four months.

The bulbs were cured for at least three weeks before they were selected for uniformity in size. Bulbs with a diameter greater than 3.0 cm were used in the study. Mishapen and split bulbs were discarded. Sound bulbs of each cultivar from each site were placed on perforated aluminium storage racks (Plate 2) in three batches of 60 bulbs. The bulbs were well spread out on the storage racks to allow free circulation of air. The experiment was done at room temperature (20.9-21.9°C) in a ventilated room.

Experimental design

The storage trial was in a randomized complete block design in three replicates. Each replicate consisted of sixty bulbs for both trials.

3.2.3 Sampling

Number of bulbs that had external symptoms of rotting and sprouting after every ten days were recorded. Number of bulbs rotted or sprouted was expressed as percent cumulative bulb loss.

3.3 Experiment III - Seed production

3.3.1 Locations.

Seed production experiment was conducted at four locations: Kabete (Nairobi district), Kibirigwi (Kirinyaga district), Marigat (Baringo district) and Njabini farmers training centre in Nyandarua district.

3.3.2 Materials

Mother bulbs of the eight new and three existing cultivars harvested in August, 1990 and February, 1991 were used in the study. The bulbs were stored at different temperature regimes for a period of eight weeks, then planted to fields in the four sites for two seasons.

3.3.3 Methods

Seeds were produced by the bulb-to-seed method. Bulbs were harvested at maturity and selected for uniformity in size.They were cured for three weeks . Bulbs of diameter 4 - 6.5 cm were used in this study.

In the first seed production trial (1990), bulbs obtained from 1990 trials were stored for 8 weeks at four temperature regimes: 0°C, 10°C, in a well ventillated storage room (13.4°C) at high altitude location (Njabini - 2530 m), and at room temperature (20.9°C), Kabete (1820 m). Bulbs obtained from the 1991 trials were used in the second trial.

Plate 2: Onions in storage racks at University Field Station, Kabete (1990) :

They were stored for the same duration at 5°C, 10°C, room temperature, Kabete (21.9) and Njabini (14.4). The temperature regimes of 0°C and 10°C (both trials) were achieved by using refrigerated incubators at Faculty of Agriculture, Kabete Campus. Temperature regime of 5°C for the second trial was achieved by using a cold room, at Tigoni Potato Research Centre, maintained at a constant temperature.

During the storage period for the first trial mean monthly temperature of 18.0°C and 16.4°C were recorded at Kabete and Njabini, respectively. Mean monthly temperature of 19.2°C at Kabete, 14.7°C at Njabini were recorded during the storage period for the second trial.

After the 8 weeks of storage, bulbs were retrieved and planted at four locations for both seasons. Prior to planting, the bulbs were dipped in a Ridomil solution (140 g/20 l of water) to reduce the incidence of rotting in the soil. DAP was applied as a basal fertilizer at a rate of 200 kg ha^{-1}. At about 4 weeks after planting the bulbs, they were top dressed with CAN at a rate of 115 kg ha^{-1}. The crop was kept weed-free and irrigated after every two weeks. Thrips were controlled by spraying Rogor L40 (Dimethioate) at a rate of 1.5 litres ha^{-1} as necessary. Ridomil M2 at a rate of 3.5 kg ha^{-1} at intervals of 14 days and dithane at a rate of 2 kg ha^{-1} at 7-10 days interval were used to control downy mildew and purple blotch, respectively.

3.3.4 Locations and Experimental Design

After storage, bulbs were planted at Kabete, Kibirigwi, Marigat and Njabini. Bulbs of the first trial were planted on Dec. 4, 5, 6 and 7, 1990 at Njabini, Marigat, Kabete and Kibirigwi, respectively. In the second trial, bulbs were planted on May 10, 18, 17 and 25, 1991 at Kibirigwi, Marigat, Njabini and Kabete respectively.

The experimental design was a split-plot design, with cultivars as the main plots and storage temperature as sub plots, with three replicates. Bulbs were spaced at 45 cm betwen rows and 10 cm within rows in plots of 3 m long and 3.2 m wide. Each temperature treatment had twenty bulbs per plot. Honey bee hives were placed near the onion fields to provide bees for pollination.

Seeds were harvested when they opened to reveal the black seeds. After drying in incubators at 20-25°C for two weeks, the seeds were threshed by hand and cleaned to remove chaff.

3.3.5 Data Collection

Data was recorded on the following traits.

(a) **Flowering date**

Days from planting the bulbs to the date when 50% of the inflorescences had their spathes open

(b) **Length of seed stalk**

The flower stalk height was measured, from where it attaches to the bulb to where it is attached to the umbel, in centimetres.

(c) **Number of umbels per mother bulb**

Ten mother bulbs were randomly picked, the number of umbels on them counted and mean number of umbels $bulb^{-1}$ calculated.

(d) **1000-Seed weight**

A thousand seeds per replicate in each trial were counted and weighed. Weight was expressed in grams.

(e) **Seed-yield**

The amount of seeds harvested from an area of 9.6 m^2 were weighed and expressed in kg ha^{-1}.

(f) **Percentage germination**

Four hundred seeds of each cultivar per treatment on location basis were subjected to a germination test on moist filter paper at 24°C.

3.4 Data analysis

3.4.1 Experiment I - Genotype-Environment Interactions and Stability Analysis

3.4.1.1 Analysis of variance

Each location in a given season was considered as an individual environment. The data from each environment was subjected to analysis of variance and then a combined analysis for all the environments was done as shown in Appendix I and II, respectively. Prior to combined analysis, Bartlett's test (Steel and Torrie, 1980) was used to test homogeneity of variances.

The F-tests for the environment-wise analysis and combined analysis were done as shown in Appendices I and III, respectively. The pooled error was used to test for the significance of variance due to genotype x environment interaction. If this variance was found to be significant, the data was subjected to stability analysis as outlined by Eberhart and Russell (1966).

3.4.1.2 Linear Model

Locations were assumed to be random and cultivars fixed effects. Data was analysed according to the model:

$$Y_{ijk} = \mu + g_i + \beta_j + (g\beta)_{ij} + E_{ijk}$$

Where i = 1, 2.........11

j = 1, 2......... 7

μ = Overall mean at all locations sampled

g_i = Effect of the ith variety, with restriction Σg_i

= 0

β_j = Random effects of the jth environment sampled from a population of mean zero and variance $\delta^2\beta_j$, $\Sigma^{\beta j}=0$

$g\beta)_{ij}$ = Interaction effect of the ith variety in jth environment with a restriction of $(g\beta)_{ij}$ and variance $\delta^2_{g\beta}$

E_{ijk} = Random error with mean zero and variance δ^2_e.

3.4.1.3 Eberhart and Russel Model (1966)

Eberhart and Russell (1966) model derives the stability parameters from the regression approach. Performance of each genotype was regressed on the environmental indices to give the stability parameters. The stability parameters were defined according to the model:

$$Y_{ij} = M + \beta_i I_j + \delta_{ij}$$

Where i = 1, 2.......11

j = 1, 2....... 7

Y_{ij} = variety mean of the ith variety at the jth environment.

M = mean of the ith variety over all environments.

β_i = regression coefficient that measures the response of the ith variety to varying environments.

δ_{ij} = deviation from regression of the ith variety at the jth environment.

I_j = environmental index defined as the difference between the marginal mean of the environments and the overall mean.

In this model, regression coefficient (b_i) and the deviation from regression (δ_{ij}) provide estimates of the stability parameters. These parameters are estimated as follows.

$$b_i = \frac{\sum_j Y_{ij} I_j}{\sum_j I_j^2} \qquad S^2 d_i = \frac{\sum_j \delta_{ij}}{(S-2)} - \frac{S_e^2}{r}$$

Where S_e^2 = the estimate of pooled error.

$$\sum_j \delta^2_{ij} = (\sum_j Y^2_{ij} - \frac{Y^2_{i.}}{t}) - \frac{(\sum_j Y_{ij} I_j)^2}{\sum_j I_j^2}$$

According to this model, a stable genotype is the one with high mean over environments, unit regression coefficient (b_i = 1.00) and the deviations from regression of zero ($S^2 d_i$ = 0). The analysis of variance of this model is as shown in Appendix IV. Statistical references for main effects, interactions and pooled error are shown in Appendix III (McIntosh, 1983). Pooled error was estimated as the pooled error over all the environments averaged over the number of replicates. The hypothesis that any regression coefficient does not differ from unity was tested by the t-test (Steel and Torrie, 1980).

3.4.2 Experiment II - Shelf-life

3.4.2.1 Analysis of variance

The locations where cultivars were grown were considered as different environments. Data from each storage trial was analysed separately to determine the significance of main and interaction effects (Table 1). Prior to the analysis, the percentage storage loss data was transformed into arcsins because the range of percentages between the lowest and highest figure was greater than forty (Little and Hills, 1978).

A combined analysis based on the mean cumulative values, for all storage trials was done. Bartlett's test was used to test the homogeneity of variances before the combined analysis. Outline of the combined analysis is shown in Appendix II.

The pooled error in the combined analysis was obtained from the means of pooled errors over all the environments. Significance of variances due to genotype x environment interactions was tested by the pooled error. Mean separation was done by least significant difference (L.S.D at 0.05).

3.4.3 Experiment III - Seed Production

Anova was performed for the data from each trial (Appendix V). In the analysis, varieties were taken to be the main plots and storage temperature the subplots.

In the combined analysis (Appendix VI), varieties and storage temperature were assumed to be fixed effects (McIntosh, 1983). The sum of squares for replicates and experimental errors (main plot and sub plot errors) are equal to the totals of these items in the individual analysis (Gomez and Gomez, 1984). Appropriate F-tests are as shown in Appendices V and VI.

Table 1: Source of variation, degrees of freedom, mean squares and F-test for eleven onion cultivars grown in seven environments and stored at room conditions for four months in Kenya, 1990-1991.

Source of variation	Degrees of freedom	Mean sum of squares	F-test
Replicates (R)	(R-1)	M1	M1/M4
Cultivars (V)	(V-1)	M2	M2/M5
Sampling dates (D)	(D-1)	M3	M3/M5
Cultivars x sampling dates	(V-1) (D-1)	M4	M4/M5
Error	(R-1) (VD-1)	M5	

RESULTS

4.1 EXPERIMENT 1: GENOTYPE-ENVIRONMENT INTERACTIONS

4.1.1 Mean Performance

Combined analysis for all the traits is given in Table 1. The environmental effects were significant for all the traits indicating the variability of the seven environments. Genotypic effects were highly significant for all traits except maturity while genotype-environment interactions were highly significant for all traits. The significant genotype-environment interactions indicated that ranking of the cultivars on the basis of their performance differed with locations.

4.1.1.1 Maturity

Days to 50% foliar down are shown in Table 3. KON8 was the latest maturing cultivar in 1990 while KON5 was the earliest. At Kabete (1990) KON5 matured in 158.4 days and KON8 matured in 178.4 days. KON1 was the latest maturing cultivar (169.2 days) and KON6 was the earliest (155.8) at Kibirigwi in the same year. At Oljorok the earliest and latest maturing cultivars were KON4 (180.4 days) and KON8 (210.4 days), respectively. Cultivars matured earliest at Kibirigwi and latest at Oljorok in 1990. In 1991, Red Creole matured latest over all the four environments while KON2 matured earliest. KON5 was the earliest (154.8 days) and Red Creole latest maturing cultivar (178.4 days) at Kabete. At Kibirigwi latest and earliest maturing cultivars were Tropicana Hybrid (175

Table 2: Means squares from combined analysis of variance for five traits of eleven onion cultivars grown in seven environments in Kenya, 1990-1991.

Source of variation	D.f.	Bulb-yield (tons ha^{-1})	Bulb-weight (grams)	Days to maturity	Percent dry matter content	Shape index $x10^{-1}$
Environments	6	1249.0**	8820.9**	2065.5**	7.2*	71.0**
Reps. within environments	28	18.8	71.6	61.4	21**	1.5
Genotypes	10	327.0**	3348.4**	415.1	26.3**	590.0**
G X E	60	79.1**	510.4**	502.0**	0.6**	17**
Pooled error	280	2.7	36.7	6.1	0.2	0.2

*, **, Significant at 5 and 1 percent probability levels, respectively

Table 3: **Days to maturity of eleven onion cultivars grown in seven environments in Kenya, 1990-1991**

	1990			1991				
Varieties	Kabete	Kibirigwi	Ol Jorok	Kabete	Kibirigwi	Ol Jorok	Marigat	Mean
KON1	177.6 ┼(2)	169.8 (1)	191.2 (4)	161.4 (7)	156.8 (9)	206.8 (7)	153.6 (6)	173.9 (5)
KON2	174.8 (3)	167.0 (4)	186.2 (8)	158.0 (9)	153.2 (11)	198.8 (8)	146.0 (10)	169.1 (9)
KON3	170.8 (6)	159.8 (10)	196.8 (3)	163.4 (6)	156.4 (10)	207.0 (5)	153.3 (7)	172.4 (7)
KON4	160.4 (10)	169.2 (2)	180.4 (11)	160.4 (8)	158.0 (8)	207.8 (4)	149.8 (4)	169.4 (6)
KON5	158.4 (11)	162.4 (8)	188.0 (6)	154.8 (11)	161.6 (4)	202.0 (8)	144.6 (11)	167.4 (11)
KON6	171.2 (5)	155.8 (11)	184.8 (9)	158.0 (9)	159.2 (6)	198.4 (10)	152.2 (8)	168.5 (10)
KON7	167.6 (7)	163.8 (5)	205.6 (2)	165.8 (5)	159.0 (7)	211.0 (3)	154.2 (5)	175.3 (4)
KON8	178.4 (1)	167.4 (3)	210.4 (1)	174.2 (3)	161.6 (4)	215.4 (1)	159.2 (4)	180.9 (1)
Red Creole	161.2 (9)	162.8 (7)	188.3 (5)	178.4 (1)	170.8 (2)	212.6 (2)	172.6 (1)	178.1 (2)
Tropicana Hybrid	172.0 (4)	160.0 (9)	182.3 (10)	177.8 (2)	175.0 (1)	207.2 (6)	162.0 (2)	176.6 (3)
Bombay Red	166.0 (8)	163.0 (6)	186.3 (7)	172.4 (4)	162.8 (3)	197.4 (11)	160.4 (3)	172.6 (6)
Mean	169.0	163.7	191.1	165.9	161.3	205.9	155.3	170.6
C.V. %	2.7	4.9	2.4	2.7	2.9	3.3	2.9	3.1
L.S.D.(0.05)	5.9	10.7	5.2	6.0	6.4	7.3	6.3	6.8

┼ Ranks are given in parenthesis.

days) and KON2 (153.2 days), respectively. KON8, matured in 215.4 days at Oljorok, while the earliest cultivar was Bombay Red (197.4 days). Latest maturing cultivar at Marigat was Red Creole (172.6 days) while earliest was KON5 (144.6 days). In this year, cultivars matured earliest at Marigat (155.3 days) and latest at Oljorok (205.9 days).

In 1990, the existing cultivar matured earlier than most of the exotic cultivars. Red Creole, the earliest maturing existing cultivar in 1990, matured at the same time with KON6 which was the earliest among new cultivars. In 1991, all the existing cultivars matured later than the new cultivars. KON2 which was the earliest among new cultivars had a mean of 164 days to maturity while Bombay Red matured in 173.3 days. The latter was the earliest maturing cultivar among the existing ones in 1991. There was not much difference in maturity between the two years.

The earliest maturing cultivar over all the environments was KON5 (169.4 days). KON8 recorded the longest maturity period (181 days) over all environments. Among the new cultivars KON5 was the earliest to reach maturity (167.4 days) while KON8 was the latest (180.9 days). Most of the new cultivars except KON5, KON6 and KON8 were comparable in maturity to the existing cultivars. All cultivars matured earliest at Marigat (155.3 days) and latest at Oljorok (205.9 days).

4.1.1.2 Bulb-shape

Shape-indices over environments are indicated in

Table 4. There were significant differences for this trait among the cultivars. There was no variation in bulb shape with environment. At Kabete and Oljorok in 1990, bulbs were nearly globe-shaped (i.e. diameter equal to height). At Kabete and Oljorok in 1990, all varieties were nearly globe-shaped except KON2, KON4 and KON5 which tended towards flat shape. At Kibirigwi, KON6, KON7 were flat-shaped while Red Creole and Bombay Red were oval-shaped. There was not much variation in bulb shaped among the three sites. Most of the onion bulbs were globe-shaped.

In 1991, bulbs at Kabete were globe-shaped except those of KON1, Tropicana Hybrid and Bombay Red which were flat shaped. KON5 and KON6 were oval-shaped. Bulbs were round shaped at Kibirigwi except KON2, KON4, KON6 and KON7 which were oval-shaped. Bulbs of KON5, KON6, KON7 and Red Creole were flat-shaped at Oljorok while the rest had nearly ideal shape. At Marigat it was only the bulbs of KON3, KON5, KON6 and KON7 that were oval-shaped. The rest were nearly globe-shaped. There was not much variation in bulb-shape between these four sites in 1991.

However, there was no variation in bulb-shape between the two years. Bulbs of 1990 were nearly round-shaped while those of 1991 tended towards oval-shape. The existing cultivars tended towards globe shape than most of the new cultivars. The new cultivars with almost ideal shape were KON1, KON2, and KON3. Bulbs of Tropicana Hybrid and Bombay Red were the most ideal shaped among the existing cultivars.

