# STUDIES ON THE EFFICIENCY OF TWO BREEDING METHODS APPLIED TO IMPROVE YIELD AND QUALITY IN TWO MAIZE POPULATIONS CARRYING BRACHYTIC-2, OPAQUE-2 AND SUGARY-2 GENES

by

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## CERTIFICATES

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

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

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## ABSTRACT

A study was conducted on normal KCB and KCE and their modified mutant populations carrying brachytic-2, opaque-2 and sugary-2 genes. The objective was to study the effect of three mutant genes on yield and protein characters, the efficiency of two recurrent selection methods (reciprocal recurrent selection and $S_1$ testing methods) and an attempt to improve grain yield, the appearance and the texture of opaque grains.

After formation of the two triple mutant populations of KCB and KCE, they were improved using the two methods separately through one cycle. The improved populations, their hybrids and previously converted populations together with four commercial checks making a total of 25 entries were evaluated in 5 x 5 triple lattice designs at four locations.

Results showed that the brachytic-2 gene may or may not affect grain yield, but cefinitely reduced plant and ear height; it improved lodging resistance and kept the leaf number constant. It failed to improve the crop index. The opaque-2 gene improved nutritional value but lowered the grain yield; it made grains much more susceptible to pests and diseases.

Modified grains with varying frequencies rectified some of the opaque defects. Double mutant population had better yields, and quality characters; this was probably due to the favourable epistatic interactions between the two genes. However, at the triple mutant level tremendous improvement was realised.

The relationships between yield and quality traits were negative. KCE population made faster genetic gains than KCB. The reciprocal recurrent selection was much more efficient than $S_1$ testing. Introgression of genes from KCB population into KCE and vice versa, that took place at the time of formation affected their response to heterosis unfavourably. However, after one cycle of selection in both methods the populations responded positively.

Breeding programmes for the release of open pollinated varieties may have a choice between $S_1$ testing and reciprocal recurrent selection methods, depending on the skill of labour and available resources. However, in view of a programme for hybrid production, reciprocal recurrent selection is the most appropriate.

It would be difficult to encourage the production of high protein quality maize if it yielded less than

normal maize. In this study it was clearly indicated that the yield performance of triple mutant hybrids was equal to the best commercial hybrid grown in Kenya and as good as their normal counterparts. There is scope for further improvement in triple mutant populations and their hybrids using any of the recurrent selection procedures. The role of genetic modifiers needs to be studied further particularly their inheritance.

# CHAPTER 1

## INTRODUCTION

Maize is the most important food crop in Kenya. It constitutes the staple food for the majority of the country's 15 million people. It occupies the largest area of land amongst crop plants and it is grown by nearly all small scale farmers in Kenya. According to the Ministry of Agriculture (1979/80) 20 million bags each of 90 kg or some 2 million metric tons of maize are produced annually on about one million hectares of land. Approximately 70 percent of the area under maize is planted with hybrids or composites and the remaining 30 percent is planted with either local maize or some advanced generation of hybrids. Spectacular increase in maize production followed the development of high yielding hybrid varieties in 1964 and their subsequent multiplication and distribution by Kenya Seed Company, Kitale (Appendix 1).

The maize breeding method used in Kenya is known as a "Comprehensive Breeding System". It utilises two distinct populations. Originally the populations were Kitale Synthetic II and Ecuador 573,

which were highly cross compatible and gave high yielding hybrids such as H 611, H 612, H 613 B and H 614 C. Later on Kitale composite B (KCB) and Kitale composite E (KCE) populations were improved by reciprocal recurrent selection, by modified ear-to-row selection and by selection following $S_1$ testing. It was, however, realised that both Kitale Synthetic II and Ecuador 573 consisted of tall plants, with a plant height ranging between 380 and 450 cm. The hybrids between populations, though superior in yield, became excessively tall. For instance, H 613 B. one of the best commercial hybrids, stands around 500 cm. This kind of height renders plants susceptible to lodging and also leads to low grain to vegetative yield ratio.

Therefore, there is a need to reduce plant height and to improve the harvest index of these populations without affecting the grain yields. One of the approaches could be incorporation of a dwarfing gene such as brachytic-2 ($br_2br_2$) to reduce plant height.

Although maize covers a good proportion of the protein requirement of people in Kenya, it lacks in protein quality. The most serious deficiency is the low content of the two essential amino acids,

tryptophane and lysine, which man and non-ruminant animals cannot synthesize. Mertz, Bates and Nelson (1964) discovered that the "opaque-2 gene ($o_2o_2$)" could double the kernel's lysine content when introduced into a normal strain of maize. The opaque-2 gene when incorporated is reported to be associated with reduction in grain yield, susceptible to ear rot and poorer storage ability. However, these defects apparently can be corrected by the use of genes capable of modifying the operation of the opaque-2 gene. It, therefore, appears appropriate to incorporate sugary-2 genes into Kitale composite B and Kitale composite E opaque-2 populations, followed by a study on their influence on yield, protein quantity and quality characters. When these mutant genes are incorporated into these two populations, they seem to offer a good scope to improving protein quality and reducing the plant height without interference with the grain yield. Such improved populations could be used as open pollinated varieties and/or for developing new hybrids.

Once the mutant genes brachytic-2, opaque-2 and sugary-2 have been introduced into these populations it would be imperative to improve them and also their hybrids through suitable breeding methods.

Experiments done at Kitale have shown that reciprocal recurrent selection (R) and selection on the basis of $S_1$ testing are efficient in improving yield of Kitale Synthetic II and Ecuador 573 populations (Darrah, Eberhart and Penny 1972). It is, therefore of interest to investigate the relative efficiencies of these two breeding methods in improving yield performance of mutant populations of Kitale composite B, Kitale composite E and their hybrids.

Therefore the objective of this research project are:

(i) To study the effects of three mutant genes, brachytic-2, opaque-2 and sugary-2 in the genotypic background of Kitale composite B and Kitale composite E, with respect to grain yield, protein quality and quantity, plant height and other characters.