Table 4: Shape-index of eleven onion cultivars grown in seven environments in Kenya, 1990-1991

	1990			1991				
Varieties	Kabete	Kibirigwi	Ol Jorok	Kabete	Kibirigwi	Ol Jorok	Marigat	Mean
KON1	0.9 (6)	1.0 (6)	0.9 (7)	1.1 (1)	0.9 (9)	1.1 (1)	1.0 (1)	1.0 (1)
KON2	1.1 (9)	1.2 (1)	1.0 (2)	0.9 (7)	0.6 (11)	0.9 (6)	0.9 (5)	1.0 (1)
KON3	1.1 (3)	1.1 (4)	1.0 (2)	1.0 (4)	0.8 (6)	1.0 (2)	0.8 (8)	1.0 (1)
KON4	1.2 (1)	1.0 (6)	1.1 (1)	0.9 (7)	0.7 (7)	1.0 (2)	0.8 (8)	0.9 (11)
KON5	1.2 (1)	1.1 (4)	1.1 (1)	0.8 (9)	0.7 (7)	0.8 (11)	0.7 (11)	0.9 (11)
KON6	1.0 (11)	1.2 (1)	1.1 (1)	0.7 (11)	0.6 (11)	0.8 (11)	0.7 (11)	0.9 (11)
KON7	1.1 (3)	1.2 (1)	1.0 (2)	0.8 (9)	0.7 (7)	0.9 (6)	0.9 (5)	0.9 (11)
KON8	0.9 (6)	0.9 (8)	0.9 (7)	1.0 (4)	0.9 (3)	0.8 (11)	1.0 (11)	0.9 (1)
Red Creole	0.9 (6)	0.8 (11)	0.9 (7)	1.0 (4)	1.0 (2)	0.8 (11)	1.0 (1)	0.9 (11)
Tropicana Hybrid	0.9 (6)	0.8 (11)	1.0 (11)	1.1 (1)	1.1 (1)	1.0 (2)	0.9 (5)	1.0 (1)
Bombay Red	1.0 (11)	0.9 (8)	0.9 (7)	1.1 (1)	0.9 (3)	1.0 (1)	1.0 (1)	1.0 (1)
Mean	1.0	1.0	1.0	0.9	0.8	0.9	0.9	0.9
C.V. %	8.9	13.0	23.8	9.5	6.7	10.1	19.6	13.1
L.S.D.(0.05)	0.1	0.2	0.3	0.1	0.1	0.1	0.2	0.2

†Ranks are given in parenthesis

4.1.1.3 Dry-matter content

Mean dry matter content (%) is shown in Table 5. Dry matter content ranged from 4.0-10.6% to 8.3-12.4% for new and existing cultivars, respectively. There was little variation in this trait over environments. However, there were significant differences among the cultivars.

In 1990 Tropicana Hybrid had the highest dry matter content in all environments; Kabete (10.6%), Kibirigwi (12.4%) and Oljorok (11.6%). At Kabete, KON3 and KON7 both recorded the lowest dry matter content of 5.7%. At Kibirigwi and Oljorok KON3 had the lowest dry matter content of 5.0% and 5.4%, respectively. In this year there was not much variation in this trait among environments.

Red-Creole had the highest dry matter content (10.5%) followed by Tropicana Hybrid (10.2%), in 1991. Red Creole had the highest dry matter content at Kabete (11.0%) and at Oljorok (11.6%). KON3 had the lowest at Kabete (5.3%) while KON4 recorded the lowest (6.8%) at Oljorok. At Kibirigwi Tropicana Hybrid had the highest dry matter content (10.9%) while KON3 had the lowest (4.8%). KON6 had the lowest (3.4%) and Tropicana Hybrid had the highest (9.2%) dry matter content at Marigat. There was significant variation in this trait among the four environments. Marigat recorded the lowest dry

Table 5: Percent dry matter content of eleven onion cultivars grown in seven environments in Kenya, 1990-1991.

	1990			1991				
Varieties	Kabete	Kibirigwi	Ol Jorok	Kabete	Kibirigwi	Ol Jorok	Marigat	Mean
KON1	8.6 (4)+	6.0 (7)	6.8 (5)	6.5 (5)	5.8 (7)	7.6 (5)	4.6 (8)	6.6 (5)
KON2	7.8 (7)	6.2 (6)	6.3 (8)	6.4 (6)	6.1 (5)	7.0 (8)	5.2 (5)	6.4 (6)
KON3	5.7 (11)	5.0 (11)	5.4 (11)	5.3 (11)	4.8 (11)	6.8 (11)	3.9 (10)	5.3 (11)
KON4	7.3 (9)	5.7 (9)	6.6 (6)	5.5 (10)	5.5 (9)	6.8 (11)	4.8 (6)	6.0 (9)
KON5	7.9 (6)	7.9 (5)	5.4 (11)	5.7 (7)	5.7 (8)	6.8 (11)	4.7 (7)	6.3 (7)
KON6	8.4 (5)	6.0 (7)	6.3 (8)	5.7 (7)	5.9 (6)	7.4 (6)	3.4 (11)	6.2 (8)
KON7	5.7 (11)	5.5 (10)	6.4 (7)	5.6 (9)	5.3 (10)	7.2 (7)	4.0 (9)	5.7 (10)
KON8	10.6 (1)	9.3 (3)	9.6 (2)	8.7 (4)	8.4 (4)	9.7 (3)	7.2 (4)	9.1 (3)
Red Creole	9.5 (3)	11.0 (2)	8.4 (4)	11.0 (1)	10.3 (2)	11.6 (1)	9.0 (2)	10.1 (2)
Hybrid Tropicana	10.6 (1)	12.4 (1)	11.6 (1)	9.8 (3)	10.9 (1)	10.9 (2)	9.2 (1)	10.8 (1)
Bombay Red	7.7 (8)	8.9 (4)	8.6 (3)	10.7 (2)	9.0 (3)	9.1 (4)	8.3 (3)	8.9 (4)
Mean	8.2	7.6	7.4	7.4	7.1	8.3	5.9	7.4
C.V. %	13.9	15.0	13.4	5.9	9.6	6.8	12.9	11.1
L.S.D.(0.05)	1.3	1.4	1.3	0.6	0.9	0.6	1.2	1.0

+Ranks are given in parenthesis

matter content (5.9%) and Oljorok the highest (8.3%).

In both years the existing cultivars had higher dry matter content than the new cultivars. There was not much variation in dry matter content between the two years. Tropicana Hybrid had the highest dry matter over all environments (10.8%) and KON3 had the lowest (5.3%). Among the new cultivars KON8 had the highest dry matter content (9.1%). Onion cultivars with high dry matter (>20%) are preferred for processing than for fresh market.

4.1.1.4 Bulb Weight

Mean bulb-weight for all environments is shown in Table 6.

In 1990 KON4 and Bombay Red had the heaviest and lightest bulbs at the three sites, respectively. KON4 (166 g) and Red Creole (83.0 g) had the heaviest and lightest bulbs respectively at Kabete. At Kibirigwi KON1 (162.5 g) had the highest mean bulb weight while Bombay Red (64 g) had the lowest. KON7 (150 g) had the highest and Bombay Red (78 g) the lowest at Oljorok in 1990. There was not much variation in mean bulb weight among the three sites.

In 1991 KON7 had the highest mean bulb weight (125.4 g) for all four locations. The cultivars with the lowest mean bulb weight at Kabete and Kibirigwi were KON8 (42.9) and Red Creole (32 g), respectively. Bombay Red had the lowest mean bulb weight at Ol jorok (40g) and KON4 had the lowest at Marigat (68.9). Marigat had maximum expression of this trait for most of the cultivars.

Table 6: Bulb weight (grams) of eleven onion cultivars grown in seven environments in Kenya, 1990-1991.

	1990			1991				
Varieties	Kabete	Kibirigwi	Ol Jorok	Kabete	Kibirigwi	Ol Jorok	Marigat	Mean
KON1	145.0 (5)+	162.5 (1)	128.5 (4)	190.0 (1)	65.0 (5)	90.0 (4)	179.0 (1)	137.1 (1)
KON2	135.0 (7)	110.0 (8)	130.0 (3)	117.0 (7)	61.0 (6)	97.0 (3)	136.0 (3)	112.3 (5)
KON3	163.0 (2)	145.0 (4)	120.0 (5)	130.0 (5)	72.0 (4)	113.0 (1)	124.0 (7)	123.0 (4)
KON4	166.0 (1)	144.3 (5)	133.0 (2)	159.0 (2)	73.5 (3)	84.0 (5)	127.0 (5)	126.7 (3)
KON5	140.0 (6)	155.0 (3)	120.0 (5)	135.0 (4)	35.0 (9)	62.0 (8)	68.0 (11)	102.1 (7)
KON6	159.0 (4)	156.6 (2)	115.0 (7)	127.0 (6)	58.0 (8)	62.0 (8)	93.0 (10)	110.1 (6)
KON7	160.0 (3)	121.0 (7)	150.0 (1)	138.0 (3)	79.5 (2)	98.0 (2)	186.0 (2)	133.2 (2)
KON8	102.0 (8)	109.0 (9)	110.0 (8)	42.0 (11)	55.0 (7)	70.0 (6)	123.0 (8)	87.3 (9)
Red Creole	83.0 (11)	140.0 (6)	90.0 (9)	64.0 (9)	32.0 (11)	50.0 (10)	130.0 (4)	84.1 (10)
Tropicana Hybrid	93.0 (10)	102.0 (10)	90.0 (9)	58.0 (10)	84.0 (1)	70.0 (6)	127.0 (5)	89.1 (8)
Bombay Red	102.0 (8)	64.0 (11)	78.0 (11)	84.0 (8)	34.0 (10)	40.0 (11)	102.0 (9)	72.0 (11)
Mean	131.6	128.1	115.0	113.1	59.0	76.0	126.8	107.3
C.V. %	13.7	12.6	14.5	11.8	9.7	9.58	15.3	12.5
L.S.D.(0.05)	18.8	17.3	19.8	16.2	13.3	13.1	21.0	17.1

+Ranks are given in parenthesis

The existing cultivar with the highest mean bulb weight in 1990 was Red Creole. Among the new cultivars KON1 had the highest. In 1991 Tropicana Hybrid had the highest among the existing cultivars while KON1 had the highest among new cultivars. 1990 had higher mean bulb weight than 1991.

The exotic cultivars had higher mean bulb weight than the existing ones during the two years. The existing cultivars had mean bulb weight below overall mean. Tropicana Hybrid (89.1 g) had the heaviest bulbs among existing cultivars for all environments. KON1 (137.1) had highest mean bulb weight among the new cultivars followed by KON7 (133.2 g). Among the new cultivars KON8 (87.3 g) had the lowest mean bulb weight. Marigat, Kabete and Kibirigwi (1990) had the highest mean bulb weight while Kibirigwi in 1991 had the lowest.

4.1.1.5 Bulb-yield tons ha^{-1}

Bulb-yield of 11 cultivars is shown in Table 7. There was significant variation for yield among the cultivars and environments. (Table 7).

In 1990, the highest yielding cultivar for the three locations was KON3 (40 tons ha^{-1}) while Bombay Red (10.2 tons ha^{-1}) was the lowest yielding. The highest yielding cultivar at Kabete was KON3 (59.2 tons ha^{-1}) and Bombay Red (12.6 tons ha^{-1}) was the lowest. The highest and lowest yielding cultivars at Kibirigwi were KON3 (41.9 tons ha^{-1}) and Bombay Red (14.7 tons ha^{-1}) respectively. KON4 (19.4 tons ha^{-1}) was the best yielding at Oljorok while Bombay Red (3.4 tons ha^{-1}) was the worst. Kabete was the best yielding environment and Oljorok was the worst in 1990.

The best yielding cultivar in 1991 was KON7 and the worst was KON6. At Kabete KON1 (53.7 tons ha^{-1}) had the highest yield followed by KON3 (46.7 tons ha^{-1}). Bombay Red (14.4 tons ha^{-1}) had the worst yield at Kabete. Best yielding cultivar at Kibirigwi was Red-Creole (17.6 tons ha^{-1}) followed by Tropicana Hybrid (16.8 tons ha^{-1}) and KON3 was the worst yielding cultivar (3.9 tons ha^{-1}). KON3 (32.2 tons ha^{-1}) and KON8 (12.2 tons ha^{-1}) were the best and worst yielding cultivars at Oljorok in 1991, respectively. At Marigat KON7 (64.4 tons ha^{-1}) was the highest yielding and KON5 was the worst (14.4 tons ha^{-1}). Marigat (35.9 tons ha^{-1}) and Kabete (34.3 tons ha^{-1}) were the best yielding environments. Kibirigwi (9.7 tons ha^{-1}) was the worst yielding environment.

The new cultivars did better than the existing ones in both years. KON3 (35.6 kg/ha) was the best cultivar among exotic ones while Tropicana Hybrid (20.7 tons ha^{-1}) was the best existing cultivar for both years. KON7 was the best yielding in 1991 but did better than KON3 which was the best yielding in 1990. Yields were higher in 1991 than in 1990. KON7 was the second highest yielding cultivar with maximum expression of this trait at Marigat (64.4 tons ha^{-1}). KON8 (20.6 tons ha^{-1}) was the worst yielding among the new cultivars though it did better than Red Creole (18.0 tons ha^{-1}) which was second best among the existing cultivars. Bombay Red bolted in all environments (Plate 3) and had the lowest mean yield for all environments except at Marigat in 1991 where it outyielded a few of the new varieties. The best yielding environment for both years was Marigat. Kabete in 1990 ranked second while the worst environment was Kibirigwi in 1991. The low yields were attributed to a severe infection of the varieties with pink-root rot disease which resulted in small sized bulbs. At Oljorok in 1990 the major problem was downy mildew which resulted in relatively low yields.

4.1.2 Analysis for Genotype x Environment Interactions

Environmental indices and mean squares from regression analysis according to Eberhart and Russell (1966) model are summarised in Table 8 and 9, respectively. There were significant differences among varieties for all the traits except shape index. Genotype x environment (linear) effects were highly significant for bulb-yield and shape index but not significant for bulb weight, maturity and dry matter. This indicated that the varieties differed in their linear responses to changes in environment for bulb yield and shape index. Deviations from regression were

Table 7: **Bulb yield (tons ha^{-1}) of eleven onion cultivars grown in seven environments in Kenya, 1990-1991.**

	1990			1991				
Varieties	Kabete	Kibirigwi	Ol Jorok	Kabete	Kibirigwi	Ol Jorok	Marigat	Mean
KON1	39.7 (6)+	33.5 (3)	17.2 (5)	53.7 (1)	8.4 (4)	23.4 (7)	53.9 (2)	32.8 (3)
KON2	37.0 (7)	27.2 (5)	14.7 (7)	33.7 (6)	7.4 (8)	28.1 (4)	40.1 (4)	26.9 (5)
KON3	59.2 (1)	41.9 (1)	18.9 (3)	46.7 (2)	6.2 (9)	32.2 (1)	44.3 (3)	35.6 (1)
KON4	52.4 (2)	38.7 (2)	19.4 (1)	36.5 (4)	7.7 (7)	27.8 (5)	23.6 (8)	29.4 (4)
KON5	42.0 (4)	20.7 (8)	19.1 (2)	27.4 (9)	3.9 (11)	31.1 (2)	14.4 (11)	22.7 (6)
KON6	39.8 (5)	25.0 (6)	14.9 (6)	21.8 (10)	6.03 (10)	25.3 (6)	23.6 (8)	22.3 (7)
KON7	49.4 (3)	28.7 (4)	17.7 (4)	44.1 (3)	8.2 (5)	30.6 (3)	64.4 (1)	34.7 (2)
KON8	22.8 (8)	22.8 (7)	8.1 (8)	31.3 (8)	8.2 (5)	12.2 (11)	38.4 (5)	20.6 (9)
Red Creole	15.7 (9)	18.4 (9)	4.2 (10)	32.1 (7)	17.6 (1)	14.9 (10)	23.1 (10)	18.0 (10)
Tropicana Hybrid	13.3 (10)	17.2 (10)	4.7 (9)	35.7 (5)	16.8 (2)	19.2 (9)	38.1 (6)	20.7 (8)
Bombay Red	12.6 (11)	14.7 (11)	3.4 (11)	14.4 (11)	16.6 (3)	21.2 (8)	30.5 (7)	16.2 (11)
Mean	34.9	26.2	12.9	34.3	9.7	24.2	35.9	25.5
C.V. %	2.8	7.9	3.7	4.1	2.1	4.5	5.5	4.4
L.S.D.(0.05)	8.6	24.2	11.4	12.4	6.6	28.0	17.0	15.5

+Ranks are given in parenthesis

Plate 3: Bombay Red bolting at Perkerra Irrigation Scheme, Baringo district.

Table 8: **Environmental indices for eleven onion cultivars grown in seven environments in Kenya, 1990-1991.**

Environment	Bulb yield (tons ha^{-1})	Bulb weight (g)	Days to maturity	Percent dry matter x 10^{-1}	Shape index x10^{-2}
Kabete 1990 Long rains	9.5	24.6	-4.2	7.8	8.0
Kibirigwi 1990 Long rains	0.8	21.0	-9.4	2.4	8.7
Ol jorok 1990 Long rains	-12.5	7.9	17.8	0.1	5.6
Kabete 1990-91 Short rains	8.9	-31.1	-7.3	-0.4	-0.2
Kibirigwi 1990-91 Short rains	-15.7	-48.1	-11.8	-3.3	-13.2
Ol jorok 1990-91 Short rains	-1.3	6.0	32.7	8.8	-3.1
Marigat 1990-91 Short rains	10.4	19.7	-17.9	-15.4	-5.8

Table 9: Mean squares from regression analysis (Eberhart and Russel, 1966 model) for eleven onion cultivars grown in seven environments in Kenya, 1990-1991.

Source of variation	Df	Bulb yield (tons ha^{-1})	Bulb weight (g)	Days to maturity	Percent dry matter	Shape index x 10^{-2}
Genotypes (G)	10	327.1**	3348.4**	415.1**	26.3*	0.6
E+ (G x E)	66	185.4	1266.0	644.1	1.2	2.2**
E(linear)	1	7496.3**	52930.1**	22073.0**	43.1**	42.5**
G x E (linear)	10	140.0**	425.3	55.2	0.8	6.8**
Pooled deviations	55	60.7**	479.4**	33.3**	06**	0.6**
KON1	5	46.5**	663.9**	30.3**	0.4*	0.7*
KON2	5	5.7	161.8**	43.6**	0.2	0.3
KON3	5	39.8**	220.2**	9.6	0.2	0.4
KON4	5	112.4**	270.6**	38.5**	0.3	0.6*
KON5	5	117.0**	986.8**	26.7**	0.7**	0.1*
KON6	5	48.9**	552.8**	15.4*	0.3	1.3**
KON7	5	50.2**	454.5**	20.2**	0.4*	0.5
KON8	5	34.6**	660.3**	26.0**	0.2	0.5*
Red Creole	5	52.2**	634.0**	88.8**	1.7**	0.6*
Tropicana Hybrid	5	99.0**	464.0**	56.9**	0.9**	0.5*
Bombay Red	5	64.8**	205.0**	9.8	1.0**	0.6*
Pooled error	308	2.7	36.7	6.1	0.2	0.2

*,**, Significant at 5 and 1 percent probability levels respectively.

highly significant for all traits implying that the varieties differed in their non linear responses to changes in environment.

Tests of individual variety deviation from linear regression with respect to bulb-yield were significant for all varieties except KON2. All varieties showed significant deviation from linear regression for bulb weight. Deviations for maturity were significant for all varieties except KON3 and Bombay Red. Deviations for dry matter content was significant for KON1, KON5, KON7, Red Creole, Bombay Red and Tropicana Hybrid while the rest did not show significant differences for this trait. Bulb-shape deviations from linear regression were significant (P = 0.05) for varieties KON1, KON4, KON5, KON8, Red Creole, Tropicana Hybrid and Bombay Red. KON6 was significant at (P = 0.01) while KON2 and KON3 had no significant deviations for shape index.

4.1.3 Adaptability and stability parameters

4.1.3.1 Bulb-yield (tons ha^{-1})

Stability parameters for bulb-yield are summarised in Table 10. The varieties that had mean yield above the overall mean were KON1, KON2, KON3, KON4 and KON7. KON1, KON3 and KON7 had regression coefficients significantly greater than unity ($b>1$ and $\beta_i > 0$), thus were specifically adapted to favourable environments. KON2 and KON4 had regression coefficients ($b = 1$ and $\beta_i = 0$) hence had general adaptability. KON6 and KON8 and had below average yields and bi = 1, hence the two varieties were poorly adapted to all environments. KON5 Red Creole, Tropicana Hybrid and Bombay Red had below average yields, bi<1 and β_i<1 thus were specifically adapted to low-yielding environments.

All varieties except KON2 had deviation from regressions (S^2d_i) significantly (P = 0.01) greater than zero indicating that they were not stable for bulb-yield. KON2 combined both good adaptation and stability but yields were just slightly above overall mean yield. KON4, though not stable, had good attributes of good yield and general adaptability besides its red-brown colour that is preferred by consumers.

Table 10: Yield (tons ha^{-1}) and stability parameters of eleven onion cultivars grown in seven environments in Kenya, 1990-1991.

Variety	Mean	Regression coefficients		Deviation from
	$\bar{X}$	Phenotypic bi	Genotypic $\beta i \times 10^{-1}$	regression S^2d_i
KON1	32.8 (3)	1.5**	5.4	40.9**
KON2	26.9 (5)	1.1	1.0	2.3
KON3	35.6 (1)	1.6**	6.0	37.1**
KON4	29.4 (4)	1.0	0.2	109.7**
KON5	22.7 (6)	0.7**	-3.2	114.3**
KON6	22.3 (7)	0.8	-2.3	46.2**
KON7	34.7 (2)	1.7**	7.0	47.5**
KON8	20.6 (8)	1.0	-0.3	31.8**
Red Creole	18.0 (10)	0.5**	-5.0	49.5**
Tropicana Hybrid	20.7 (9)	0.7**	-2.6	96.3**
Bombay Red	16.2 (11)	0.4**	-6.4	62.1**
Mean	25.5	1.0	0.0	54.3

*,** Significant at 5 and 1 percent probability levels respectively.

+ Ranks given in parenthesis

4.1.3.2 Bulb-weight (grams)

All the new varieties except KON5 and KON8 had mean bulb-weight above the overall mean. The existing varieties had low bulb-weight. KON1, KON4 and KON6 had bulb weight greater than the overall mean and (b_i >1) and $ß_i$ >0. The three varieties had low stability and were specifically adapted to favourable environments. KON7 and KON3 had b_i=1 and ß = 0 thus were stable and had general adaptation. The existing cultivars and KON8 were adapted to unfavourable environments. Deviation from regression (S^2di) were significantly different from zero for all cultivars indicating that they were not stable for this trait. KON7 was the best variety because it had high bulb weight and geneadaptation though it was not stable for this trait (Table 11).

4.1.3.3 Maturity

Earliest maturing varieties were KON2, KON4, KON5 and KON6. KON2, KON4, KON5 and KON6 had b_i = 1 and ß = 0 thus were stable and had wide adaptation for days to 50% maturity. Red Creole had specific adaptation to unfavourable environments (b<1). KON1 was also widely adapted for this trait but was late maturing in all environments. KON3, KON7 and KON8 were late maturing and were specifically adapted to favourable environments while Tropicana Hybrid and Red Creole were late maturing and specifically adapted to unfavourable environments.

Table 11: Bulb-weight (g) and stability values of eleven onion cultivars grown in seven environments in Kenya, 1990-1991

Variety	Mean	Regression coefficients		Deviation From
	$\bar{X}$	Phenotypic bi	Genotypic ßi	Regression $S^2 d_i$
KON1	137.1 (1)+	1.4**	0.4	627.2**
KON2	112.3 (5)	0.9**	-0.2	125.1**
KON3	123.9 (4)	0.9	-0.1	183.5**
KON4	126.7 (3)	1.1**	0.1	233.9**
KON5	102.1 (7)	1.3**	0.3	950.1**
KON6	110.1 (6)	1.2**	0.2	516.1**
KON7	133.2 (2)	1.1	0.1	417.8**
KON8	87.3 (9)	0.7**	-0.3	623.6**
Red Creole	84.1 (10)	1.2**	0.2	597.2**
Tropicana Hybrid	89.1 (8)	0.4**	-0.6	427.3**
Bombay Red	72.0 (11)	0.9**	-0.2	168.3**
Mean	107.1	1.0	0.0	

*, ** Significant at 5 and 1 percent probability levels respectively

+ Ranks are given in parenthesis.

All varieties except KON3 and Bombay Red had deviation from regression (S^2d_i) significantly different from zero hence were not stable for this trait. KON6 was the best cultivar since it was early maturing, widely adapted for the trait though not very stable (S^2d_i significant at P = 0.05) (Table 12).

4.1.3.4 Dry matter content

Cultivars KON2, KON3, KON4 and KON7 had b_i=1 and ß=0 and mean dry matter less than the overall mean thus were poorly adapted for this trait. The existing cultivars had high dry matter content but b<1 implying that they were specifically adapted to the unfavourable conditions only. KON6 and KON8 (b>1) were specifically adapted to favourable environments (Table 13).

Deviations from regressions were significantly different from zero for all varieties except KON2, KON3, KON4, KON6 and KON8. These were the most stable cultivars for this trait.

KON8 had good attributes of high dry matter content (10.8%) wide adaptation and good stability. Though KON4 and KON3 had low dry matter content, they had good adaptation and stability for this trait.

Table 12: Days to maturity and stability values of eleven onion cultivars grown in seven environments in kenya, 1990-1991.

Variety	Mean	Regression coefficients		Deviations from regression
		Phenotypic	Genotypic	
	$\bar{X}$	bi	$\beta i \times 10^{-1}$	Sd_i^2
KON1	173.9 (4)+	1.0	0.3	24.2**
KON2	169.1 (8)	1.0	-0.3	37.5**
KON3	172.4 (6)	1.2	1.4	1.6
KON4	169.4 (7)	1.0	0.2	32.4**
KON5	167.4 (10)	1.1	0.7	20.6**
KON6	168.5 (9)	0.9	-0.8	9.3*
KON7	175.3 (3)	1.2**	2.4	14.1**
KON8	180.9 (1)	1.2**	2.2	19.9**
Red Creole	178.1 (11)	0.9**	-1.5	82.8**
Tropicana Hybrid	176.6 (2)	0.8**	2.3	50.9**
Bombay Red	172.6 (5)	0.8**	2.5	3.7

*, ** - Significant at 5 and 1 percent probability levels, respectively.

+ Ranks are given in parenthesis.

Table 13: Percent dry matter content and stability values of eleven onion cultivars grown in seven environments in Kenya in 1990 and 1991.

Variety	Mean	Regression coefficients		Deviation From
		Phenotypic	Genotypic	Regression
	X	bi	$\beta i \times 10^{-1}$	S^2d_i x 10-2
KON1	6.6 (5)+	1.5**	4.5	24.9*
KON2	6.4 (6)	0.9	-1.1	0.8
KON3	5.3 (11)	1.0	-0.3	4.9
KON4	6.0 (9)	0.9	-0.6	12.1
KON5	6.3 (7)	1.2**	2.3	60.2**
KON6	6.2 (8)	1.8**	8.1	17.4
KON7	5.7 (10)	1.0	0.3	20.8*
KON8	9.1 (3)	1.2**	2.4	6.9
Red Creole	10.1 (2)	0.7**	-3.3	158.0**
Tropicana Hybrid	10.8 (1)	0.7**	-3.0	77.7**
Bombay Red	8.9 (4)	0.0**	-9.9	83.6**
Mean	7.4	1.0	0.0	

*, ** Significant at 5 and 1 percent probability levels respectively

+ Ranks are given in parenthesis.

Table 14: Shape index and stability values of eleven onion cultivars grown in seven environments in Kenya, 1990-1991.

Variety	Mean	Regression coefficients		Deviation From Regression
		Phenotypic	Genotypic	
	$\bar{X}$	bi	ßi	$S_d^2 i \times 10^{-3}$
KON1	1.0	-0.2**	-0.8	4.2*
KON2	1.0	2.2**	1.9	1.1
KON3	1.0	1.3	0.3	1.5
KON4	0.9	1.9**	0.9	4.1*
KON5	0.9	2.6**	1.6	-1.6*
KON6	0.9	2.6**	1.6	1.0**
KON7	0.9	2.0**	1.0	2.2
KON8	0.9	0.1**	-0.9	3.0*
Red Creole	0.9	-0.6	-0.4	4.0*
Tropicana Hybrid	1.0	-0.6	-0.4	2.6
Bombay Red	1.0	-0.2**	-0.8	3.7*
Mean	0.9	1.0	0.0	

*, ** Significant at 5 and 1 percent probability levels respectively

4.1.3.5 Shape Index

KON1 and the three existing cultivars had negative regression coefficients (Table 14) implying that environments with high environmental indices had low bulb diameter to height ratio. KON2, KON4, KON5, KON6 and KON7 had regression coefficients (b_i) greater than one thus were specifically adapted to favourable environments. KON1, KON8 and Bombay Red ($b<1$) were specifically adapted to unfavourable environments for this trait. KON3, Red-Creole and Tropicana Hybrid were widely adapted to all environments for this trait.

Deviations from regression were significant for all varieties except KON2, KON3, KON7 and Tropicana Hybrid which were stable for this trait. KON3 was the best cultivar because it had almost globe-shaped bulbs, wide adaptation and stable for shape-index.

4.2 EXPERIMENT II - SHELF LIFE

4.2.1 Analysis of Variance

The analysis of variance of eleven onion cultivars grown in seven environments then stored for four months at room conditions is shown in Table 15. Cultivars and sampling date effects were highly significant for all the environments. Highly significant differences were detected for cultivar x sampling date interactions for all environments.

Combined analysis of variance for shelf life of the

Table 15: Mean squares for shelf-life of eleven onion cultivars grown in seven environments and stored at room conditions for four months in Kenya, 1990-1991.

Source of variation	D.f	1990			1991			
		Kabete	Kibirigwi	Oljorok	Kabete	Kibirigwi	Oljorok	Marigat
Cultivars	10	7854.3**	7069.6**	7468.5**	5776.5**	1158.9**	7754.6**	3685.7**
Replicates	2	23.4	57.2	1.1	17.2	63.6	172.0	6.1
Sampling dates	11	11871.7**	10881.8**	10927.0**	8796.9**	11652.1**	9991.5**	8563.4**
Cultivars x sampling dates	110	58.0**	63.6**	82.6**	203.1**	53.1**	65.7**	74.0**
Error	264	9.0	8.8	11.0	6.0	24.3	12.7	6.9

** Significant at 1 percent probability level.

Table 16: Mean squares from combined analysis of variance of eleven onion cultivars grown in seven environments and stored at room conditions for four months in Kenya, 1990-1991.

Source of variation	Degrees of freedom	Mean squares
Locations	6	295.5**
Reps. within location	14	48.7
Cultivars	10	3023.0**
Locations x cultivars	60	88.4**
Error	140	49.5

** Significant at 1 percent probability level.

eleven cultivars is shown in Table 16. Location and cultivar effects were significant (P = 0.01). Location x cultivar interaction effects were also highly significant. Ranking of the cultivars on basis of their shelf life varied with environments.

4.2.2 Mean Performance for Shelf Life

Percent storage loss of the eleven onion cultivar grown in seven environments and stored for four months is shown in Table 17. Storage loss during the four months of storage ranged from 26.7 to 100% storage loss. In 1990, the best-storing cultivars were KON1 and KON2 (37.2%) and the worst was KON6 (100%) followed by Bombay Red (99.6%). For Kabete 1990 storage trial, KON2 (37.2%) had the lowest storage loss followed by KON4 (46.1%) while KON6, Tropicana Hybrid and Bombay Red (100%) had the highest. The best and worst cultivars for Kibirigwi 1990 storage trials, were KON4 (35.6%) and KON6 (100%), respectively. Second best in this trial was KON1 (40.6%) followed by KON2 (50.0%). KON1 (37.2%) had the lowest storage loss for Oljorok 1990 storage trials, while Bombay Red (100%) was the worst. There was not much variation in percent storage loss for bulbs grown at Kabete, Kibirigwi and Oljorok.

In the 1991 storage trials, the best cultivar was KON2 with 28.2% storage loss at Marigat and the worst cultivar was Bombay Red (100%). For Kabete 1991 storage trials, KON2 (27.2%) had the least storage loss followed by KON4 (35.6%) while KON6 had the highest losses (100%). In this trial, Bombay Red (98.9%) was second worst cultivar. Kibirigwi 1991 storage trial recorded bulbs with the worst shelf life. In this storage trial, KON4 and KON7 (66.7%) had the least storage loss while Tropicana Hybrid had the highest (100%). KON2 (26.7%) and Bombay Red (100%) had the lowest and highest storage loss, respectively in the Oljorok storage trials. KON4 (36.7%) was the second best in this storage trial. For the Marigat storage trial, KON2 (28.2%) was the best cultivar followed by KON4 (37.2%). The worst cultivar in this storage trial was KON6 (100%) followed by Bombay Red (86.7%). In this year the bulbs grown at Kibirigwi stored very poorly. This was due to an infection in the field with pink-root rot and Fusarium basal rot diseases. Bulbs grown at Marigat had the best shelf life this year.

The best existing and exotic cultivars in 1990 were KON1 (44.3%) and Red Creole (83%), respectively. In the 1991 storage trials the best existing cultivar was also Red Creole (82.8%) compared to the best exotic cultivar KON2 with only 38.6% storage loss. Performance of the eleven cultivars is shown in Figures 1-5.

The cultivars with the least mean storage loss over all seven environments was KON2 (41.1%) followed by KON4 (44.3%). Bombay Red and KON6 (97.6%) had the highest mean storage loss over all environments. The worst exotic cultivar over all environments was KON6 (97.6%)

Table 17: Percent storage loss of eleven onion cultivars grown in seven environments and stored at room conditions for four months in Kenya, 1990-1991.

	1990			1991				
Cultivars	Kabete	Kibirigwi	Ol Jorok	Kabete	Kibirigwi	Ol Jorok	Marigat	Mean
KON1	55.0	40.6	37.2	42.2	73.9	39.4	48.7	48.1
	(3)+	(2)	(1)	(3)	(4)	(3)	(3)	(3)
KON2	37.2	50.0	46.1	27.2	72.2	26.7	28.2	41.1
	(1)	(3)	(2)	(1)	(3)	(1)	(1)	(1)
KON3	67.2	56.1	66.7	51.1	75.6	66.7	52.2	62.2
	(6)	(4)	(5)	(4)	(5)	(4)	(4)	(5)
KON4	46.1	35.6	52.4	35.6	66.7	36.7	37.2	44.3
	(2)	(1)	(3)	(2)	(1)	(2)	(2)	(2)
KON5	65.0	80.6	66.9	61.7	75.6	70.0	63.9	69.1
	(5)	(7)	(6)	(6)	(6)	(6)	(6)	(6)
KON6	100.0	100.0	100.0	100.0	86.1	97.2	100.0	97.6
	(11)	(11)	(11)	(11)	(8)	(8)	(11)	(11)
KON7	80.0	78.9	94.4	94.4	66.7	70.0	84.4	81.3
	(7)	(6)	(9)	(9)	(1)	(6)	(9)	(7)
KON8	58.9	67.2	52.8	52.8	80.6	66.7	50.6	61.4
	(4)	(5)	(4)	(5)	(7)	(4)	(5)	(4)
Red Creole	80.0	86.1	82.8	82.8	88.9	97.8	66.1	83.5
	(7)	(9)	(7)	(7)	(7)	(9)	(7)	(9)
Tropicana Hybrid	100.0	81.7	90.0	90.0	100.0	98.9	81.7	91.8
	(11)	(8)	(8)	(8)	(11)	(10)	(8)	(9)
Bombay Red	100.0	100.0	98.9	98.9	98.9	100.0	86.7	97.6
	(11)	(11)	(10)	(10)	(10)	(11)	(10)	(11)
Mean	71.8	70.6	71.4	67.0	80.5	70.0	63.6	70.7
L.S.D(0.05)	4.8	4.8	5.3	3.9	7.9	5.7	4.2	5.2
C.V.%.	4.3	4.2	4.7	3.5	7.0	5.0	3.7	4.6

+Ranks are given in parenthesis

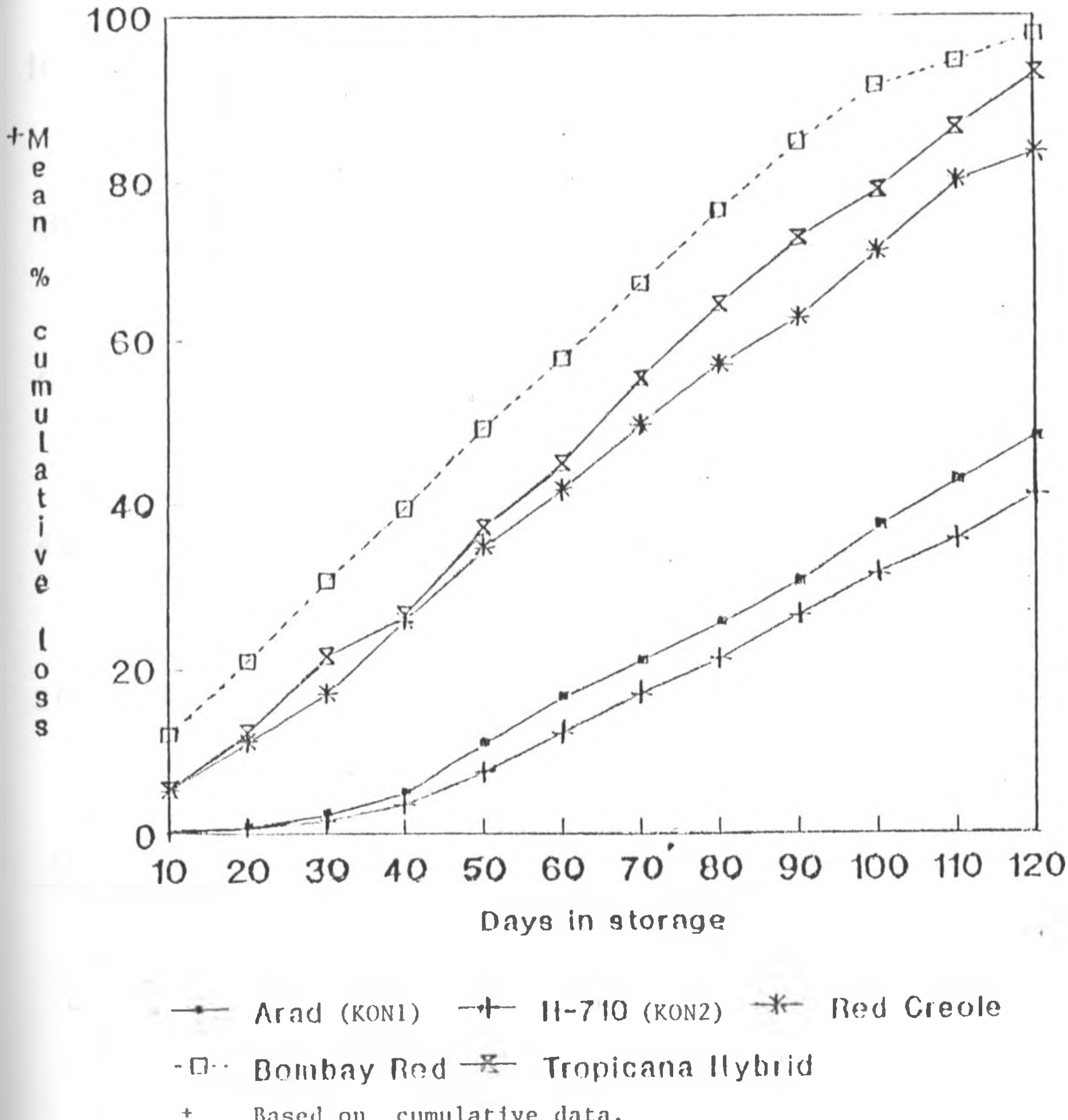


Fig 1. Shelf-life of exotic and existing onion cultivars at ambient conditions in Kenya.