(ii) To compare the efficiency of reciprocal recurrent selection and $S_1$ testing methods in improving yield and quality characters in triple mutant population and their hybrids after one cycle of selection.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1. History and origin of maize

According to Mangelsdorf and Reeves (1959) the maize plant is native to the Americas testified by the remains of prehistoric maize dating back as far as 3000 to 5000 B.C. in Mexican caves. It was the principal food of the Indians when Columbus discovered America. It is still the most important cereal food in Mexico, Central America and many countries in South America.

Maize has two close relatives, gamma grass *(Tripsacum dactyloides)* and teosinte *(Euchlaena mexicana)*. Gamma grass grows wild in the Eastern and South Eastern sections of the United States and Central and South America. Teosinte is generally regarded as the closest relative to maize, since the two species cross readily. The annual form of teosinte has ten pairs of chromosomes, the same number that is found in maize. Two locations have been suggested as possible origin of maize, i.e. the highlands of Peru, Ecuador and Bolivia as one,

the other being the southern regior of Mexico. It is also felt that the maize plant may have developed from the primitive pod corn, while teosinte originated as a hybrid between pod corn and gamma grass. The modern races of maize would then have originated through introgression of teosinte into maize. (Mangelsdorf, MacNeish and Galiant 1952) indicated that despite various theories neither the place nor the mode of the origin of maize can be stated with certainty.

## 2.2. Importance of maize

In World production of cereal grain, maize ranks in the third place, behind wheat and rice. More than one half of the total World crop is grown in the United States, where it is used primarily as a feed grain for livestock. Maize is a major source of calories for many millions of people in several parts of the developing World. It could also be a good source of protein if the quality is improved.

## 2.3. Hybrid maize

An important era in maize breeding began in 1909 when Shull suggested a method for producing hybrid maize seed. The previous year, he had reported

that ordinary maize is composed of many complex hybrids which decline in vigour with inbreeding and that it was the breeders' task to maintain the best hybrid combination. The commercial production of single-cross hybrid, however was not yet economical.

It was in 1918 that Jones solved the problem by suggesting that for commercial production, a double cross hybrid was ideal. This step made production of hybrid maize seed economically feasible; a first commercially grown double-cross hybrid maize was produced and grown in Connecticut in 1921. The use of hybrid maize in the United States Corn Belt became extensive in 1930's. Within the period between 1936 and 1945 hybrid maize in the corn belt increased from 5 to 90 percent. Now, 100 percent of the Corn Belt is planted to hybrid maize (Poehlman and Borthakur 1968).

After the second World war hybrid maize started to spread beyond the boundary of the United States of America into Latin America, Asia and Africa. Paliwal (1964) reported that inbred lines developed

and released through the Coordinated Maize Improvement Scheme (CM-lines) made it possible for various public and private breeding programmes in India to release hybrid maize. However, the Indian cultivated varieties of open pollinated maize had not yielded good inbred lines, probably because the original germplasm was poor and had a narrow genetic base. Current maize improvement programmes in South Eastern Asia are based mainly on inbred lines introduced from Columbia, Mexico, U.S.A. and Kenya.

South Africa and Rhodesia were the first countries in Africa to realise some success in the production of maize hybrids. Shortly after World War II Rhodesia became the first country after the U.S.A. to release maize hybrids for commercial production. Success in Rhodesia can be ascribed to continuity in the maize breeding programme and to the high standard of field experimentation. Originally all the lines were derived from one variety only, Salisbury Flat White, but lately the scope of material has expanded and include some of the materials from Mexico,

Van Eijnatten (1965) while working in Nigeria reported that hybrids from United States of America and South Africa failed to give good results. As a

result, local breeding programmes were intensified. Lines developed from local varieties and from some exotic cultivars, e.g. Ikom White, Akwete, Mexico 5 and Lagos White, when crossed, showed low specific combining ability, suggesting that the future for hybrid development was not yet as promising as expected. However, composite populations were considered of great importance.

## 2.4. Introduction of maize in Kenya

The Portuguese, great voyagers and traders, sailed all around the Coast of Africa. Burtty-Dary (1914) mentions that the maize was being grown in Ethiopia in 1423, at which time the Portuguese were unsuccessfully trying to establish themselves in the country. In order to establish communication with India, the Portuguese built Fort Jesus at Mombasa after 1593 and they maintained a presence there almost continuously until 1729. Though there is no written evidence that they actually introduced maize to the Coast, it is quite probable that they did, since they were certainly instrumental in introducing it to other parts of Africa and Asia.

After reaching the Kenya Coast, maize did not spread inland quickly, because the Portuguese made no

attempt to develop the country as they did not intend to build up slave trade in this area. As a result of that there was very little contact between the Coast and the interior of Kenya, until the Arab slave traders and European powers in the 19th century opened up the Kenyan hinterland through explorers, missionaries, administrators and settlers. Kamba and Kikuyu were apparently the first tribes to take up the cultivation of maize. Dawson (1911) reported that the variety grown was small seeded, mixed in colour and had only a single ear per plant. This may indicate that the early introductions from the Coast were Lowland flint types not adapted to the higher attitudes. He also mentioned that varieties such as Canadian flint, Cuzco, Old Cabin Home and Hickory King had already been imported by 1900 AD. The Kenyan Agricultural Department and early European settlers also imported a considerable range of varieties from South Africa, Rhodesia and the United States of America early in the 20th century.

## 2.5. Hybrid maize in Kenya (Harrison 1970)

The first attempt at maize breeding in Eastern Africa were in Rhodesia and Kenya and were for the benefit of commercial European farmers. The Kenyan

programme, however, was only a spare-time activity of wheat breeders, and consequently, made little progress. Some single and double hybrids were produced and evaluated in yield trials, but very few outyielded the open pollinated varieties. Conclusions were that the genetic base from which the inbred lines were derived was too narrow. This programme was abandoned during the war and, though it was resumed in 1948, a fire in the maize crib at Njoro in 1953 destroyed both the records and most of the breeding materials.

Two main developments stimulated interest in maize breeding in East Africa. These were: the meetings of the East African Specialist Committee for Agricultural Botany under the Chairmanship of Hutchinson and secondly the arrival of *Puccinia polysora* Underw., the tropical maize rust, in West Africa in 1951 and the devastation it caused there. This led to a breeding programme for resistance being set up by the East African Agricultural and Forestry Research Organisation (EAAFRO) under the leadership of Storey *et al.* (1958).