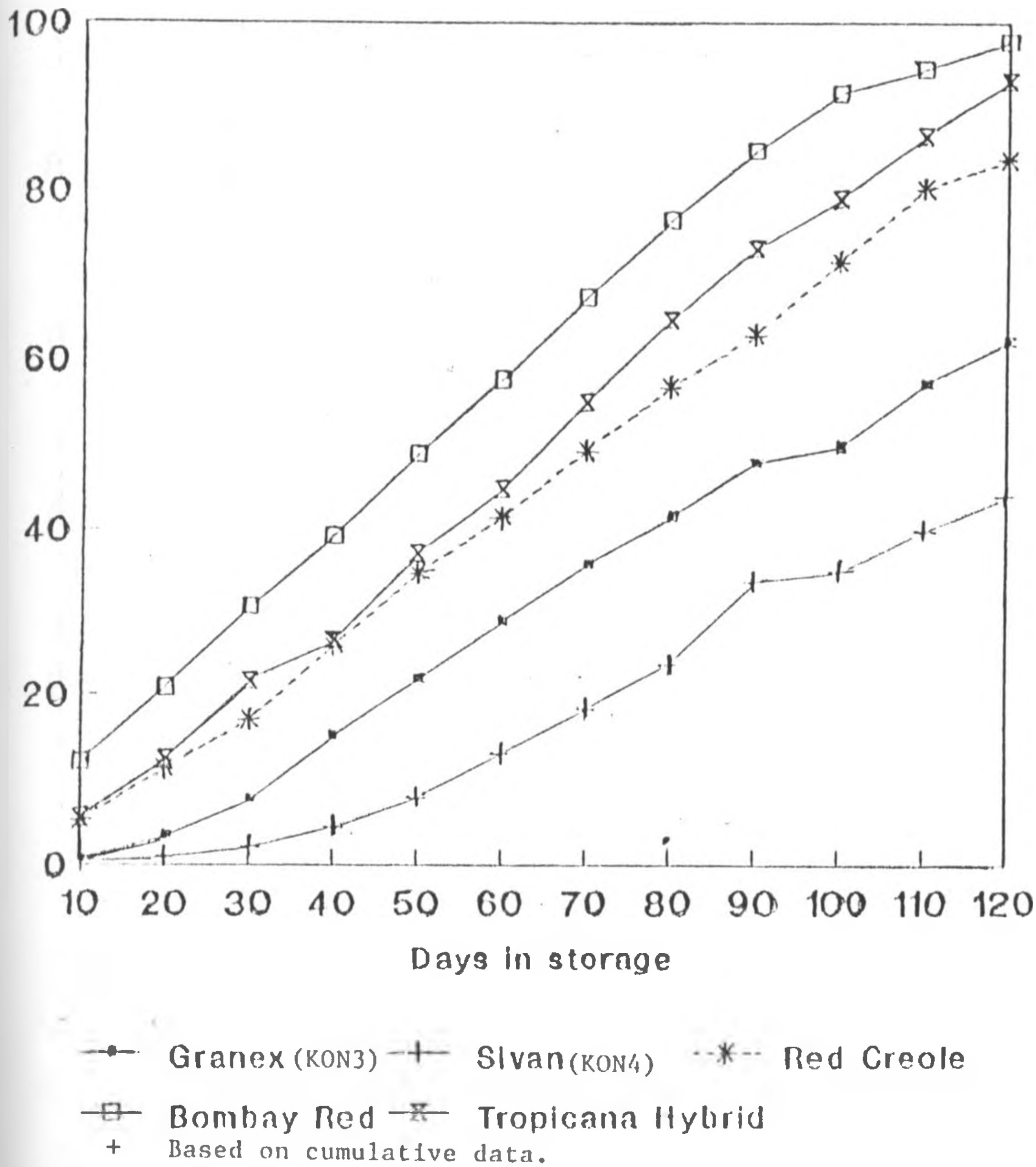
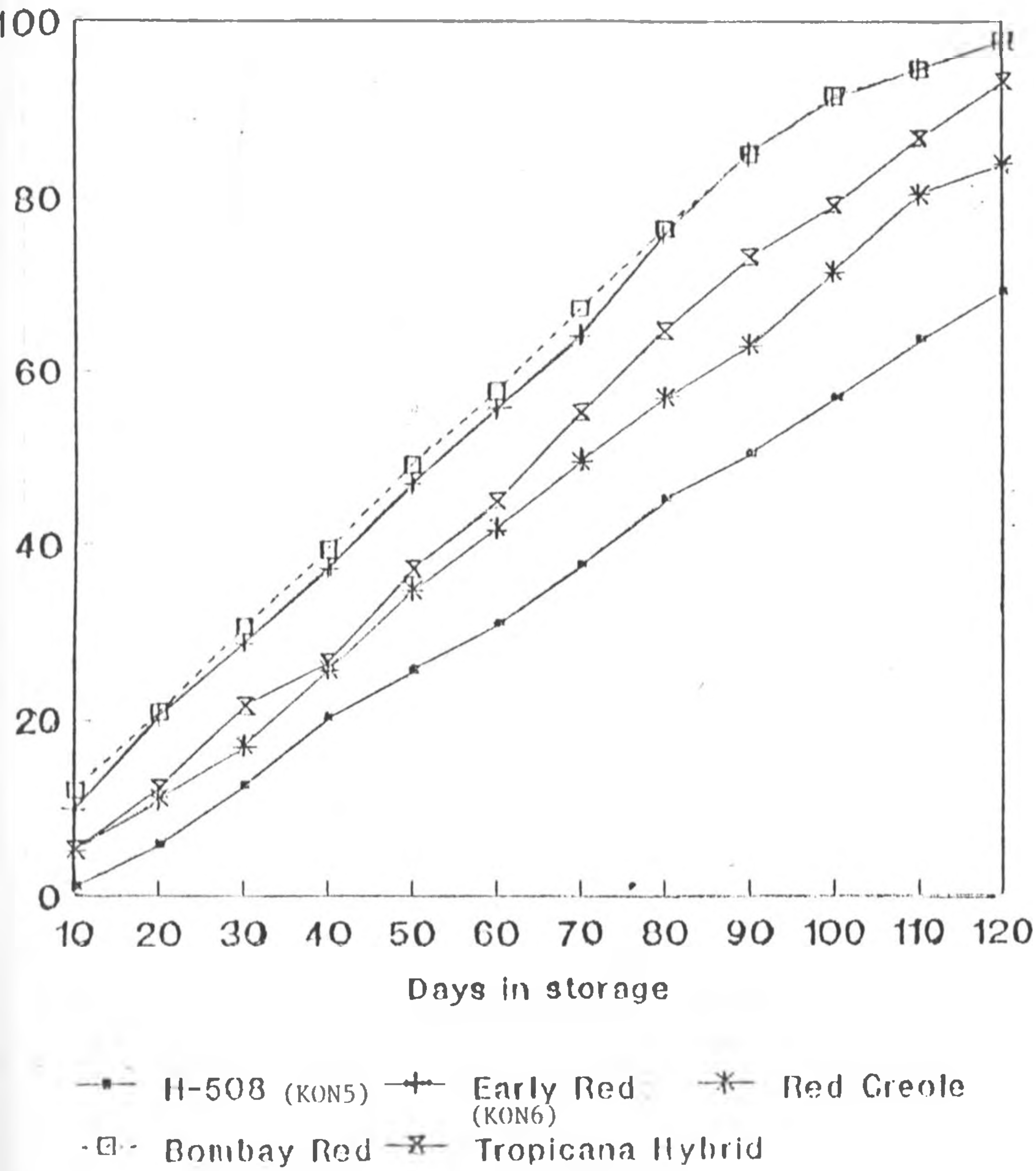
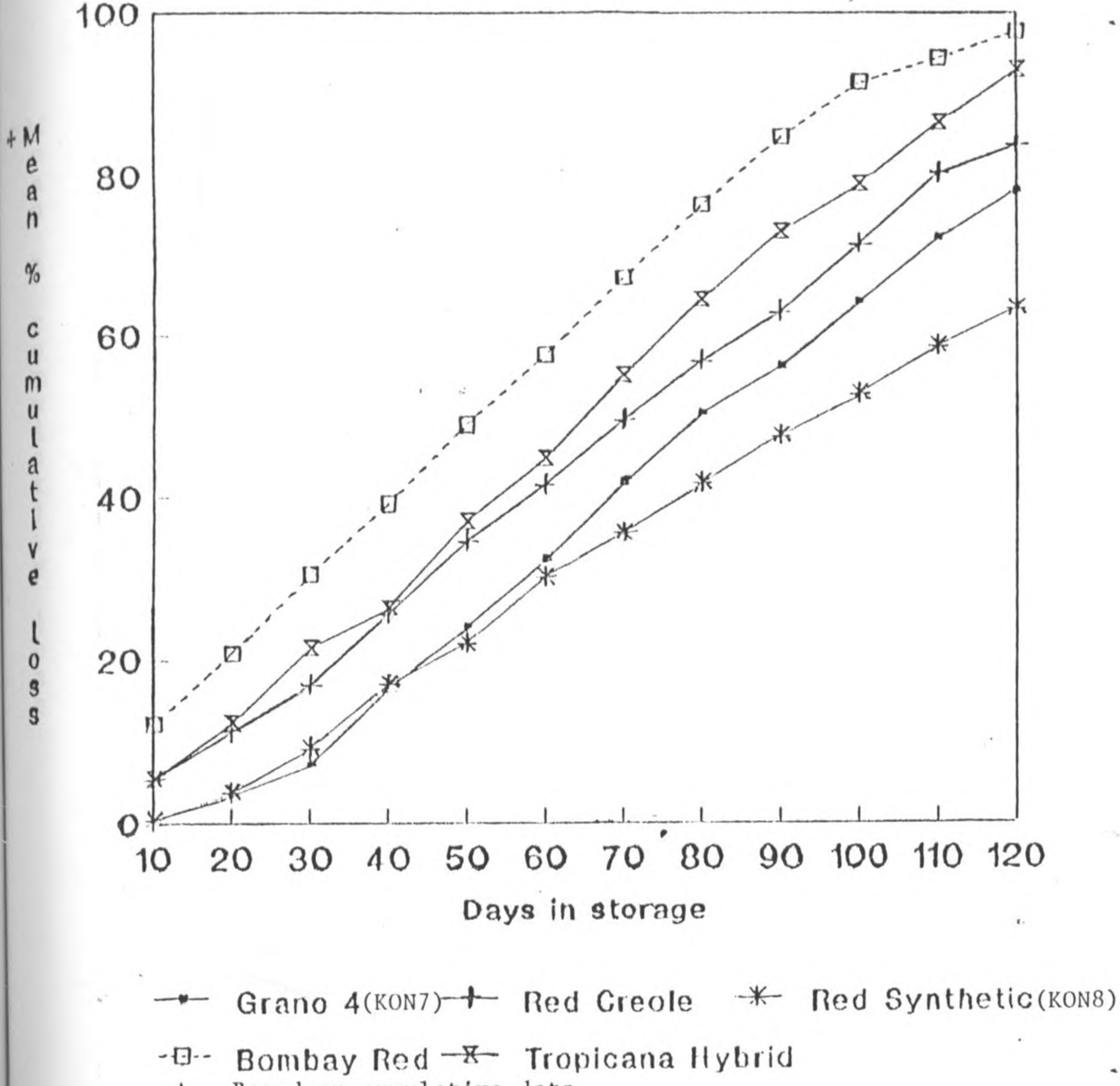


Fig 2. Shelf-life of exotic and existing onion cultivars at ambient conditions in Kenya.



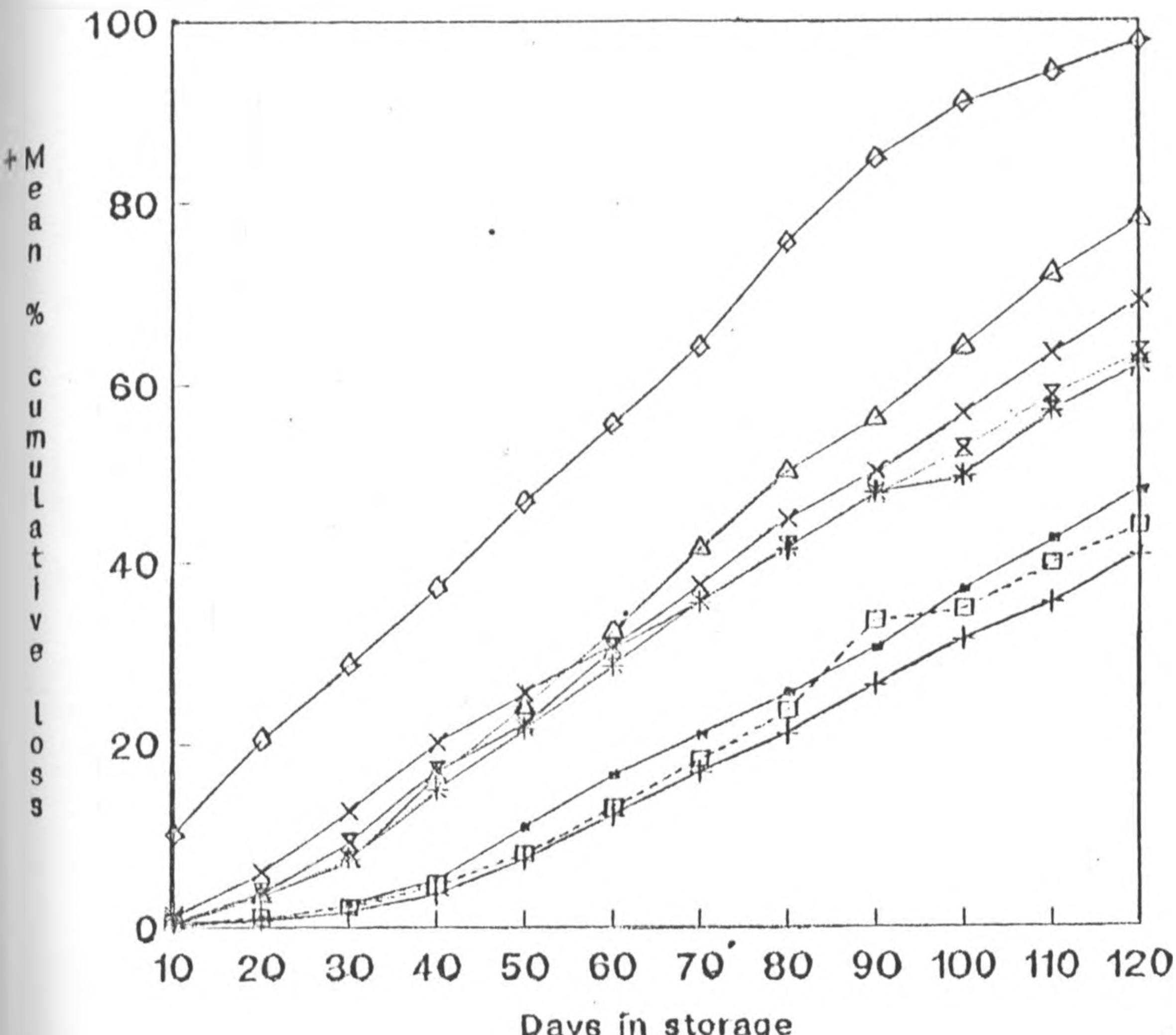
\+ Based on cumulative data.

Fig 3. Shelf-life of exotic and existing onion cultivars at ambient conditions in Kenya.



\+ Based on cumulative data.

Fig 4. Shelf-life of exotic and existing onion cultivars at ambient conditions in Kenya.



KON1 KON2 KON3 KON4

KON5 KON6 KON7 KON8

\+ Based on cumulative data.

Fig5. Shelf-life of exotic onion cultivars at ambient conditions in Kenya.

followed by KON7 (81.3%). Red-Creole (83.5%) was the best existing cultivar over all environments while Bombay Red did poorly in all storage trials. The new cultivars had better shelf-life than the existing ones.

4.3 EXPERIMENT III - SEED PRODUCTION

4.3.1 Analysis of Variance

Combined analysis for all the traits for 1990 and 1991 seed production are shown in Tables 24a and b, respectively. Location and varietal effects were highly significant for all traits except percentage germination (1991) where only varietal effects was significant. Temperature effects were significant for all traits. For percentage germination only variety X temperature was significant in both years while the other interactions were significant in 1991.

4.3.2 Days to 50% Flowering

Days to flowering are shown in Table 18. This trait was affected by the bulb storage temperature and the location where the cultivars were grown. The trait also varied among cultivars. Bulbs stored at 10°C flowered earlier than those stored at other temperatures (Plate 4). Those stored at Njabini (14.4°C) flowered earlier than for 5°C and Kabete storage (21.9°C) temperature. Bulbs stored in the latter temperature were the latest to flower. This storage temperature response was consistent in all cultivars except Bombay Red. Bulbs of this cultivar stored at Kabete room temperature flowered

A B

Plate 4: Bulbs stored at 10 °C (A) flowered earlier than those stored at 5° C (B), Kibirigwi, 1991

Table 18: Days to 50% flowering of eleven onion cultivars stored at different temperatures and grown in four locations in kenya in 1991.

Cultivars	Temperature °C	Kabete	Kibirigwi	Marigat	Njabini	Mean
KON1	5	99.7	74.7	81.3	108.9	91.1
	10	90.0	63.0	70.7	100.0	80.9
	14.4	95.7	69.7	72.7	104.9	85.7
	21.9	111.7	74.0	83.0	113.0	95.4
KON2	5	68.7	88.3	84.3	99.3	85.20
	10	62.0	79.7	75.0	83.6	75.1
	14.4	64.3	86.3	80.3	92.4	80.8
	21.9	83.0	86.7	85.0	102.1	89.2
KON3	5	71.0	80.3	80.0	100.7	83.0
	10	63.7	66.0	73.3	87.8	72.7
	14.4	67.3	77.7	76.3	94.7	79.0
	21.9	78.3	82.7	83.0	110.0	88.5
KON4	5	92.0	82.7	83.3	111.3	92.3
	10	86.3	70.7	70.3	93.7	80.3
	14.4	89.3	76.7	76.7	100.6	85.8
	21.9	103.7	77.3	84.3	116.3	95.4
KON5	5	81.3	78.0	78.7	98.7	84.2
	10	71.7	65.3	64.0	89.1	72.5
	14.4	77.0	73.7	70.7	94.6	79.0
	21.9	94.3	78.0	82.0	101.6	87.3
KON6	5	64.7	70.3	70.0	89.1	73.5
	10	60.7	60.7	57.7	77.5	64.2
	14.4	62.7	66.0	62.0	86.4	69.3
	21.9	74.0	70.7	78.3	92.4	78.9
KON7	5	81.7	73.7	85.0	95.6	83.9
	10	76.0	63.0	76.0	86.1	75.3
	14.4	79.0	68.3	79.3	92.5	79.8
	21.9	87.0	74.7	85.0	103.6	87.6
KON8	5	75.3	81.3	73.3	87.7	79.4
	10	70.0	66.0	61.0	78.7	68.9
	14.4	73.0	76.0	65.3	81.8	74.0
	21.9	82.3	82.3	79.0	94.1	84.5
Red Creole	5	67.7	73.7	74.3	85.6	75.3
	10	61.7	65.3	64.3	76.1	66.9
	14.4	64.7	67.0	68.0	69.6	67.3
	21.9	75.7	75.0	80.3	90.1	80.3
Tropicana Hybrid	5	70.3	66.7	70.3	82.4	72.4
	10	62.3	57.7	57.3	76.6	63.5
	14.4	67.0	63.0	67.7	79.3	68.5

	21.9	80.0	68.7	76.3	86.6	77.9
Bombay Red	5	62.7	85.7	54.0	87.3	72.4
	10	57.0	74.3	53.7	82.6	66.9
	14.4	53.7	84.7	47.0	79.5	66.2
	21.9	56.0	71.0	44.0	76.3	61.8
Mean		75.2	73.6	72.3	91.8	78.2
C.V. (%)		2.3	2.2	2.1	5.4	3.0
Main plot (Cultivar) L.S.D. (.05)		2.3	1.7	2.0	5.7	2.9
Sub-plot (Temperature) L.S.D. (.05)		2.8	2.6	2.4	3.8	2.9

14.4°C = Storage room temperature for Njabini

21.9°C = Storage room temperature for Kabete.

earlier than for 5°C, 10°C and Njabini (14.4°C) storage treatment. Bulbs stored at 5°C were the latest to flower for this cultivar.

At Kabete, Bombay Red was the earliest to flower at all temperature treatments. It took 57 days to flower for bulbs stored at 10°C and 53.7 days for 14.4°C storage temperature. The latest cultivar to flower at Kabete was KON1 (90 days at 10°C and 111.7 days for Kabete (21.9°C). Tropicana Hybrid was the earliest to flower at Kibirigwi (57.7 days at 10°C) while KON2 (88.3 days at 10°C) was the latest. At Marigat, the earliest and latest flowering cultivars were Bombay Red (44 days at 21.9°C) and KON7 (85 days at 5°C), respectively. Red Creole flowered in 76.1 days (earliest) and KON4 in 116.3 at 21.9° C (Latest) at Njabini.

The existing cultivars flowered earlier than the new ones at all temperature treatments and locations. Bombay Red was the earliest existing cultivar to flower (61.8 days at 21.9°C) in all the four locations. KON6 was the earliest exotic cultivar in all sites (64.2 days at 10°C). Cultivars flowered earliest at Marigat and latest at Njabini. Flowering at Njabini (1991) was unique from that of other sites. Cultivars in this site flowered later than in other sites (Plate 5). After the spathes opened they stayed for a long time before the florets opened and subsequently only a few of them

Plate 5: Onions flowering at Njabini Farmers Training Centre,1991.

formed seeds.

4.3.3 Umbels per Mother Bulb.

Umbels mother bulb^{-1} of the eleven cultivars is shown in Table 19a and b. The number of umbels per mother bulb varied with bulb storage temperature, cultivars and locations. Storage temperature of 10°C recorded the highest number of umbels while bulbs stored at Kabete conditions (20.9 and 21.9°C) had the lowest. Bombay Red had more umbels for bulbs stored at Kabete (20.9 and 21.9°C) conditions and less umbels for 5°C storage temperature.

KON7 had the highest number of umbels at all sites in 1990. Cultivars with lowest number of umbels per mother bulb were KON6 (1.5) at Kabete and 2.2 at Kibirigwi, KON8 (2.0) at Marigat and KON8 (3.1) at Njabini. In 1991, KON2 had the highest number of umbels per mother bulb (5.2 at 10 °C) while Tropicana Hybrid had the least (1.8 at 21.9 ° C), at Kabete. At Kibirigwi, cultivars with highest and least number of umbels mother bulb^{-1} were KON4 (4.2 at 10 ° C) and, KON6 (1.5 at 5 °C), respectively. KON7 (4.4 at 10 °C) had the highest and Red Creole (1.1 at 21.9 °C) had the least at Marigat. KON7 (3.6 at 10 °C) had the highest and KON6 (1.0) the least number of umbels mother bulb^{-1} at Njabini. In both years, the exotic and existing cultivars with the highest number of umbels mother bulb^{-1} were KON7 and Tropicana Hybrid, respectively. Cultivars had more umbels per mother bulb at Njabini in

Table 19a: Umbels mother bulb^{-1} of eleven onion cultivars stored at different temperature treatments and grown in four locations in Kenya in 1990.

Cultivars	Temperature+ °C	Kabete	Kibirigwi	Marigat	Njabini	Mean
		Locations				
KON1	10	2.9	4.3	3.6	4.6	3.9
	13.4	2.6	4.0	3.1	4.3	3.5
KON2	10	3.0	4.7	3.3	4.4	3.9
	13.4	2.6	4.5	2.7	4.1	3.4
KON3	10	3.2	4.7	3.7	4.8	4.1
	13.4	3.0	4.3	1.8	4.4	3.4
KON4	10	3.2	4.5	4.2	3.8	3.9
	13.4	2.8	4.2	3.4	3.2	3.4
KON5	10	3.0	4.2	3.0	4.2	3.6
	13.4	1.7	3.9	1.6	3.8	2.7
KON6	10	1.8	2.2	2.5	4.4	2.7
	13.4	1.5	3.0	1.5	4.0	2.3
KON7	10	3.7	4.9	4.7	5.4	4.7
	13.4	2.6	4.5	3.6	4.8	3.9
KON8	10	2.5	3.9	2.3	3.6	3.1
	13.4	2.1	3.6	2.0	3.1	2.7
Red Creole	10	2.4	2.6	2.5	4.0	2.9
	13.4	2.0	2.3	2.5	3.0	2.6
Tropicana Hybrid	10	3.0	3.1	3.1	4.0	3.3
	13.4	1.7	2.9	2.3	3.8	2.7
Bombay Red	10	3.1	2.3	2.5	3.6	2.9
	13.4	2.8	2.5	3.0	3.4	2.9
	20.9	3.0	2.5	3.2	3.5	3.1
Mean		2.5	3.7	2.8	4.0	3.3
C.V. (%)		6.0	2.3	5.7	4.3	4.5
Main plot (Cultivar) L.S.D (.05)		0.09	0.06	0.16	0.11	0.11
Sub plot (Temperature) L.S.D (.05)		0.17	0.18	0.09	0.18	0.16

+13.4=Storage room temperature for Njabini

20.9=Storage room temperature for Kabete

19b: Umbels mother bulb^{-1} of eleven onion cultivars stored at different temperature and grown in four locations in Kenya in 1991.

Cultivars	Temperature	Locations				
	°C	Kabete	Kibirigwi	Marigat	Njabini	mean
KON1	5	3.1	2.7	2.2	2.2	2.6
	10	4.4	3.6	3.1	3.0	3.5
	14.4	3.5	3.0	2.8	2.9	3.1
	21.9	2.5	2.8	1.9	1.5	2.2
KON2	5	3.0	1.9	2.6	1.8	2.3
	10	5.2	2.4	3.6	2.9	3.6
	14.4	4.2	2.0	3.0	2.5	2.9
	21.9	2.4	1.8	2.0	1.1	1.8
KON3	5	3.2	1.6	2.1	1.4	2.1
	10	3.9	2.2	3.3	2.6	3.0
	14.4	3.5	1.9	2.7	1.8	2.5
	21.9	2.5	1.6	1.3	1.3	1.7
KON4	5	3.2	3.2	2.9	2.5	3.0
	10	4.6	4.2	4.0	3.2	4.0
	14.4	3.9	3.6	3.4	2.9	3.5
	21.9	2.5	3.2	2.3	1.6	2.4
KON5	5	3.0	2.0	1.9	1.5	2.1
	10	4.9	3.0	2.5	2.9	3.4
	14.4	3.4	2.4	2.1	1.7	2.4
	21.9	2.7	1.9	1.2	1.2	1.7
KON6	5	2.8	1.0	1.7	1.1	1.7
	10	3.6	1.5	2.2	1.4	2.2
	14.4	3.1	1.2	2.0	1.3	1.9
	21.9	1.9	1.1	1.5	1.0	1.4
KON7	5	3.1	2.2	2.9	2.1	2.6
	10	4.5	3.2	4.4	3.6	3.9
	14.4	3.9	2.7	3.3	3.0	3.2
	21.9	2.3	2.1	2.7	1.7	2.2
KON8	5	2.5	1.1	1.8	1.1	1.6
	10	3.4	1.8	2.4	2.2	2.4
	14.4	2.8	1.4	2.0	1.8	2.0
	21.9	2.0	1.0	1.6	1.0	1.4
Red Creole	5	2.6	1.1	1.4	1.0	1.5
	10	3.2	1.6	2.1	1.8	2.2
	14.4	3.0	1.2	1.8	1.1	1.8
	21.9	1.9	1.1	1.1	1.0	1.3
Tropicana Hybrid	5	2.5	1.5	2.0	1.1	1.8
	10	4.0	1.9	2.8	2.1	2.7
	14.4	3.7	1.8	2.4	1.7	2.4
	21.9	1.8	1.3	1.9	1.0	1.5

Bombay Red	5	2.3	1.2	2.2	1.7	1.9
	10	2.8	2.3	2.5	2.1	2.4
	14.4	3.5	2.4	2.9	2.3	2.8
	21.9	3.7	2.5	3.2	2.5	3.0
Mean		3.2	2.1	2.4	1.9	2.4
C.V. (%)		5.3	7.6	6.1	10.0	6.9
Main plot (Cultivar) L.S.D (.05)		0.2	0.1	0.1	0.2	0.2
Sub-plot (Temperature) L.S.D (.05)		0.3	0.3	0.2	0.3	0.3

N.B. 14.4°c Storage room temperature for Njabini.

21.9°c Storage room temperature for Kabete.

1990 and at Kabete in 1991. Of the seven environments in both years cultivars had least umbels mother $bulb^{-1}$ at at Njabini (1991).

4.3.4 **Stalk height (Scape)**

Stalk height of the eleven onion cultivars are shown in Tables 20a and b. Stalk height varied with cultivars, locations and bulb storage temperature. The bulbs stored at 10°C had taller flowerstalks than those of other temperature treatments. Bulbs stored at 0°C and Kabete room temperature (1990) did not produce any flower stalks.

The cultivar with the tallest flowerstalks was KON4 (87.9cm) and Bombay Red (56.9cm) had the shortest at Kabete in 1990. KON7 (78.3cm) was the tallest and KON6 (56.7cm at 13.4 ° C) was the shortest at Kibirigwi. At Marigat , KON7 (83.4 cm) had the tallest flowerstalks while KON6 (51.0 at 13.4 ° C) had the shortest. Cultivars with shortest and tallest flower stalks at Njabini were, KON1 (81.4cm) and KON6 (58.3cm), respectively.

In 1991, the cultivar that produced the tallest flowerstalks was KON2 (91cm) at Kabete, KON1 (93.5cm) at Kibirigwi, KON2 (83.9cm) at Marigat and KON3 (91.8cm) at Njabini. Bombay Red had the shortest scapes this year.

The new cultivars had taller scapes than the existing ones. KON1 had the tallest scapes in all environments at 10°C in 1990 and 1991. KON8 produced twisted flower stalks in all locations that were prone

Plate 6: KON8 with twisted flower stalks at Njabini, 1990

Table 20(a): Stalk height (cm) of eleven onion cultivars stored at different temperature treatments and grown in four locations in Kenya in 1990.

Cultivars	Temperature+ °C	Kabete	Kibirigwi	Marigat	Njabini	mean
		Locations				
KON1	10	83.3	78.0	79.3	81.4	80.5
	13.4	75.9	57.3	60.9	76.0	67.5
KON2	10	83.4	79.5	63.2	67.5	73.4
	13.4	74.4	72.1	61.0	64.7	68.1
KON3	10	79.1	66.7	64.0	79.3	72.3
	13.4	67.6	62.5	61.0	74.5	66.4
KON4	10	87.9	67.0	75.6	77.9	77.1
	13.4	75.1	61.1	70.4	73.4	70.0
KON5	10	81.8	64.8	65.7	66.1	69.6
	13.4	77.4	61.7	59.9	61.5	65.1
KON6	10	66.5	59.1	53.8	58.3	59.4
	13.4	63.3	56.7	51.0	58.7	57.4
KON7	10	77.5	78.3	83.4	77.3	79.1
	13.4	72.6	67.3	73.2	71.2	71.1
KON8	10	67.4	67.0	56.3	63.3	63.3
	13.4	59.6	64.0	56.3	60.7	60.2
Red Creole	10	72.0	61.1	54.9	60.7	62.2
	13.4	59.6	57.8	52.8	58.2	57.1
Tropicana Hybrid	10	66.5	66.4	63.1	69.4	66.4
	13.4	62.5	60.9	53.2	61.8	59.6
Bombay Red	10	56.9	60.1	53.2	60.2	57.6
	13.4	58.3	63.6	54.0	60.0	59.0
	20.9	57.6	61.2	57.5	61.8	59.5
Mean		70.6	63.7	61.2	66.2	65.4
C.V. (%)		4.6	2.0	3.1	2.6	3.3
Main plot (Culitvar) L.S.D. (.05)		2.5	0.9	1.6	1.1	1.5
Sub plot (Temperature) L.S.D (.05)		3.7	0.9	2.2	2.0	2.2

N.B. +13.4°C = Storage room temperature for Njabini
20.9 C = Storage room temperature for Kabete

Table 20b: Stalk height (cm) of eleven onion cultivars stored at different temperature treatments and grown in four locations in Kenya in 1991.

Cultivars	Temperature+	Locations				
	°C	Kabete	Kibirigwi	Marigat	Njabini	mean
KON1	5	80.4	79.4	63.2	77.8	75.2
	10	87.8	93.5	75.7	91.7	87.2
	14.4	84.2	82.7	70.3	83.5	80.2
	21.9	77.5	78.3	59.2	73.8	72.2
KON2	5	84.0	77.7	67.1	81.7	77.6
	10	91.0	80.7	83.9	89.0	86.2
	14.4	89.4	80.2	75.7	85.8	82.8
	21.9	83.8	73.2	61.9	77.6	74.1
KON3	5	83.4	78.9	57.3	80.3	74.9
	10	89.0	82.1	64.6	91.8	81.9
	14.4	89.3	80.4	59.3	82.6	77.9
	21.9	73.9	78.3	52.0	78.0	70.6
KON4	5	79.3	80.8	71.2	77.2	77.1
	10	86.2	87.5	80.8	87.0	85.4
	14.4	72.8	83.6	73.4	79.1	77.2
	21.9	72.3	77.7	68.6	69.9	72.3
KON5	5	80.1	73.3	59.3	78.8	72.9
	10	90.3	83.4	68.2	87.9	82.5
	14.4	83.8	79.4	59.6	81.9	77.0
	21.9	74.3	71.5	55.4	75.2	69.1
KON6	5	69.5	69.4	52.2	69.7	65.2
	10	82.6	72.4	62.4	82.2	74.9
	14.4	71.4	73.5	54.5	76.2	68.9
	21.9	67.2	69.0	52.5	67.0	63.9
KON7	5	77.7	76.4	66.1	76.6	74.2
	10	86.7	82.0	74.2	86.4	82.3
	14.4	83.6	80.8	66.0	79.7	77.5
	21.9	71.0	74.2	62.6	71.9	69.9
KON8	5	71.0	77.0	58.2	72.7	68.8
	10	85.8	81.8	67.1	87.2	76.6
	14.4	81.4	69.5	60.5	77.6	74.1
	21.9	67.5	77.7	56.3	68.8	66.4
Red Creole	5	76.0	74.7	56.7	66.8	65.2
	10	82.6	75.0	66.3	83.8	74.1
	14.4	79.2	70.4	57.9	72.7	66.3
	21.9	68.4	73.5	53.9	63.0	62.3

Tropicana Hybrid	5	75.0	67.3	52.7	76.7	63.9
	10	84.5	78.1	69.4	81.4	74.2
	14.4	78.5	71.6	59.1	79.2	67.6
	21.9	64.7	64.9	49.9	69.0	60.2
Bombay Red	5	70.0	51.3	47.3	67.1	54.5
	10	66.3	69.5	44.6	66.6	60.2
	14.4	75.0	70.8	53.2	71.1	62.9
	21.9	78.7	73.8	59.5	77.2	66.2
Mean		78.8	76.1	62.1	77.8	72.6
CV (%)		4.6	4.2	2.7	2.7	4.1
Main plot (Cultivar) L.S.D(0.05)		5.4	3.6	1.8	3.8	3.7
Sub-plot (Temperature) L.S.D. (.05)		5.9	5.3	2.7	3.4	4.3

NB:+ 14.4°C = Storage room temperature for Njabini

21.9°C = Storage room temperature for Kabete.

to lodging (Plate 6). Existing cultivar with the tallest scapes in the first year (1990) was Tropicana Hybrid and Red Creole was the tallest in 1991. In both years cultivars had the tallest flowerstalks at Kabete.