Storey *et al.*(1958)stated that *P. polysora* first appeared in 1952. Lines carrying genes for resistance $R_{pp}$ 10 and $R_{pp}$ 11, were back crossed to various local

maize stocks and the derivatives were offered to the national breeding programmes in Tanzania, Uganda and Kenya. Similar work was done in respect of maize streak, *P. sorghi* and *Helminthosporium turcicum*.

At Kitale breeding for resistance to both *P. sorghi* and *H. turcicum* started in 1959 and 1963, respectively. The lines carrying resistance were obtained from Hooker of Illinois and Ullstrup of Purdue, Indiana. Unfortunately donor parent to one disease proved highly susceptible to others and above all they were not adapted to high altitude conditions. This programme was abandoned when useful field tolerance was found in collections from high altitudes in Latin America where the two diseases are as serious as at Kitale. This material combined tolerance to both diseases and in addition it proved reasonably adapted to the Kitale environment. It was, therefore, incorporated into the main breeding populations.

In 1954 attention was drawn to the work of Comstock, Robinson and Harvey (1949) in North Carolina, U.S.A. indicating that over-dominance was not as important in the expression of hybrid vigour as had been thought. A large part of hybrid vigour could also be explained by straight dominance and additive gene action. Therefore, the development was proposed of

early generation inbred lines with high general combining ability for the formation of synthetic varieties.

The recommendations were adopted for the high altitude late maturity maize breeding programme based at Kitale and in 1955 a full time maize breeder M.N. Harrison was appointed to start developing the Kenyan national maize breeding programme. Dowkers' breeding programme for early maturing maize in the dry and marginal areas of Machakos started in 1957 at Katumani. This aimed at the production of synthetic varieties and later on the "Katumani composite" which proved popular in the region. Katumani maize also played an important role in the initiation of a breeding programme at Embu for medium maturing maize. One of the products from crosses between early Katumani Synthetics and late Kitale hybrids was Embu hybrid 511. The medium maturing hybrid was released in 1968.

From 1959 onwards the Kitale programme has forged ahead steadily as a result of Harrison's effort. He collected available local materials, basically Kenya Flat White, which had over the years attained a high level of adaptation and some uniformity. By intercrossing this material, Kitale

station maize was formed later indicated as Kitale Synthetic I. Inbred lines developed from this local population through half sib family selection were evaluated by progeny testing and a minimum of ten of the best performers were put together to form a new synthetic, Kitale synthetic II, that was released in 1961 to farmers west of the Rift Valley because it outyielded the Kitale synthetic I by 10 to 12 percent.

Single-cross hybrids were also tried and the results proved promising to such an extent that a group of inbred lines yielded in all combinations on the average 30 percent above Kitale synthetic II. Subsequently, a double-cross hybrid H 622 was released for planting in 1964. In 1959, Harrison introduced from Central and South America a larger collection of germplasm and after crossing these with the local materials identified the possibility of using exotic materials in the Kitale programmes. Certain crosses of Kenyan and Central American maize types in both cases open pollinated varieties, showed the existence of high combining ability. Crosses of Kitale Synthetic II to Costa Rica 76 and Ecuador 573 in particular yielded 40 percent above the best parent, Kitale Synthetic II. The varietal

cross between Ecuador 573 and Kitale Synthetic II, was therefore released along with the classical hybrids in 1964, as the varietal hybrid H 611. This itself was a breakthrough as the approach shifted from the orthodox inbreeding and hybridisation to population improvement and the release of populations or population crosses.

As a follow-up to this, a comprehensive breeding system proposed by Eberhart, Harrison and Ogada (1967) came up as an appropriate method to exploit the situation. The outline of the comprehensive breeding system presently used in Kenya has four main phases:

(1) Evaluation of local and exotic varieties to identify the best breeding material.

(2) Compositing selected breeding material into one or more populations in such a manner that each population has considerable genetic variation for the trait requiring improvement and that the cross of these populations will show heterosis.

(3) Recurrent selection in each population to increase the frequency of favourable genes in order to develop populations and

population crosses that are improved with each cycle of selection.

(4) Release of commercial varieties in one of the following forms:

(a) the cross of two populations as a varietal hybrid,

(b) single, three way or double-cross hybrids from inbred lines developed from the elite material after each cycle of selection,

(c) a synthetic variety derived from advanced generations of the population cross in areas where hybrid production is not yet feasible.

Classical hybrids on the basis of inbred lines derived from Kitale station maize achieved a moderate improvement in yield of 30 to 40 percent over that of the basic populations. Varietal hybrids or top-cross hybrids performed much better reaching yield levels of 42 to 62 percent above that of the Kitale station maize. This was attributed to the wide genetic base in the parental population. This

information led to the development of populations with even wider genetic bases to serve as breeding stocks.

## 2.6. Study of breeding methods

During the period between 1964 and 1968 a study of breeding methods was initiated at Kitale with the aim to compare their efficiencies under East African conditions when using local and introduced maize populations. The results of this study were to enable the selection of the suitable breeding method. Kitale synthetic II and Ecuador 573 were used as breeding materials (Darrah, Eberhart and Penny 1976). The breeding methods compared were:

(i) Mass selection (M)

(ii) $S_1$ progeny testing (S)

(iii) Full-sib selection (F)

(iv) Ear-to-row selection (E)

(v) Reciprocal recurrent selection (R)

After six years of comparison, (Darrah, Eberhart and Penny 1976) carried out the final evaluation at Kitale. Reciprocal recurrent selection proved much more effective for interpopulation improvement than the others. It made 3.5 percent gain in grain yield per

year or 7 percent per cycle.

## 2.7. Formation of composite populations

Two basic breeding stocks with broad genetic base were formed between 1963 and 1967. These were Kitale composite B (KCB) and Kitale composite E (KCE). Genes were introgressed from KCB into KCE and vice versa. This was intended to increase vigour and genetic variability within each population, in order to provide good scope for selection within the populations themselves and for the potential to obtain hybrids (Eberhart, Harrison and Ogada 1967).