4.3.5 1000 Seed weight (grams)

Seed weight of 11 cultivars grown in seven environments is shown in Tables 21a and b. This trait varied among cultivars, storage temperature and locations. Bulbs stored at 10°C had higher seed weight than those stored at other temperature treatments in all cultivars. The lightest seeds were for bulbs stored at Kabete room conditions (20.9 and 21.9°C). Bulbs of Bombay Red stored at Kabete temperature (20.9 and 21.9°C) had heavier seeds than those of 10°C, 5°C and Njabini storage (13.4 and 14.4°C) temperature. The lightest seeds of Bombay Red were for bulbs stored at 5°C.

In the first seed production trial, KON7 (5.0g at 10°C) had the heaviest seeds while KON6 (2.1 g at 13.4 °C) had the lightest seeds at Kabete. At Kibirigwi KON1 had seed weight of 5.1 (heaviest) and Bombay Red (2.7g) (lightest). KON4 had the heaviest seeds (5.8g) at Marigat whereas KON6 (2.6 g at 13.4 °C) had the lightest. The cultivars with heaviest and lightest seeds at Njabini were KON7 (5.5 g at 10 °C) and Bombay Red (2.9 g at 10 °C).

Table 21a:1000-seed weight (g) of eleven onion cultivars stored at different temperature treatments and grown in four locations in Kenya in 1990

Cultivars	Temperature+	Locations				
	°C	Kabete	Kibirigwi	Marigat	Njahini	mean
KON1	10	3.7	5.1	5.3	5.2	4.8
	13.4	3.3	4.9	5.1	4.7	4.5
KON2	10	4.7	5.1	4.2	4.8	4.7
	13.4	4.3	4.9	4.1	4.4	4.4
KON3	10	4.8	4.8	4.5	4.4	4.6
	13.4	4.1	4.5	4.2	3.9	4.2
KON4	10	4.7	4.4	5.8	4.2	4.8
	13.4	4.6	4.2	5.4	3.7	4.5
KON5	10	4.6	3.2	4.9	3.9	4.2
	13.4	3.9	3.1	4.6	3.3	3.7
KON6	10	2.3	2.9	2.9	3.8	3.0
	13.4	2.1	2.8	2.6	3.2	2.7
KON7	10	5.0	5.0	4.8	5.5	5.1
	13.4	4.6	4.6	4.5	4.8	4.6
KON8	10	2.7	4.2	3.0	3.6	3.4
	13.4	2.6	3.9	2.8	2.9	3.0
Red Creole	10	2.9	2.9	4.1	3.8	3.4
	13.4	2.6	2.6	3.9	3.3	3.1
Tropicana Hybrid	10	4.1	3.8	3.3	3.1	3.7
	13.4	3.7	3.2	3.2	3.0	3.3
Bombay Red	10	3.2	2.7	3.2	2.6	3.0
	13.4	3.2	2.5	3.2	2.7	2.9
	20.9	3.3	2.8	3.3	2.9	3.1
Mean		4.0	4.0	4.1	3.6	3.9
C.V. (%)		2.7	4.2	1.8	4.9	3.4
Main plot (Cultivar) L.S.D (.05)		0.05	0.12	0.05	0.12	0.09
Sub plot (Temperature) L.S.D. (.05)		0.12	0.18	0.09	0.22	0.15

+13.4°C = Storage room temperature for Njabini
20.9°C = Storage room temperature for Kabete.

Table 21b: 1000-seed weight (g) of eleven onion cultivars stored at different temperature treatments and grown in four locations in Kenya in 1991.

Cultivars	Temperature+	Locations				
	°C	Kabete	Kibirigwi	Marigat	Njabini	mean
KON1	5	4.1	3.5	3.6	2.9	3.5
	10	5.4	3.8	4.6	3.6	4.3
	14.4	5.1	3.6	3.8	3.2	3.9
	21.9	3.9	2.3	2.9	2.7	2.9
KON2	5	2.9	3.3	3.0	3.2	3.1
	10	3.4	6.6	4.2	4.0	4.6
	14.4	3.2	4.5	3.3	3.7	3.7
	21.9	2.6	2.3	2.5	2.5	2.5
KON3	5	3.7	2.4	2.5	2.1	2.7
	10	4.3	2.9	4.0	2.6	3.5
	14.4	4.1	2.7	3.3	2.2	3.1
	21.9	3.4	2.2	2.4	2.0	2.5
KON4	5	3.9	2.8	3.2	2.5	3.1
	10	4.7	3.5	3.8	3.3	3.8
	14.4	4.3	2.9	3.4	3.0	3.4
	21.9	3.1	1.8	2.7	2.1	2.4
KON5	5	3.4	2.5	2.8	2.6	2.8
	10	4.5	3.6	3.7	3.1	3.7
	14.4	4.3	3.3	3.4	2.9	3.5
	21.9	3.3	1.9	2.2	2.0	2.4
KON6	5	2.6	2.2	2.5	2.2	2.3
	10	3.2	2.8	3.0	2.5	2.9
	14.4	3.0	2.5	2.6	2.3	2.6
	21.9	2.0	2.0	1.4	1.9	1.8
KON7	5	4.2	4.2	3.1	3.3	3.7
	10	5.3	6.4	4.4	4.1	5.0
	14.4	5.0	4.3	3.7	3.8	4.2
	21.9	3.9	3.0	3.0	3.0	3.2
KON8	5	2.6	2.1	2.8	2.0	2.4
	10	3.2	3.1	3.5	2.6	3.1
	14.4	3.1	2.2	3.0	2.3	2.6
	21.9	2.6	1.8	2.4	2.0	2.2
Red Creole	5	2.3	2.2	2.1	2.1	2.2
	10	3.2	2.9	3.0	3.0	3.0
	14.4	2.9	2.5	2.6	2.5	2.6
	21.9	2.1	1.9	1.7	1.9	1.9

ropicana Hybrid	5	3.0	2.9	3.0	2.6	2.9
	10	3.9	3.2	3.7	3.7	3.6
	14.4	3.4	3.1	3.3	3.2	3.3
	21.9	2.5	2.3	2.7	2.3	2.4
ombay Red	5	2.9	2.2	3.2	1.6	2.5
	10	2.9	2.3	3.0	2.2	2.6
	14.4	2.9	2.6	3.5	2.4	2.8
	21.9	3.0	2.6	3.8	2.6	3.0
ean		3.5	3.0	3.1	2.7	3.1
.V. (%)		4.1	9.4	5.2	7.4	6.6
ain plot (Cultivar) .S.D (.05)		0.2	0.3	0.2	0.3	0.3
ub-plot (Temperature) .S.D. (.05)		0.2	0.5	0.5	0.3	0.4

14.4°C = Storage room temperature for Njabini

21.9°C = Storage room temperature for Kabete.

In 1991 seed production trial, KON1 had seed weight of 5.4g (heaviest) and Bombay Red (3.0g) (lightest) at Kabete. At Kibirigwi, KON2 had the heaviest seeds (6.6g) and KON6 (2.8g) had the lightest. KON1 (4.6g) was the best at Marigat while KON6 (3.0g) and Red Creole (3.0g) were the worst. At Njabini the heaviest and highest seeds at 10°C were those of cultivars KON7 (4.1g) and Bombay Red (2.2g), respectively.

In 1990, the best exotic cultivar was KON7 (5.1 g) and Tropicana Hybrid (3.7 g) was the best among existing cultivars. KON7 (5.0 g) and Tropicana Hybrid (3.6 g) were the best in 1991. Marigat was the most favourable environment for the expression of this trait in 1990 while Kabete was the best in 1991 .

4.3.6 **Seed Yield (kg/ha)**

Seed yield of the eleven cultivars stored at different temperature treatments are given in Tables 22a and b. Seed yield varied among cultivars, bulb storage temperature and locations. Best seed yield was obtained from bulbs stored at 10°C followed by those stored at Njabini. Bulbs stored at Kabete room temperature had the worst seed yield followed by those stored at 5°C. Unlike other cultivars, Bombay Red had better seed yield for bulbs stored at Kabete room temperature (20.9 and 21.9 C) and the worst for bulbs stored at 5°C. Bulbs

ble 22a:Seed yield (kg ha $^{-1}$) of eleven onion cultivars stored at different
perature treatments and grown in four locations in Kenya in
1990.

ltivars	Temperature+ °C	Locations Kabete	Kibirigwi	Marigat	Njabini	mean
ON1	10	527.8	683.7	746.7	704.4	665.7
	13.4	454.4	621.1	755.2	622.2	613.2
ON2	10	597.0	688.0	674.1	685.6	661.2
	13.4	522.2	651.1	620.0	617.3	602.7
ON3	10	640.7	610.3	685.6	677.8	653.6
	13.4	509.6	578.5	627.7	622.2	584.5
ON4	10	652.6	669.6	706.7	663.7	673.1
	13.4	553.3	645.1	677.7	682.2	614.6
ON5	10	614.1	513.1	770.0	653.3	637.7
	13.4	522.2	462.9	695.6	548.2	557.2
ON6	10	368.1	408.1	318.1	597.0	422.9
	13.4	325.9	392.5	299.3	532.6	387.6
ON7	10	685.3	733.7	756.3	755.6	737.7
	13.4	577.0	665.5	696.3	685.9	656.2
ON8	10	397.0	415.4	370.7	420.0	400.8
	13.4	339.3	357.0	373.3	370.4	360.0
ed Creole	10	360.0	462.2	406.7	533.3	440.6
	13.4	340.8	405.1	393.9	442.9	397.7
opicana Hybrid	10	359.4	428.1	510.4	320.0	404.5
	13.4	343.2	358.5	361.9	278.5	335.5
mbay Red	10	475.6	405.1	228.1	285.2	348.5
	13.4	478.5	414.0	229.6	284.4	351.7
	20.9	490.7	431.9	239.4	289.6	362.9
ean		484.1	521.8	528.0	520.2	515.8
.V. (%)		3.0	2.1	4.6	4.3	3.8
in plot (Cultivar) .S.D. (.05)		10.1	8.0	20.6	16.4	13.8
ub plot (Temperature) .S.D. (.05)		20.3	12.7	28.1	26.2	21.8

able 22b:Seed yield (kg ha^{-1}) of eleven onion cultivars stored at different emperature treatments and grown in four locations in Kenya in 1991.

ultivars	Temperature °C	Kabete	Kibirigwi	Marigat	Njabini	mean
		Locations				
ON1	5	271.9	234.8	221.8	214.0	235.6
	10	726.2	645.5	800.0	414.1	646.5
	14.4	457.9	420.7	608.9	382.4	467.5
	21.9	129.8	173.6	164.3	161.4	157.0
ON2	5	215.4	220.8	228.6	228.8	223.4
	10	712.9	502.6	447.1	427.9	522.6
	14.4	613.8	401.5	359.0	298.2	443.1
	21.9	113.2	153.3	172.9	115.3	138.7
ON3	5	197.0	244.4	185.2	169.4	199.0
	10	390.5	462.2	513.9	385.7	438.1
	14.4	258.4	362.2	321.2	252.6	298.6
	21.9	138.5	187.4	173.8	126.8	156.6
ON4	5	395.5	352.6	266.8	261.0	319.0
	10	691.5	574.8	720.0	417.1	600.9
	14.4	513.0	471.1	650.6	391.2	506.5
	21.9	146.8	268.1	192.9	139.4	186.8
ON5	5	308.5	293.3	154.4	253.4	252.4
	10	781.5	400.5	622.4	362.4	541.7
	14.4	345.1	344.4	499.9	348.7	384.6
	21.9	136.5	125.5	90.7	152.6	126.3
ON6	5	197.3	201.5	50.5	84.8	133.5
	10	367.5	245.9	319.6	208.3	310.3
	14.4	331.3	316.3	258.2	191.8	274.4
	21.9	74.6	88.8	43.4	41.8	62.2
ON7	5	320.8	235.6	211.3	209.6	244.3
	10	766.7	636.3	674.0	574.8	663.0
	14.4	491.8	523.0	551.6	485.5	512.9
	21.9	113.6	128.1	184.5	105.2	132.8
ON8	5	241.4	233.3	94.0	94.9	165.9
	10	404.3	390.7	210.3	207.3	303.2
	14.4	266.7	343.7	198.4	189.4	249.6
	21.9	77.9	65.1	78.4	78.8	75.1
ed Creole	5	99.3	151.8	49.6	68.6	92.3
	10	353.7	274.1	381.1	166.2	293.8
	14.4	297.5	263.0	275.5	152.2	247.0
	21.9	72.0	90.3	41.9	44.7	63.5

Tropicana Hybrid	5	219.0	230.4	123.2	128.9	175.4
	10	516.3	364.4	418.9	389.3	422.2
	14.4	372.2	297.8	242.1	249.5	290.4
	21.9	84.4	129.3	105.2	104.4	105.8
Bombay Red	5	436.4	295.2	107.6	44.6	212.0
	10	403.0	315.9	107.6	95.4	230.5
	14.4	521.5	324.5	113.4	98.0	264.6
	21.9	537.8	345.2	139.6	156.3	303.0
Mean		343.6	304.4	281.6	222.1	288.0
C.V. (%)		4.2	8.3	4.3	2.4	5.3
Main plot (Cultivar) L.S.D. (.05)		18.9	21.1	10.8	6.6	14.4
Sub plot (Temperature) L.S.D. (.05)		23.8	41.5	19.8	8.5	23.4

* 14.4°C = storage room temperature for Njabini
21.9°C = storage room temperature for Kabete.

stored at 0 °C did not flower but remained dormant and finally rotted. Those stored at Kabete ambient temperature (20.9 °C) in 1990 did not produce flower stalks whereas the ones stored in 1991 (21.9 °C) did. In 1990, KON7 had the highest seed yield (685.3 $kgha^{-1}$ at 13.4 °C) at Kabete while KON6 was the worst (325.9 $kgha^{-1}$ at 10 °C). At Kibirigwi, KON7 was still the best (733.7 kg ha^{-1} at 10°C) while KON8 (357 kg ha^{-1} at 13.4 °C) was the worst. The best and worst cultivars at Marigat were KON5 (770.0 kg ha^{-1} at 10°C) and Bombay Red (228.1 $kgha^{-1}$ at 10 °C, respectively. At Njabini KON7 (755.6 $kgha^{-1}$ at 10°C) recorded the highest seed yield and Bombay Red (284.4 $kgha^{-1}$) the least.

In the second seed production trial (1991), KON5 recorded the highest seed yield (781.5 $kgha^{-1}$ at 10°C) while Red Creole had the least (72 at 21.9 °C) at Kabete. At Kibirigwi, KON1 (645.5, 10 °C) had the best seed yield while KON8 had the worst (65.1 $kgha^{-1}$ at 21.9 °C). KON1 (800.0 $kgha^{-1}$) and Red Creole (65.1 $kgha^{-1}$), had the highest and least seed yield at Marigat, respectively. At Njabini KON7 (574.8 $kgha^{-1}$ at 10°C) was the best cultivar while KON6 was the worst (41.8 $kgha^{-1}$ at 21.9°C).

The best cultivar for seed production over all the four locations was KON7 yielding 737.7 $kgha^{-1}$ in 1990 and 663.0 $kgha^{-1}$ in 1991. Marigat was the most favourable environment for seed production in 1990 while

Plate 7 :Onions seed production at Kabete in 1991

Kabete was the best in 1991 (Plate 7).

4.3.7. Percentage germination

Percentage germination of the eleven onion cultivars stored at different temperature treatment is given in Tables 23a and b. Germination varied among cultivars and locations (1991). In 1990, the only interaction that was significant was Var. x Temp. whereas in 1991 all interactions except Loc. x Temp., were significant.

In 1990, KON8 (94.4% at 10° C) had the best seed germination over all environments. At Kabete, KON2 (94.8% at 13.4° C) had the highest percentage germination while KON7 (86.5% at 13.4° C) had the lowest. KON4 (95.5% at 10° C) and KON3 (86.5% at 13.4° C), had the best and worst percentage germination, respectively, at Kibirigwi. KON2 (96.0% at 10° C) had the highest percentage germination while KON1 (65.3% at 13.4° C) had the lowest at Marigat. At Njabini, KON8 (94.5% at 10° C) had the highest and KON3 (88.2% at 10° C) the lowest percentage germination. There was no variation in seed germination among environments in this year.

In 1991, cultivars harvested at Njabini had the highest seed germination (82.0%) while there was no significant difference among other sites. KON4 had the best seed germination over all environments in this year. At Kabete, KON4 (85.3% at 10° C) had the highest while KON5 (72.7% at 21.9° C) had the lowest percentage able 23a: Percentage germination of seeds of eleven onion cultivars stored at different temperature treatments and grown in four locations in Kenya in 1990.

ultivars	Temperature+ °C	Kabete	Kibirigwi	Marigat	Njabini	Mean
		Locations				
ON1	10.0	92.3	89.8	88.8	89.0	90.0
	13.4	92.0	94.0	65.3	93.3	86.4
ON2	10.0	92.3	94.8	96.0	92.2	93.8
	13.4	94.8	94.0	94.5	93.8	94.3
ON3	10.0	88.7	86.8	88.7	88.2	88.1
	13.4	88.3	86.5	83.8	87.3	86.5
ON4	10.0	92.7	95.5	95.7	92.7	94.1
	13.4	93.5	92.3	90.7	92.5	92.2
ON5	10.0	93.3	92.8	94.3	94.0	93.6
	13.4	87.2	87.3	86.3	87.3	87.0
ON6	10.0	89.8	90.0	90.7	91.0	90.4
	13.4	91.7	90.8	92.2	91.7	91.6
ON7	10.0	91.7	91.8	91.3	91.0	91.4
	13.4	86.5	88.3	86.8	87.7	87.3
ON8	10.0	94.2	93.8	95.3	94.5	94.4
	13.4	92.3	90.9	92.8	92.3	92.1
ed Creole	10.0	90.7	91.0	90.7	89.5	90.5
	13.4	91.5	92.3	90.7	92.5	91.7
ropicana	10.0	88.8	90.8	88.3	88.5	89.1
ybrid	13.4	88.5	90.3	89.2	90.2	89.5
ombay Red	10.0	89.3	90.0	89.2	89.2	89.4
	13.4	91.7	91.0	89.8	91.0	90.9
	20.9	90.0	90.8	89.0	90.0	90.0
lean		90.9	91.2	89.6	90.8	90.6
.V. (%)		2.0	1.6	9.4	1.6	7.3
lain plot (cultivars) ..S.D. (.05)		2.3	1.7	6.3	1.8	3.0
ub plot (Temperature) ..S.D. (.05)		4.3	3.7	4.2	3.6	4.0

13.4; Storage temperature for Njabini
20.9; Storage temperature for Kitale

Table 23b: Percentage germination of seeds of eleven onion cultivars stored at different temperature treatments and grown in four locations in Kenya in 1991.