## 2.8. Population improvement

When KCB and KCE populations which had been improved by different recurrent selection methods, were evaluated along with other varieties, there was no yield improvement either in the composite population *per se* or in their $F_1$ hybrids (Appendix 2). However, Kitale synthetic II (KSII) and Evuador 573 (Ec 573) showed significant improvements. Ec 573 improved by ear-to-row selection made 44.0 percent improvement in grain yield over the original population. A cross between

KSII and Ec 573, later commercially referred to as H 611, showed a well marked heterosis. When KSII and Ec 573 were improved by reciprocal recurrent selection through three cycles, a cross between them showed even higher gains. The greatest change occurred from cycle zero ($C_0$) to cycle 1 ($C_1$) and thereafter the changes were smaller (Appendix 2). It was, therefore, much more difficult to improve composite populations and their hybrids *per se* than their respective component parents and their hybrids.

## 2.9. Use of brachytic-2 ($br_2br_2$)

Johnson (1971) reported that brachytic-2 gene reduced plant height in maize, however, the progress in height reduction was slow and complicated by other factors. There are other kinds of brachytics, e.g. brachytic-1 ($br_1$ $br_1$), brachytic-3 ($br_3$ $br_3$), pigmy (pg), dwarf-1 ($dw_1$ $dw_1$), etc. All these have the characteristic of height reduction. Brachytic genes are reported to improve the grain to fodder ratio (Leng 1957). However, little is known on its genetics and associated effects on the materials into which it is introduced.

Harrison saw the work of Leng with the brachytic-2 gene that was reported in 1958. After that Kitale synthetic II was flown out and crossed to the inbred line US 13 carrying this gene. The dwarfed Kitale synthetic II brought back, was therefore the source of the brachytic-2 gene that was later transferred into both KCB and KCE. Leng (1957) mentioned that short stalk hybrids were not popular in the mid-west of the U.S.A., because there was a tendency of lowering the yield. The short height of brachytic material should not necessarily be a big drawback. Campbell (1965) emphasized that due to modifiers within the brachytic-2 populations it was possible to select within these populations near-normal tall plants. Harrison (1961) produced a dwarf version of Kitale synthetic II with the idea that all the future lines extracted from it, would be dwarf without the necessity to convert the lines. The dwarfing of a maize plant is a quick means of reducing the height of tall maize, increasing relative stalk strength and improving the efficiency of the plant. The inefficient plants tend to devote most of the energy intercepted towards foliage and support structure

formation and less towards grain development.

Johnson (1971) reported that brachytic-2 gene reduced plant height, however, the progress in height reduction was slow and complicated by other factors. It was then decided that plant height be reduced by selection, "plant baja" or short plant selection. Ten cycles of recurrent selection in Tuxpeno reduced the height by 1 m (approximately 10 cm per cycle of selection) thereby demonstrating that "plant baja" - selection was just as good as using brachytic-2 gene. Darrah, Eberhart and Penny (1976) working with the two different populations, KSII and Ec 573, stated that selection for reduced ear height and lodging resistance in the breeding nursery improved yield performance in them and their crosses. It was then emphasized that greater attention to ear height and lodging resistance was required to reduce harvesting losses in the commercial maize crop in Kenya.

Glover (1970) reported on a gene conditioning plant structure, different from brachytic-2 known as "compact". He concluded that the compact gene would have been better to work with instead of of brachytic-2 because of its performance at high

population densities. When growth patterns of the three Kenya maize varieties, H 613 C, H 512 and Katumani, were compared, by Law (1974). Katumani had the highest harvest index (48 percent ). This was explained by the smaller stem which accounted for only 22 to 24 percent of the short dry weight in comparison with 27 to 35 percent in the other varieties. Grain yields were low but at a higher plant density, this could be improved. The variety was capable of gaining in yield per day of growing season but not the other varieties. Hybrid H 512 had a lower net assimilation rate (NAR) in the vegetative phase which contributed to sink limitation of photosynthates, probably caused by cold environment in Kitale. H 613 C produced more dry matter than any other variety but excessive proportion of this was used for stem growth resulting in low harvest index. A comparison of four cycles of improved, advanced generations of Kitale composite A (KSII x Ec 573) indicated that there were no significant differences in leaf area or growth pattern,

but there were significant differences in stem morphology. $C_4$ stems were considerably thicker and slightly shorter than $C_o$. Despite the fact that 1974 was particularly bad for lodging, $C_o$ plots lodged 69 percent compared to 32 percent in the $C_4$ plots. During the grain filling period, dry matter in grain per plant differed. $C_o$ plots accumulated 212 gm per plant compared to 260 gm per plant in $C_4$. When the plots of $C_o$ and $C_4$ were harvested the final yield obtained were 95 q/ha and 102 q/ha, respectively.

The effects of brachytic-2 gene ($br_2$ $br_2$) on different Kitale maize characters was reported by Omolo (1978) as shown in Appendix 3. He found that brachytic-2 gene did not affect the grain yield but reduced plant height and lodging percentage.

## 2.10 Discovery of Opaque-2 gene $o_2o_2$

Although maize is considered an excellent source of carbohydrates, the protein quality is low since it is deficient in essential amino acids such as lysine and tryptophane. This deficiency

is a major constraint in maize as a food grain and has to be supplemented from other sources.

Mertz, Bates and Nelson (1964) discovered the ability of opaque-2 gene to control the amino acid balance by changing the protein composition and increasing the content of lysine and tryptophane ir maize endosperm (Appendix 4). Studies with isogenic lines of W 64 showed that the endosperm of opaque-2 contains twice as much lysine and trytophane but the total protein remained constant.

With the discovery of the opaque genes interest has been generated for the development of hybrids, varieties or composites with high nutritional quality (Alexander, Dudley and Lambert 1970). Asnani and Gupta (1970) confirmed that the opaqueness was governed by a single gene. The phenotypic character of opaque-2 maize was found when the opaque-2 existed in homozygous condition ($o_2$ $o_2$). Mcwhirter (1971) identified another maize mutant gene which also affected lysine content and designated it opaque-1 ($o_1$ $o_1$). While studying the starch modifying mutant genes and their combination with the opaque-2, Paez (1973) found that sugary-2 ($su_2$ $su_2$), shrunken-1 ($sh_1$ $sh_1$), shrunken-2 ($sh_2$ $sh_2$), brittle-1 ($bt_1$ $bt_1$)

and brittle-2 ($bt_2$ $bt_2$) similarly increased lysine content of the endosperm.