Cultivars	Temperature+	Locations				
	°C	Kabete	Kibirigwi	Marigat	Njabini	mean
KON1	5.0	80.5	75.0	78.7	83.3	79.4
	10.0	77.7	75.8	78.0	85.0	79.1
	14.4	75.8	78.8	81.3	83.8	80.0
	21.9	79.2	77.8	77.2	85.3	79.9
KON2	5.0	84.5	75.5	71.8	86.5	79.6
	10.0	81.7	82.3	72.2	86.3	80.6
	14.4	79.7	74.0	72.7	82.7	77.3
	21.9	74.5	74.0	73.5	84.7	76.7
KON3	5.0	81.0	82.8	76.5	83.3	80.9
	10.0	75.0	80.7	74.2	82.3	78.0
	14.4	77.2	79.8	75.5	84.5	79.3
	21.9	77.7	79.7	73.0	83.0	78.3
KON4	5.0	85.3	76.5	79.2	85.7	81.7
	10.0	73.3	70.2	78.5	83.3	76.3
	14.4	75.5	75.7	78.3	75.2	76.3
	21.9	76.3	77.7	76.3	80.3	77.7
KON5	5.0	79.8	72.7	75.7	81.7	77.5
	10.0	76.5	74.7	74.2	82.3	76.9
	14.4	77.3	73.7	77.7	80.7	77.3
	21.9	72.7	71.7	73.3	79.3	74.3
KON6	5.0	74.7	75.3	68.7	77.8	74.1
	10.0	74.3	80.0	71.3	82.2	77.0
	14.4	79.3	77.2	77.7	78.2	78.1
	21.9	76.5	76.0	73.2	77.0	75.7
KON7	5.0	72.7	76.0	80.5	83.2	78.1
	10.0	73.2	74.0	80.8	82.7	77.7
	14.4	75.3	77.7	75.2	84.0	78.0
	21.9	75.5	76.3	76.8	82.5	77.7
KON8	5.0	75.7	80.8	80.8	85.7	80.8
	10.0	75.3	72.0	80.7	85.7	77.9
	14.4	76.5	77.7	77.0	82.5	78.4
	21.9	78.5	75.3	72.5	83.3	77.4
Red Creole	5.0	75.3	73.5	75.0	80.2	76.0
	10.0	75.0	74.4	74.5	80.3	76.1
	14.4	78.2	73.7	73.0	81.5	76.6
	21.9	76.0	80.5	77.5	77.8	78.0

Tropicana Hybrid	5.0	73.0	83.2	72.3	80.0	77.1
	10.0	78.3	68.7	72.3	80.0	74.8
	14.4	79.3	74.3	75.0	80.2	77.2
	21.9	77.2	72.3	77.2	77.3	76.0
Bombay Red	5.0	76.0	74.7	75.3	82.5	77.1
	10.0	74.7	80.0	74.5	79.7	77.2
	14.4	75.2	78.5	73.3	81.5	77.1
	21.9	74.7	76.7	79.0	81.3	77.9
Mean		76.8	76.3	75.7	82.0	77.7
C.V. (%)		2.1	4.9	2.4	3.3	3.4
Main plot (Cultivar) L.S.D. (.05)		3.4	7.2	3.7	4.9	4.8
Sub plot (Temperature) L.S.D. (.05)		4.2	9.7	4.7	7.1	6.8

+14.4 = Storage room temperature for Njabini.
21.9 = Storage room temperature for Kabete.

germination. Tropicana Hybrid (83.2% at 10° C) had the best while it had the worst (68.7% at 10° C) at Kibirigwi. At Marigat,KON8 (80.8% at 10° C) and KON6 (68.7% at 10°C), had the highest and lowest percentage seed germination, respectively. KON5 had the best (86.5% at 10° C) and KON4 had the worst (74.1% at 10° C) at Njabini.

Seed germination varied among years. All cultivars had better seed germination in 1990 than in 1991. Seeds harvested from Kabete , Kibirigwi and Njabini had better seed germination than those from Marigat in both years. KON8 (94.4 % in 1990) had the best germination in the two years.The best germinating cultivars in 1990 were not necessarily the best in 1991.There was not much variation in percentage germination among bulb storage temperatures

Table 24a: Mean squares from combined analysis of variance for five traits of eleven onion cultivars stored at different temperatures and grown in four locations in Kenya in 1990.

Source of variation	D.f.	Seed yield kg/ha	Stalk height (cm) $x\ 10^{-1}$	Umbels $plant^{-1}$ $x\ 10^{-2}$	1000-seed weight(g)	Percentage germination
Locations	3	21920.3**	658.6**	200.1**	107.2**	24.7
Reps/locations	8	329.1	3.7	0.1	0.9	26.5
Variety	10	239983.4**	1180.9**	63.0**	827.4**	2943.2**
Loc. x Var.	30	29399.3**	81.7**	10.2**	117.0**	21.5
Error	80	222.2	2.7	0.1	0.9	20.6
Temperature	2	10645406.6**	165056.9**	4053.0**	57297.1**	299368.7**
Loc. x Temp.	6	16215.1**	180.1**	53.5**	38.8**	36.1
Var. x Temp.	20	172768.1**	1885.4**	58.3**	816.1**	3018.2**
Var.x Temp.x Loc.	60	4230.5**	29.0**	3.2**	28.9**	17.5
Error	176	188.2	2.3	0.1	0.9	21.1

** Significance at 1 percent level of significance.

le 24(b): Mean squares from combined analysis of variance for six traits of eleven onion cultivars stored at different temperatures and grown in four locations in Kenya in 1991.

rce of iation	D.f.	Seed yield Kg/ha	Stalk height (cm)	Days to flowering	1000 seed -weight (gms)x10^{-1}	Umbels Plant^{-1} x 10^{-1}	Percentage germination
ations	3	130473.5**	6685.6**	11086.4**	103.4**	438.0**	1090.9**
s/Locations	8	429.8	25.0	7.0	0.7	0.3	7.7
iety	10	250577.8**	1831.8**	2496.2**	109.1**	92.9**	68.0**
. x Var.	30	46198.7**	197.3**	612.1**	22.5**	14.2	40.8**
or	80	305.7	27.1	7.0	0.5	0.3	10.3
perature	3	2428227.0**	2954.3**	4154.8**	296.6**	257.0**	33.7**
. x Temp.	9	37631.7**	71.3**	126.2**	4.74**	16.6**	12.5
. x Temp.	30	59350.3**	83.3**	86.6**	8.41**	7.8**	22.5**
. x Temp. x Loc.	90	10144.5**	29.8**	17.1**	3.1**	1.5**	20.2**
or	264	305.9	8.8	5.6	0.4	0.3	6.8

Significant at 1 Percent level of significance.

CHAPTER V

DISCUSSION

5.1 EXPERIMENT I GENOTYPE X ENVIRONMENT INTERACTIONS:

5.1.1 Mean Performance

The major objectives of onion breeding in Kenya are to develop high yielding, early maturing and disease resistant cultivars with long shelf-life. The existing cultivars have not adequately met these objectives. Cook (1963) observed that the existing cultivars, Bombay Red was susceptible to purple blotch. Introduction of other cultivars to broaden the genetic base to meet these objectives is indispensable. Such cultivars have to meet other consumer preferences such as globe shaped bulbs with red to brown skin colour.

Hybrids and open-pollinated cultivars were introduced from Israel. The results indicated that some of the introduced cultivars have considerable potential for Kenyan onion growers. The cultivars were grown in environments which were a fair representative to those of main onion growing areas. The exotic cultivars outyielded the existing ones in all environments except at Kibirigwi in 1991. The hybrids, because of hybrid vigour, did better than the open-pollinated populations. The best exotic cultivars were KON1, KON3, KON4 and KON7. KON4, a red brown hybrid yielded 52.2 tons ha^{-1} at Kabete in 1990. The top ranking cultivar overall environments was KON3 (35.6 tons^{-1}). Generally the exotic cultivars did quite well in most of the locations compared to the existing ones. However, they were highly susceptible to purple blotch (*Alternaria porri*) which is one of the most important fungal diseases of onions in Kenya. The disease was more prevalent in areas with high humidity and temperature. Selection for resistance to *Alternaria porri* should be investigated.

Marigat was the best site for onion production. Perhaps this was due to the high temperatures which encouraged bulbing and also low disease incidence. Jones and Manns (1963) noted that onions bulbed more quickly at warm than at cool temperatures The serious problems at Marigat were thrips and nutgrass. Mohdhar (1977) noted that thrips were present in onion crop throughout the year and necessitated routine control measures. Thrips were successfully controlled by spraying Rogor L40. Existing cultivars did relatively poorly in all environments. Bombay Red showed tendency to bolt in all environments thus resulting in poor yield.

Early maturing cultivars are desired because they have potential of escaping diseases and moisture problem. Moreover, they give the farmer ample space and time to be planted with other crops because of their fast removal from the field. The earliest maturing cultivar over all environments was Red Creole while KON8 was late maturing. There was not much variation in maturity between the exotic and the existing cultivars. Maturity varied with the environments. All cultivars matured earliest at Marigat and latest at Oljorok. Low temperatures at Oljorok (max.21.6°C and min. 6.9° C) induced poor bulbing as opposed to high temperatures at Marigat (max.33.4 and min.17.0°C) which resulted in rapid bulbing.

Bulb weight varied between cultivars and environments. The exotic cultivars had higher bulb weight than the existing ones. The exotic cultivars were adapted to most environments thus had maximum expression of this trait. Marigat and Kabete recorded the highest bulb-weight. Favourable environmental conditions for onion production in these sites led to maximum expression of bulb weight.

Dry matter in bulb onions varies from low levels of (7-10) to high levels of (15-20%)(Currah and Proctor, 1990). Onions with high dry matter content (>20%) are preferred for processing. Dry matter content for the eleven cultivars ranged from 4.0 to 12.4%. This trait did not display much variation across environments but varied among cultivars. The exotic cultivars had lower dry matter content than the existing ones. Among the new ones, KON8 recorded the highest dry matter content (9.1%). Tropicana Hybrid had the highest dry matter content (12.4% at Kibirigwi). The exotic cultivars bred in Israel had low dry matter content. This agrees with what had been reported by Currah and Proctor (1990). Onions with high dry matter content tend to yield less than onions with low dry matter content. The latter also exhibit rapid bulbing.

Bulb-shape is an important selection criteria, the preferred shape depending on the market (Dowker and Fennel, 1974a). Generally, globe-shaped bulbs (shape-index = 1) are preferred by consumers. Dowker and Fennel (1974a) observed that bulb-shape and bulb weight are negatively correlated. They argued that variation in bulb shape over environments was due to the effect of the environment on the bulb weight. However, this trait varied among cultivars but not environments. Existing cultivars had low bulb weight and tended towards globe-shape than the exotic ones.

5.1.2. Genotype-Environment Effects

The objective in many plant breeding programmes is the selection of genotypes that are consistently high yielding over the range of environments that occur in different locations or seasons. However, this selection is impeded by the failure of genotypes to have the same relative performance in different environments. This phenomenon is caused by genotype-environment interactions.

For the traits considered, genotype x environment interactions were significant for bulb yield and shape-index but not significant for bulb weight, maturity and dry-matter content. This indicates that the cultivars responded differently when grown under different environments for bulb-yield and bulb shape. Dowker and Fennel (1974b) detected no significant G x E interactions for yield and storage qualities in the cultivars they were working with. Fennell and Salter (1977) observed significant G x E interactions for maturity and bulb yield in cultivars of Japanese origin.

The desired genotypes should show low G x E interactions for agriculturally important traits, or may be flexible for other traits. Such genotypes are said to be well buffered as they can adjust their genotypic and phenotypic states in response to changing environmental conditions a phenomenon called genetic homeostasis (Verma and Gill, 1975).

The lack of significant G x E interactions for bulb weight, maturity and dry matter indicates that the relative performance of the cultivars was essentially similar in all environments tested. The significant genotype x environment interactions observed for bulb yield and shape indicates that selection for average performance over the entire area from which the locations were drawn may not be considered. This interaction variance can be reduced by finding a criterion for establishing sub-regions or areas. Such criteria for stratification or division into regions could be the soil type or rainfall (Verma and Gill, 1975). Most suitable cultivars for Marigat and Oljorok were KON7 and KON4. Cultivar KON3 was the best for Kibirigwi and Kabete.

5.1.3 Adaptation and Stability Analysis

Stability of performance is the ability of the genotype to show minimum interaction with environments. Adaptability refers to the response of a particular genotype to varying environments. Regression technique of Eberhart and Russell (1966) was used to determine the adaptability and stability parameters. Regression coefficient (bi) and mean performance (xi) were used to determine the adaptability of the cultivars. Stability was estimated as the squared deviations from regression coefficients (s^2di). An ideal cultivar should have above average mean performance, unit regression coefficient (bi = 1) and least deviation from regression (s^2di = 0).

Bulb-Yield

The varieties with mean yield above the overall mean were KON1, KON2, KON3, KON4 and KON7. KON1, KON3 and KON7 were specifically adapted to favourable environments (Marigat and Kabete). KON2 and KON4 had general adaptability. Open pollinated cultivars (KON 8, and KON6) and Tropicana Hybrid were poorly adapted to all environments. Red Creole and Bombay Red were adapted to unfavourable environments (Oljorok and Kibirigwi in 1991).

All varieties except KON2 were not stable for bulb yield. KON4, though not stable, had good attributes of high yield, good adaptation in all environments and red-brown colour preferred by consumers. Other desirable cultivars were KON2, KON7, KON1 and KON3. The red coloured exotic cultivars KON6 and KON8 had poor adaptation and stability. Existing cultivars also had poor stability and adaptability. The most favourable environment was Marigat while Oljorok was the worst.

Bulb-Weight

KON1, KON4 and KON6 were specifically adapted to favourable environments. KON7 and KON3 had, general adaptation and were stable for this trait. The existing cultivars and KON8 had poor adaptation. All cultivars were not stable for this trait. KON7 was the best cultivar in respect to bulb weight because it had good adaptation for this trait. Kabete had the heaviest bulbs while Kibirigwi (1991) had the lightest.

Maturity

KON2, KON4, KON5 and KON6 had general adaptation and good stability for maturity. These cultivars also matured early. KON1 also had general adaptation but was late maturing. Existing cultivars had poor adaptation for maturity. KON3 and KON7 and KON8 had specific adaptation to favourable environments. In general, the best cultivars were KON2, KON4, KON5 which had good productivity, adaptation and stability for maturity. Cultivars matured earliest at Marigat and latest at Oljorok.

Dry-matter Content

Though the existing cultivars had high dry matter, their adaptability and stability was poor. KON2, KON3, KON4 and KON7 had poor adaptation. KON6 and KON8 were stable for dry matter. Tropicana Hybrid had the highest dry matter content though it had poor adaptation and stability. KON6 and KON8 had the best attributes of good adaptation and stability for this trait. Oljorok had bulbs with the highest dry matter content while Marigat had the least.

Shape-Index

KON2, KON4, KON5, KON6 and KON7 were specifically adapted to favourable environments. KON1 and KON8 and Bombay Red were specifically adapted to unfavourable environments. KON3, Red Creole and Tropicana Hybrid were widely adapted for bulb-shape. KON2, KON3, KON7 and Tropicana Hybrid were stable for this trait. KON3 was the best cultivar because it had almost globe-shaped bulbs, wide adaptation and good stability for this trait.

5.2 EXPERIMENT II - SHELF-LIFE

5.2.1 Mean peformance

Breeding cultivars with a long shelf-life is one of the major objectives in onion breeding. Storage losses in the tropics are high due to high temperatures and humidity. Trials were needed to evaluate the shelf-life of different cultivars under the tropical conditions. To minimise storage losses in onions, identification of superior genotypes is necessary.

The wastage of bulb onions in store results from rotting, sprouting, dessication and damage. In the present work losses due to dessication were not assessed. Only losses due to rotting and sprouting were assessed. The mechanisms controlling the two wastage components are different but, in commercial practice, it is the combined effect of the components which frequently determines how long a crop can be safely stored.

Storage trials were conducted for a period of four months. Storage losses during the four months ranged from 26.7 to 100%. The exotic cultivars had better shelf-life than the existing ones. The best storing exotic cultivar was KON2 with a mean storage loss of 41.1% overall storage trials. Perhaps the loss could have been less were it not for the pink-root rot infected bulbs harvested at Kibirigwi in 1991. Other better storing cultivars were KON1 and KON4. Generally, the hybrids had better shelf-life than the open-pollinated cultivars. Of the three existing cultivars, Red-Creole was the best-storing cultivar with 50% mean storage loss in two and half months of storage. Chang *et al* (1987) working on cultivars Granex, Texas Early Grano 502, White Creole and Red Creole observed that the Red Creole was the worst in terms of shelf-life. They noted 50% storage loss in two months in this cultivar. Shelf-life did not vary much with environments. Bulbs harvested from Kibirigwi in 1991 had the least shelf-life.

Many workers have associated high dry matter content with better keeping quality (Jones and Mannis, 1963; Foskett and Peterson, 1950; Chang *et al*., 1987). In contrast, the Israel cultivars had low dry matter content but had better shelf-life than the existing cultivars with high dry matter content. Peters *et al* (1989) reported that these short day Israel cultivars have been selected for improved shelf-life.

Bulb-colour has also been associated with bulb-keeping quality. Red-skinned bulbs have been reported to have better shelf-life than light skinned ones (Aman and Kadam 1990; Bajaj, 1990). Tucker and Drew (1982) and Breadale *et al* (1969) had earlier reported that skin colour had no effect on shelf-life of bulbs. The eleven cultivars used in this study had red, red-brown and yellow coloured bulbs. Most of the best storing cultivars were white and yellow in colour. Exotic cultivars such as KON8 and KON6 and the existing ones which were red coloured had poor shelf. Skin colour, therefore, had no effect on shelf-life.

5.3 EXPERIMENT III - SEED PRODUCTION

5.3.1 Effect of Bulb-Storage Temperature on Seed Production.

Cook (1963) recognized that onion breeding in Kenya will depend on a method to induce flowering. Onions require low temperature (vernalization) for flower induction (Chang *et al*, 1987; Brewster, 1982). Flowering and seed yield of onions is afffected by the storage temperature at which mother bulbs are kept (Holdsworth and Heath, 1950; Hesse *et al.*, 1979). This experiment was conducted to identify an optimum temperature for flower induction and ascertain the possibility of inducing flowers by natural vernalization of bulbs at high altitude area (Njabini).