In general it is agreed that the discovery of opaque-2 gene opened up a new perspective but there are a few problems associated with it, which require further investigation as indicated by Annapurna and Reddy (1971) and Finlay (1970). The opaque grains are soft, less dense and weigh less per unit volume (Bauman, 1974). It is also stated that in some genotypes the yield is reduced though not drastically and the soft floury grain is more susceptible to diseases and pests. With all these one would expect the acceptability by farmers to be poor. However, Finlay (1970) found that it was possible to combine a better balance of amino acids with better grain type through selection of modifiers.

Within a population of opaque-2 it is feasible to select the modified types which are almost normal in appearance, sometimes referred to as hard endosperm or vitreous types. The modified grain types will recover the yield lost and restore resistance to diseases and pests. Omolo (1977) visually selected modified grain types out of KSII and Ec 573 opaque-2. A cross between them formed

hybrid H 611 opaque modified (H 611 ($o_2$ $o_2$) mod) which recovered the yield lost (Appendix 7). Through two cycles of selection for high lysine, Paez (1973) increased lysine content from 0.27 to 0.40 percent in Lagon composite population of opaque-2.

2.11. Influence of opaque-2

In a preliminary study Omolo (1977) reported that opaque-2 gene increased lysine index by over 50 percent while there was no effect on the protein content (Appendix 5). It was found that though opaque-2 gene improved the nutritional quality, it reduced yield by 24.7 percent, failed to show any response to heterosis and reduced the weight of 1000 grains (Appendix 6). Opaque-2 genes lowered the grain yield of H 611 by 26.3 percent, (Appendix 7), significantly reduced the weight of 1000 grains and increased the percentage of diseased ears (Appendix 6). Opaque-2 ears were 56.3 percent more diseased than the normal ears. Similarly 1000 grain weight of opaque ears was reduced by 23.3 percent. It was therefore concluded that the yield reduction in opaque-2 populations and

hybrids was due to high incidence of diseases and reduction of grain weight.

## 2.12. The combined effect of two mutant genes, opaque-2 and brachytic-2 (double mutant)

Omolo (1981) studied the combined effects of opaque-2 and brachytic-2 in both KCB and KCE. The combination of brachytic-2 and opaque-2 reduced lysine and tryptophane percentage but not the total protein content (Appendix 8). The double mutant populations had lower yields and the loss of yield was associated with the presence of opaque-2 (Appendix 9). The reduction of lysine and tryptophane percentage could have been either due to presence of brachytic-2 or the interaction between the two genes or both. Reduction of plant height of the double mutant was attributed to brachytic-2 gene. There was no heterosis in the hybrids.

## 2.13. Use of sugary-2 ($su_2$ $su_2$)

Working on the possibility of modifying opaque-2 maize, Paez, Helm and Zuber (1970) found that vitreous quality, kernel density and lysine percentage

were improved when opaque-2 and sugary-2 were combined. The digestibility of the double mutant was also better than that of the single mutant opaque-2 ($o_2$ $o_2$). To confirm the use of sugary-2 ($su_2$ $su_2$) as a modifier of opaque-2, Paez (1973) carried out some allelic tests on stocks of seeds with modified endosperm phenotypes isolated from homozygous opaque-2 ($o_2$ $o_2$) lines. It was found that the genotype constitution of the modified line was opaque-2 sugary-2 ($o_2$ $o_2$ $su_2$ $su_2$). The endosperm of the stock was translucent or vitreous with hard texture and had higher percentage of lysine per unit protein than opaque-2 endosperm. Test weight and kernel density of the opaque-2/sugary-2 stock were similar to those of the normal endosperm types.

Bauman (1977) working on inheritance and improvement of protein quality and content in maize discovered that even modifying opaque by the use of other genes such as sugary-2 improved kernel hardness and vitreousness but the yield still remained lower than the normal maize. It was also reported that opaque-2/sugary-2 maize

(double mutant) had some nutritional improvement over opaque-2.

Floury-2 gene ($fl_2$ $fl_2$) has been combined with opaque-2 to give a double mutant opaque-2/ floury-2 ($o_2$ $o_2$ $fl_2$ $fl_2$) by Masiiko, Klyuchko and Trofimov (1974). Results were not successful either, they had low biological value and low yields, which confirmed the previous work done by Nelson (1965) who reported that the hybrids formed from the double mutant populations of opaque-2 and floury-2 varied in grain yield with some of them approaching the normal hybrids.

# CHAPTER 3

## MATERIALS AND METHODS

### 3.1. Kitale Composite B (KCB) and Kitale Composite E (KCE)

These two composite populations have high genetic variability within each of them and genetic diversity between them. KCB is composed of about 75 percent of Kenya Flat White and 25 percent of Costa Rica and Cometico lines. In 1963, fourteen different components which were classified as Kenya Flat White maize were put together by intercrossing. Among these were Kitale, Endebess, Kakamega and Njoro Synthetics as well as selected inbred lines, their crosses, best local farmers stock from Njoro and bulk of some lines from the genetic nursery. All these components were planted for three years (1963 to 1965) in separate rows but were allowed to mix freely by interpollination for five generations until the components lost their original identity. In 1966 ten KCB $S_1$ lines out of a separate programme were injected into the main KCB population. Four selected Ecuador 573, Costa Rica and Cometico

lines were also included into KCB population.

Kitale E (KCE) was similarly formed in 1963 in which about 25 percent of Kenya Flat White germplasm was introgressed into 75 percent of the Central American materials. A mixture of Latin American races and some Corn Belt materials which were grown in mixture for the three years 1964, 1965 and 1966 in isolated fields to form KCE. KCE showed greater genetic variability and though originally intended for a back-up composite, it was divided into two sections so that one could be rapidly improved by an intensive recurrent selection method while the other remained under mild mass selection intensity of 25 percent.