In this study, bulbs stored at 0 C did not initiate flowers but remained in a state of dormancy which culminated in rotting. Low temperature keep bulbs dormant (Karmarkar and Joshi (1941; Currah and Proctor, 1990; Thompson, 1982). Bulbs stored at Kabete room temperature (20.9°C) for the first season did not flower. However, flowering occurred for the bulbs stored in the second season.

Flowering was successful for bulbs stored at 5°C, 10°C and at high altitude area (Njabini). Bulbs stored at 10°C resulted in earlier flowering, a larger number of umbels, heavier seeds, and a higher seed yield than bulbs stored at higher or lower temperatures. Similar results were obtained by other workers. DeMille and Vest (1976) observed that bulbs stored at 7°C followed by 2°C had higher seed yield and heavier seeds than those stored at 2°C. The number of umbels plant^{-1} was not affected by storage temperature. Hesse *et al* (1979) using onion inbreds and four storage temperature treatments observed that storage treatment of 10°C for 12 weeks resulted in significantly higher seed yield, earlier flowering, most number of umbels plant^{-1} than 2°C. Jones and Manns (1963) reported that temperatures varying from 4.5 to 14°C with an optimum of 11-12°C are the best for flower induction. Brewster (1977 and 1982) observed that the most favourable temperature for inflorescence initiation is 9-13°C.

Bulbs stored at high altitude area (Njabini) with a storage room temperature of 13.4 and 14.4°C had successful flowering. They had higher seeds yield than those stored at 5°C. The latter treatment may have required a longer vernalization period because low temperature maintains bulbs in a state of dormancy.

The above responses were true for all cultivars except Bombay Red. This cultivar bolted in all sites and responded in a different manner to storage temperature treatments. The cultivar flowered earlier and had higher seed yield for bulbs stored at Kabete room (20.9 and 21.9°C) temperatures. This indicates that the cultivar had higher temperature vernalization requirement. Low temperatures delayed flower development in this cultivar.

The most favourable temperature for seed production was 10°C and natural vernalization at high altitude is feasible. Brewster (1977) observed that bulb storage at 0°C or 30°C halved the rate of leaf initiation at the apex compared to 15°C. The use of growth regulators such as GA_3 and ethephon to improve onion seed production using naturally vernalised bulbs should be investigated.

Seed Yield

The exotic cultivars had better seed yield than the existing ones. Bulbs stored at 10°C had higher seed yield than those stored at Njabini storage temperature . At storage temperature of 10°C, KON7 and KON1, were the best cultivars in 1990 and 1991, respectively. Other cultivars with good seed yield at this treatment were KON4, KON2 and KON5. In 1990, KON4 and KON1 recorded the highest seed yield for bulbs stored at Njabini. In the second trial (1991), KON4 and KON7 were the best at this treatment. Generally hybrids had higher seed yield than open pollinated cultivars at all temperature treatments. The most favourable site for seed production in 1990 was Marigat. In 1991, Marigat recorded low seed yield because the crop was infested with nut-grass when the scapes were developing. Best site for seed production in 1991 was Kabete while the worst was Njabini. The other seed production related traits, namely, umbels plant^{-1}, 1000-seed weight and stalk weight had a similar response to temperature treatment as seed yield. Demille and Vest (1976) observed that storage of bulbs at temperatures between 7.5 and 12°C resulted in a large number of umbels and a higher seed yield than that of bulbs stored at higher or lower temperatures or in common storage. Hesse and Vest (1979) noted that a storage temperature of 10°C had higher seed yield, taller scapes, more umbels than other temperatures.

Days to Flowering

Days to flowering varied with temperature treatment and cultivars. Bulbs stored at 10°C were the earliest to open and 5°C treatment were the last to open for all non-bolting cultivars. Bombay Red flowered earliest for bulbs stored at Kabete ambient conditions. Sinnadurai (1970) also reported a Nigerian cultivar which would initiate flowers with no low temperature treatment. The earliest cultivars to flower at 10°C were Tropicana Hybrid and KON6. KON6 and Bombay Red flowered earliest for bulbs stored at Njabini. The exotic cultivars did not have an advantage over the existing ones for days to flowering. Flowers opened earliest at Marigat. High temperatures at Marigat accelerated inflorescence development. At Njabini flowers opened very late compared to other sites. Perhaps this can be attributed to the prevailing low temperatures (12- 14°C) at this high altitude area. Brewster (1982) noted that high temperatures favour inflorescence growth after floral induction while low temperature inhibits.

Onion seed production is affected by bulb storage temperature as demonstrated by this study. Moreover, it is affected by shelf-life and productivity of the cultivars. Bulbs with good shelf-life are necessary for profitable seed production. Chang *et al* (1987) observed that in situations where bulb loss is more than 50% in storage, seed production is not economical. In this study, the cultivars with the highest bulb yield, KON1 (32.1), KON4 (29.4), KON7 (34.7), also had the best seed yield of 665.7, 673.1 and 737.7 respectively. Selection for high bulb yield in these cultivars is likely to result into good seed yield. Perhaps the correlation between bulb and seed yield can be explained in terms of bulb size. Currah (1981) noted that large sized bulbs produced more umbels, flowerstalks and seeds than small ones. Larger bulbs have more flower buds than smaller ones (Chang *et al*, 1987).

Seed germination

Seed germination varied among cultivars with KON8 (94.4%) in 1990 being the best .In 1991 percentage germination was lower than that of 1990 and also varied with the locations. Austin (1972) noted that percentage seed germination varied considerably between years of production. He observed that changes in weather conditions during seed growth and ripening influenced seed composition and subsequent performance. Poor seed germination may also be due the method of cleaning that was used .In 1991 seeds were cleaned with water and dried at 20°C for two weeks. In 1990 they were cleaned by blowing , sieving and winnowing.

During the two seasons Marigat recorded a higher temperature than the other three sites (Appendices 6-11). However ,seeds harvested at this site had the worst seed germination . Brewster (1982) and Gray *et al* (1986) observed that seeds from crops grown at high temperature had a higher percentage seed germination than those grown at lower temperature . This discrepancy may be attributed to seed damage caused by differetial rates of result into good seed yield. Perhaps the correlation between bulb and seed yield can be explained in terms of bulb size. Currah (1981) noted that large sized bulbs produced more umbels, flowerstalks and seeds than small ones. Larger bulbs have more flower buds than smaller ones (Chang *et al*, 1987).

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CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

1. Genotype x environment (linear) effects were highly significant for bulb yield and shape. This indicates that the varieties differed for their regression on environmental index. The relationship between genotype performance and environmental value was not linear for these traits. There was lack of correspondence between genetic and non-genetic effects for bulb yield and shape thus reducing the correlation between the phenotype and the genotype. Further breeding programs, therefore, will need to consider these effects.
2. Genotypes had varied response to specific environments for different characters considered. Most of the exotic cultivars had specific, wide adaptation and good stability to the environments tested. It is recommended that the full potential of these cultivars, especially the hybrids, be further investigated.
3. Deviations from regression were highly significant for all the traits implying that the onion cultivars differed in their non-linear responses to changes in environments.
4. The exotic cultivars had better shelf-life than the existing ones. The best exotic cultivars were KON1, KON2 and KON4. Red Creole was the best among the existing cultivars though very poor compared to the

new cultivars. It is recommended that more storage trials should be conducted to ascertain their storage potential. Cultivar selection for better shelf-life should go hand-in-hand with improved cultural practices to improve shelf-life of the new and existing cultivars.

5. All cultivars except Bombay Red had higher seed yield and weight, more umbels per mother bulb and flowered earlier for bulbs stored at 10 °C than for those stored at 5 °C, Njabini (13.4 and 14.4°C) and Kabete (20.9 and 21.9 °C). Thus, the most favourable temperature for flower induction is approximately 10°C. The optimum duration of vernalization at this optimal temperature should be investigated.

6. Bulbs stored at high altitude area (Njabini 12-14°C) had higher yield and seed weight, more umbels per mother bulb and flowered earlier than those stored at 5°C and Kabete room temperatures (20.9-21.9°C). It is possible, therefore, to produce onion seeds naturally so long as the altitude is high enough (≥2530 metres) to provide the required vernalization temperature. Use of plant growth regulators such as ethephon and gibberellic acid (GA_3) to improve seed production using naturally vernalised bulbs should be investigated.

7. The exotic cultivars had better seed production potential than the existing ones. Those cultivars

with good bulb yield and long shelf-life, such as KON1, KON2, KON3 and KON4, had excellent seed production potential. Further investigations based on cultivar selection for good productivity and long shelf-life is likely to improve seed production.

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Appendix I: Analysis of variance table when cultivars are tested at individual environments.

Source of variation	D.f.	Mean square	Expectations	F-test
Replicates	(r-1)	M1		M1/M3
Genotypes	(g-1)	M2	$\sigma^2_e + r\sigma^2_g$	M2/M3
Error	(r-1) (g-1)	M3	σ^2_e	

Appendix II: Source of variation, degrees of freedom, mean squares and expectation of mean squares for combined analysis of variance

Source of variation	d.f.	ss	ms	ems
Replications in environments	E(r-1)	Pooled over environments	RMS	
Environments	E-1	$\frac{1}{gr}\sum_j y^2_{ij}$ - c.f.	EMS	$\sigma^2_e + gr\frac{\sum E^2_i}{E-1}$
Genotypes	g-1	$\frac{1}{nr}\sum_i y^2_{i.}$ - c.f.	GMS	$\sigma^2_e + nr\frac{\sum g^2_i}{(g-1)}$
Genotype x environments	(g-1)(E-1)	$\frac{1}{r}\sum_i \sum_j y^2_{ij}$-c.f-genotypes - environment ss	G x EMS	$\sigma^2_e + \frac{r\sum\sum(gE)^2}{(E-1)(g-1)}$
Error	E(r-1)(g-1)		eMS	σ^2_e

Appendix III: F-ratios to test effects of main and interaction effects for combined analysis of variance

Source of variation	Mean squares	F-tests
Locations	M1	M1/M2
Reps/Locations	M2	
Genotypes	M3	M3/M4
Loc. x genotypes	M4	M4/M5
Pooled error	M5	

Appendix IV: Sources of variation, degrees of freedom of regressio analysis (Eberhart and Russell, 1966 model).

rce of variation	d.f.	ss	mss
al	ng-1	$\sum_i \sum_j y^2_{ij}$ - c.f.	
otypes	g-1	$\frac{1}{n} \sum_i y_{i.}^2$ - c.f.	M1
+(Genotype x Env.)	g(n-1)	$\sum_i \sum_j y^2_{ij} - \sum y^2_{i.}/n$	
ronment (Linear)	1	$\frac{1}{g} (\sum_j y_{.j} I_j)^2 / \sum_j I_j^2$	
otype x Env. (Linear)	(g-1)	$\sum_j [(\sum_j y_{ij} I_j)^2 / \sum_j I_j^2]$-env(Linear)S.S	M2
ed deviations	g(n-2)	$\sum_i \sum_j \delta^2_{ij}$	
otype 1	n-2	$[\sum_j y^2_{ij} - \frac{(y_{i.})^2}{n}] - (\sum_j y_i I_j)^2 / \sum_j I_j^2$	
2	n-2		
3	.		
.	.		
.	.		
.	.		
.	.		
11	n-2	$[\sum_j y^2_{rj} - \frac{y^2_r}{n}] - (\sum_j y_{ri} I_j)^2 / \sum_j I_j^2 = \sum_j \delta^2_{rj}$	
ed error	n (r-1) (r-1)		

Appendix V: Analysis of variance table when cultivars are tested at individual environments.

Source of variation	Degree of freedom	Mean squares	F-ratios
Replication	r-1	M1	M1/M3
Varieties (A)	a-1	M2	M2/M3
Error (a)	(r-1) (a-1)	M3	
Temperature treatment (B)	b-1	M4	M4/M6
A x B	(a-1) (b-1)	M5	M5/M6
Error (b)	a(r-1)(b-1)	M6	

Appendix VI: Source of variation, degrees of freedom, mean squares and F-ratios for combined analysis of variance.

Source of variation	Degrees of freedom	Mean squares	F-ratios
Locations (L)	L-1	M1	M1/M2
Reps. within locations	(r-1)L	M2	
Varieties (A)	a-1	M3	M3/M4
L X A	(a-1)(L-1)	M4	M4/M5
Pooled error[a]	(a-1)(r-1)	M5	
Temperature treatment (B)	b-1	M6	M6/M7
L x B	(b-1)(L-1)	M7	M7/M10
A x B	(a-1)(L-1)	M8	M8/M9
L x A x B	(a-1)(b-1)(L-1)	M9	M9/M10
Pooled error[b]	aL(r-1)(L-1)	M10	

Appendix VII: Weather data for Marigat, 1990-1991

onth	Temperature °C Max	Min	Total Rainfall(mm)	Mean Humidity %		Sunshine Hours
990				0600	1200	
January	33.1	16.8	8.4	61.5	41.6	-
February	33.6	18.7	107.9	60.5	38.5	-
March	32.5	18.4	68.0	67.5	47.3	7.7
April	32.0	18.2	112.7	74.2	51.3	6.1
May	33.2	17.6	70.6	64.1	39.6	-
June	33.1	16.1	24.5	57.6	39.9	-
July	32.7	16.6	57.5	62.7	38.1	-
August	32.9	17.6	25.3	60.3	39.2	-
September	35.0	17.4	6.6	62.5	40.5	9.0
October	33.2	16.4	60.1	63.9	38.4	-
November	32.1	17.2	25.4	58.1	41.6	-
December	32.7	17.3	23.1	54.4	33.1	-
991						
January	33.1	16.5	34.0	48.6	30.5	-
February	36.0	17.8	6.8	65.8	44.3	-
March	36.1	17.1	33.0	53.8	34.5	7.5
April	32.1	18.4	30.4	64.9	41.7	8.0
May	32.0	18.3	71.6	63.5	46.1	8.0
June	32.4	17.6	113.2	70.8	46.0	-
July	30.4	17.5	108.7	71.4	50.3	-
August	31.5	17.5	178.8	68.1	43.8	-
September	32.9	15.7	10.1	65.8	43.4	8.6

Appendix VIII: Weather data for Kabete, 1990-1991

Month	Temperature °C Max	Min	Mean	Total Rainfall (mm)	Mean Humidity % 0600	1200	Mean Sunshine Hours
1990							
January	23.0	12.0	17.5	51.6	81	54	8.8
February	24.9	14.0	19.5	47.8	80	48	7.4
March	23.3	14.3	18.8	199.7	86	62	6.2
April	22.9	14.7	18.8	275.2	88	67	5.4
May	22.7	13.9	18.4	309.3	86	61	6.6
June	21.8	11.6	16.6	6.5	88	59	5.6
July	21.5	10.4	15.8	13.6	88	57	4.7
August	20.3	11.5	15.9	21.0	88	65	2.5
September	23.6	11.3	17.5	31.8	81	48	7.0
October	23.8	13.3	18.5	90.0	82	49	7.3
November	22.0	12.8	17.8	126.0	87	62	7.0
December	22.3	13.2	17.8	74.6	83	58	8.1
1991							
January	24.4	12.7	18.5	33.9	74	49	9.8
February	25.2	13.1	19.6	0.4	68	40	10.6
March	26.1	13.7	19.9	84.8	73	41	8.7
April	23.9	14.4	19.3	158.3	86	55	7.7
May	22.4	14.8	18.4	281.4	88	69	5.3
June	21.9	12.6	17.3	12.5	87	68	4.4
July	20.3	9.9	14.95	12.9	87	63	2.9
August	22.0	10.1	16.05	40.3	86	60	4.4
September	23.9	10.1	17.0	2.8	82	46	6.9

ppendix IX: Weather data for Oljorok, 1990-1991

Month 1990	Temperature°C Max	Min	Total Rainfall(mm)	Mean Humidity %	Sunshine Hours
January	20.7	6.1	13.6	72	-
February	22.7	8.1	83.0	77	-
March	21.1	9.1	122.0	79	7.0
April	20.9	9.3	116.2	84	6.4
May	21.0	7.7	95.9	83	8.3
June	20.9	6.1	58.9	84	8.3
July	20.1	6.6	121.8	88	-
August	19.8	6.8	85.0	87	-
September	22.0	4.9	29.5	72	-
October	21.3	6.7	86.5	70	-
November	20.4	7.5	33.2	74	7.2
December	20.4	7.7	38.2	73	7.9
991					
January	23.2	6.3	23.6	66	9.5
February	24.9	5.7	3.0	58	10.1
March	24.4	7.0	118.4	59	8.2
April	22.4	8.0	46.5	75	7.8
May	21.6	8.6	84.5	84	6.7
June	20.5	8.3	120.7	86	6.9
July	19.5	7.5	120.7	87	4.2
August	19.5	6.4	229.6	74	6.2

Appendix X: Weather data for Kibirigwi, 1990-1991.

Months	Temperature °C		Total Rainfall (mm)
	Max	Min	
1990			
Janaury	29.6	14.26	108.0
February	24.66	15.02	38.60
March	27.09	16.04	210.5
April	27.11	16.29	383.6
May	26.07	16.16	428.8
June	27.22	14.46	29.0
July	26.14	14.02	39.65
August	23.98	16.35	25.40
September	27.10	15.72	36.60
October	29.80	16.50	213.4
November	28.40	16.00	125.4
December	28.00	14.20	141.7
1991			
January	28.00	14.53	101.50
Februry	31.90	16.30	52.70
March	28.95	13.15	191.20
April	29.50	15.30	186.50
May	30.20	14.96	312.00
June	30.20	15.40	44.50
July	28.01	15.66	96.00
August	27.71	14.36	37.00
September	26.4	14.88	22.30

Appendix XI: Weather data for Njabini, 1990-1991

Months	Temperature °C Max	Min	Total Rainfall (mm)
1990			
January	21.5	9.1	85.2
February	18.9	9.5	47.1
March	21.5	10.4	172.2
April	19.2	8.4	156.9
May	20.1	10.1	141.2
June	18.2	7.5	43.7
July	18.9	8.4	35.3
August	21.2	10.6	48.3
September	19.6	9.6	55.9
October	21.6	9.9	92.9
November	21.7	10.4	98.2
December	21.4	13.7	75.4
1991			
January	22.1	7.4	15.3
February	21.4	7.5	10.8
March	21.6	9.1	116.5
April	19.6	9.6	131.9
May	17.5	10.6	220.7
June	17.8	9.3	63.1
July	15.3	8.2	23.4
August	17.4	7.9	60.6