## 3.2. Mutant populations

KCB $C_o$ and KCE $C_o$ were each divided into two sub-populations. Into one sub-population of KCB $C_o$, opaque-2 gene was incorporated while brachytic-2 was injected into the other sub-population. The source of opaque-2 was W 64 while for brachytic-2 some dwarf lines of Kitale synthetic II were used (Harrison 1961).

The method used to transfer these genes from the donors to the KCB $C_o$ and KCE $C_o$ was as described by Omolo and Maroa (1977).

The segregates from the $F_2$ generations which were homozygous recessive for opaque-2 genes were random mated in isolation and thereafter formed KCB ($o_2$ $o_2$) $C_o$, KCB ($br_2$ $br_2$) $C_o$, KCE ($o_2$ $o_2$) $C_o$ and KCE ($br_2$ $br_2$) $C_o$ single mutants. The modified KCB ($o_2$ $o_2$) mod. were selected visually from the population of KCB ($o_2$ $o_2$) $C_o$ and KCE ($o_2$ $o_2$) $C_o$, on the basis of their near normal or hard endosperm appearance.

When the populations carrying opaque-2 and brachytic-2 separately were hand pollinated, the progenies combining both opaque-2 and brachytic-2 in a single population were formed, hence double mutant population of KCB ($br_2$ $o_2$) $C_o$. The grains of double mutant populations looked like opaque in appearance. The modified KCB ($br_2$ $o_2$) mod. $C_o$ and KCE ($br_2$ $o_2$) mod. $C_o$ were also visually selected from the KCB ($br_2$ $o_2$) $C_o$ and KCE ($br_2$ $o_2$) $C_o$.

The triple mutant populations of KCB and

KCE were obtained by crossing the double mutant populations of KCB ($br_2$ $o_2$) $C_o$ separately with sugary-2 ($su_2$ $su_2$) lines and back-crossed to the double mutant lines. The sources of sugary-2 were Oh 43 and W 64 from Purdue University, Indiana, U.S.A. After two back-crosses and random mating in isolation, few segregates combining the three mutant genes became the triple mutant populations of KCB ($br_2$ $o_2$ $su_2$) $C_o$ and KCE ($br_2$ $o_2$ $su_2$) $C_o$.

## 3.3. Materials evaluated

The following materials were used in the study:

| Parent populations | Characteristics |
|---|---|
| 1. KCB (++) $C_o$ | normal/control population |
| 2. KCB ($o_2$ $o_2$) $C_o$ | opaque-2 mutant |
| 3. KCB ($o_2$ $o_2$) mod. $C_o$ | opaque-2 modified mutant |
| 4. KCB ($br_2$ $br_2$) $C_o$ | brachytic-2 mutant |
| 5. KCB ($br_2$ $o_2$) $C_o$ | brachytic-2 opaque-2 double mutant (dm) |
| 6. KCB ($br_2$ $o_2$) mod. $C_o$ | brachytic-2 opaque-2 modified double mutant (dm) |

| | | |
|---|---|---|
| 7. | KCB ($br_2$ $o_2$ $su_2$) $C_o$ | brachytic-2 opaque-2 sugary-2 triple mutant (tm) |
| 8. | KCE (++) $C_o$ | normal/control population |
| 9. | KCE ($o_2$ $o_2$) $C_o$ | opaque-2 mutant |
| 10. | KCE ($o_2$ $o_2$) mod. $C_o$ | opaque-2 modified mutant |
| 11. | KCE ($br_2$ $br_2$) $C_o$ | brachytic-2 mutant |
| 12. | KCE ($br_2$ $o_2$) $C_o$ | brachytic-2 opaque-2 double mutant (dm) |
| 13. | KCE ($br_2$ $o_2$) mod. $C_o$ | brachytic-2 opaque-2 modified double mutant |
| 14. | KCE ($br_2$ $o_2$ $su_2$) $C_o$ | brachytic-2 opaque-2 sugary-2 triple mutant (tm) |

Improved populations

| | | |
|---|---|---|
| 15. | KCB tm/s/$c_1$ | cycle one of KCB triple mutant population improved through $S_1$ testing selection method ($S_1$). |
| 16. | KCB tm/R/$C_1$ | cycle one of KCB triple mutant population improved through reciprocal recurrent selection method (R) |
| 17. | KCE tm/S/$C_1$ | cycle one of KCE triple mutant population improved through ($S_1$) method |
| 18. | KCE tm/R/$C_1$ | cycle one of KCE triple mutant population improved through (R) method. |

| | | |
|---|---|---|
| Hybrids | | |
| 19. | KCB tm/$C_0$ × KCE tm/$C_0$ | cycle zero hybrid |
| 20. | KCB tm/S/$C_1$ × KCE tm/S/$C_1$ | cycle one hybrid from ($S_1$) method |
| 21. | KCB tm/R/$C_1$ × KCE tm/R/$C_1$ | cycle one hybrid from (R) method |
| Control (Hybrid/Composite) | | |
| 22. | H 614 C | late maturing, high altitude commercial hybrid |
| 23. | H 512 | medium maturing, medium altitude commercial hybrid |
| 24. | Kenseed | Kenya Seed Company experimental hybrid |
| 25. | Katumani Composite B | early maturing, low altitude commercial composite |

3.4. Field layout

The 25 populations as described in section 3.3. were grown in a 5 × 5 triple lattice design, partially balanced, replicated three times at four locations as shown below.

| Location | Altitude | Planting date |
|---|---|---|
| Katumani (a) | low (1475 m) | 17th April 1978 |
| Katumani (b) | low (1475 m) | 29th May 1978 |
| Njoro | high (2195 m) | 31st May 1978 |
| Kitale | medium (1890 m) | 30th April 1978 |

For each entry a three row plot of ten plants per row was grown in each replication. These were planted at a spacing of 75 cm between rows and 30 cm within rows. At the end of each row there were two plants to give the necessary end-row competition.

3.5. Observations

Observations on the following characters were recorded on five randomly chosen plants from the middle row in each entry per replication and their means per plot were taken.

(i) Yield and yield components

Grain yield (q/ha)

Ears per plant, per plot

Ear diameter (cm)

Ear length (cm)

Number of rows per ear

1000 grain weight from five selected ears

(ii) Plant characteristics

Plant height (cm)

Ear height (cm)

Lodging percentage

Crop index or harvest index (ratio of grain to total dry weight)

Days to silking

Number of leaves per plant

(iii) Grain properties

Protein percentage

Lysine percentage

Tryptophane percentage

Moisture percentage

(iv) Diseases and pests

Percentage of ear rot

Rust rating (1 - 5)

Blight rating (1 - 5)

Stem borer infestation percentage.

## 3.6. Selection methods

The two recurrent selection methods used in this study were:

(i) Reciprocal recurrent selection, and

(ii) $S_1$ progeny testing

These methods were applied to improve cycle zero ($C_o$) triple mutant populations of KCB and KCE.

### 3.6.1. Reciprocal recurrent selection (R)

First Season

In May 1975, the first ears of 3 selected plants in each of the 100 rows of KCB (tm) $C_o$ were crossed to bulk pollen of 10 tester KCE (tm) $C_o$ plants grown adjacent to it. The second ear of the same plants were self-pollinated. The same was done for the KCE (tm) $C_o$ but crossed to KCB $C_o$. Finally two best plants from each of the 100 rows were selected to give 195 selfed and 195 crossed ears.

Second season

During March 1976, 195 crossed ears of each population were evaluated in two separate trials with $C_o$ population included as control to make a

total of 196 entries grown in a 14 x 14 triple lattice design with one row of 10 plants each. The selfed seed of the first season was divided into two parts, the first part kept in reserve and the second lot was used for analysis of lysine and protein content at Kitale Quality Laboratory.

Third season

In April 1977, selfed seeds of 20 superior crosses of each KCB (tm) $C_o$ and KCE (tm) $C_o$ based on yield, protein and lysine content were recombined separately in isolation. The bulk harvest of each population formed KCB (tm/R) $C_1$ and KCE (tm/R) $C_1$ populations.

3.6.2. $S_1$ progeny testing

First season

In May 1975, 100 rows of each of both KCB (tm) $C_o$ and KCE (tm) $C_o$, were planted and three plants different from those used for reciprocal recurrent selection were self pollinated in both cases.

Second season

169 $S_1$ families including the $C_o$ population, were

divided into three parts. The first part was kept as remnant seeds, while the second part was evaluated in progeny rows in a 13 x 13 triple lattice design trial in March 1976. The last part of the seed was used for protein quality analysis.

Third season

In March 1977 the selected 20 lines on the basis of yield, protein and lysine contents were grown to intercross in all possible combinations in isolation. The harvested bulk seed formed KCB tm/S/$C_1$ and KCE tm/S/$C_1$ populations.

3.7. Hybrids

During the short rains of 1977/78 the following crosses were made:

KCB $C_o$ x KCE $C_o$, KCB tm/S/$C_1$ x KCE tm/S/$C_1$, and KCB tm/R/$C_1$ x KCE tm/R/$C_1$.

3.8. Analysis of protein, tryptophane and lysine

A sample of 10 grains was used for protein and lysine analyses. The embryo and pericarp were first removed from the grains. These were then milled to a fine flour and defatted for eight hours with hexane as

a solvent. The defatted samples were then dried and stored in vials. The nitrogen was determined by micro-kjeldahl procedure and the protein content was obtained by multiplying by a factor of 6.25 . Each sample was analysed twice.

Tryptophane was determined by a calorimetric procedure of Opienska-Blauth and modified by A. O. A. C. (1965). The method employs enzymatic hydrolysis followed by an *in situ* generation of a reactant that in turn reacts with the free tryptophane to produce a chromophore which is then read in a colorimeter. Approximate lysine values were obtained by multiplying the tryptophane value by a factor of four. This value has been proved to be accurate by other laboratories (Villegas and Mertz 1971). The theoretical factor 4.0 is derived from the relationship, that one part lysine is equivalent to four parts of tryptophane.

The procedure was modified since the estimate of tryptophane appeared on the lower side. The U.S. papain enzymes were suspected to be inactive. Therefore Merck papain was used in place of U.S. papain.

## 3.9. Biometrical analysis

The experimental design as well as the analyses of variance for selection experiments and multi-location yield evaluation trials were carried out according to the procedure for triple lattice designs outlined by Cochran and Cox (1957).

### 3.9.1. Selection experiments

For $S_1$ testing method a total of 169 $S_1$ lines were progeny tested in a 13 x 13 triple lattice whereas in the case of reciprocal recurrent selection method 196 crossed lines were tested in a 14 x 14 triple lattice. In both cases, twenty top performers were recombined to form the advanced population.

The following linear mathematical model was used to define the data:

$$Y_{ijk} = u + \ell_i + r_j + b_{jk} + e_{ijk}$$

where:

$Y_{ijk}$ = yield of the $i^{th}$ line in the $k^{th}$ lattice block of the $j^{th}$ replication

$u$ = over all mean of the lines

$\ell_i$ = effect of the $i^{th}$ line

$r_j$ = effect of the $j^{th}$ replication

$b_{jk}$ = effect of the $k^{th}$ block in $j^{th}$ replication

$e_{ijk}$ = experimental error

Provided the following assumptions are true

$\ell_i \sim NID\ (0, \sigma^2)$

$e_{ijk} \sim NID\ (0, \sigma^2)$

NID $(0, \sigma^2)$ = Normal and independently distributed with means at zero and constant variance.

The analysis of variance table for the selection experiment took the following form:

| Source | df | ms | expectation |
|---|---|---|---|
| Replication | r-1 | | |
| Lines | $\ell$-1 | $M_1$ | $\sigma_e^2 + r\sigma_\ell^2$ |
| Error | (k-1) (rk-k-1) | $M_2$ | $\sigma_e^2$ |

Where k = number of lines per lattice block

3.9.2. Evaluation experiments

The 25 populations in the final evaluation trial were grown in a 5 x 5 partially balanced triple lattice design during the year 1978 at four sites. The results of each location were analysed separately and then later combined over the four locations. For individual locations, the analysis procedure was similar to that of the selection experiments. The following model was adopted for the analysis of the combined experiments over locations:

$$Y_{i\ell} = u + g_i + e_\ell + ge_{i\ell}$$

where $Y_{i\ell}$ = mean performance of the $i^{th}$ genotype in the $\ell^{th}$ environment

$u$ = overall mean

$g_i$ = effect of $i^{th}$ genotype

$e_\ell$ = effect of $\ell^{th}$ environment

$ge_{i\ell}$ = effect of the genotype x environment interaction

Provided the following assumptions are true:

$$g_i \sim NID\ (0, \sigma_g^2)$$

$$e_\ell \sim NID\ (0, \sigma_e^2)$$

$$ge_{i\ell} \sim NID\ (0, \sigma_{ge}^2)$$

The analysis of variance table of multilocation trials was as follows:

| Source | df | ms | Expectation |
|---|---|---|---|
| Environment | $\ell-1$ | $M_5$ | |
| Replication/ environment | $\ell(r-1)$ | $M_4$ | |
| Genotypes | $(g-1)$ | $M_3$ | $\sigma_e^2 + r\sigma_{ge}^2 + r\ell\sigma_g^2$ |
| Genotype x environment | $(g-1)\ (\ell-1)$ | $M_2$ | $\sigma_e^2 + r\sigma_{ge}^2$ |
| Pooled error | $\ell(k-1)(rk-k-1$ | $M_1$ | $\sigma_e^2$ |

where $\ell$ = number of environments

and variance components will be estimated by solving the following equations:

$$M_3 = \sigma_e^2 + r\sigma_{ge}^2 + r\ell\sigma_g^2$$

$$M_2 = \sigma_e^2 + r\sigma_{ge}^2$$

$$M_1 = \sigma_e^2$$

where $M_1$, $M_2$ and $M_3$ are the mean square values for pooled error, genotype x environment and genotype, respectively.

3.9.3. Genetic gains

Predicted genetic gain ($\hat{G}$) per year was calculated following the procedure given by Eberhart (1970):

$$\hat{G} = (C/Y)\ HD \text{ or } \frac{CHD}{Y}$$

where D in the selection differential ($\bar{X}_s - \bar{\bar{X}}$), $\bar{X}_s$ is the mean of the selected lines and $\bar{\bar{X}}$ is the grand mean, C being the parent control and Y being the years per cycle. H is the broad sense heritability and was calculated as:

$$H = \sigma_g^2 / (\sigma_e^2/r\ell + \sigma_{ge/\ell}^2 + \sigma_g^2)$$

where $\sigma_g^2$ = genetic variance

$\sigma_{ge}^2$ = genotype x environment interaction

$\sigma_e^2$ = pooled error variance

r and $\ell$ represent replication and location respectively.

The parental control and number of years per cycle for R and $S_1$ selection methods are given by Eberhart (1970).

| Selection method | Parental control | Years/cycle |
|---|---|---|
| $S_1$ | 1 | 2 |
| R | 1 | 2 |

3.9.4. Correlations

Simple correlation coefficients between pairs of characters were worked out using the formula:

$$r = \frac{\Sigma(X_1 - \bar{X})(Y_1 - \bar{Y})}{\sqrt{\Sigma(X_1 - \bar{X})^2 \, \Sigma(Y_1 - \bar{Y})^2}} = \frac{\Sigma XY}{\sqrt{(\Sigma X^2)(\Sigma Y^2)}}$$

3.9.5. Effective population size

The effective population size is the number of actual progenitors (breeding individuals) responsible for the genetic constitution of the next generation. It was calculated according to Li (1955):

$$\bar{N} = \frac{4 \, N_f \, N_m}{N_f + N_m}$$

where $N_f$ is the number of female plants and $N_m$ the number of male plants that were actually used in the formation of the population tested.

# CHAPTER 4

# RESULTS

The mean values of all characters for four locations (hereafter referred to as environments) were analysed per location, followed by a combined analysis over the four environments. The characters studied were grouped into four categories: yield and yield components, plant characteristics, grain quality and reaction to pests and diseases.

## 4.1. Yield and yield components

The mean values of grain yield, 1000 grain weight, number of rows per ear, ear length, ear per plant and ear diameter for 25 entries grown at 4 environments are given in Tables 1, 2, 3, and 4.

### 4.1.1. Grain yield

Grain yield at Katumani location (Table 1) ranged between 49.65 (Katumani Composite B) and 103.71 q/ha (KCB tm/R/$C_1$ x KCE tm/R/$C_1$) on site (a) and between 52.11 (Katumani Composite B) and 118.09 q/ha (KCB tm/R/$C_1$ x KCE tm/R/$C_1$) on site (b) (Table 2),

Table 1. Mean grain yield (q/ha), weight of 1000 grains (gm), number of rows per ear, ear-length (cm), ear per plant and ear diameter (cm) of 25 maize populations in Katumani (a)

| Population | Yield q/ha | wt.of 1000 grains (gm) | No. of rows per ear | ear length (cm) | ears per plant | ear diameter (cm) |
|---|---|---|---|---|---|---|
| KCB(++)$C_o$ | 102.02 | 463.33 | 11.67 | 21.33 | 1.40 | 4.93 |
| KCB($o_2o_2$)$C_o$ | 57.82 | 354.33 | 13.00 | 17.00 | 1.00 | 5.13 |
| KCB($o_2o_2$)mod. | 80.11 | 381.67 | 13.33 | 20.67 | 1.13 | 5.10 |
| KCB($br_2br_2$)$C_o$ | 81.67 | 362.67 | 13.67 | 20.67 | 1.13 | 4.63 |
| KCB($br_2o_2$)$C_o$ | 77.26 | 393.00 | 12.67 | 18.33 | 1.07 | 5.20 |
| KCB($br_2o_2$)mod. | 92.17 | 402.67 | 13.00 | 19.67 | 1.33 | 5.17 |
| KCB($br_2o_2su_2$)$C_o$ | 63.00 | 321.33 | 14.67 | 17.00 | 1.07 | 4.97 |
| KCE(++)$C_o$ | 75.83 | 391.67 | 13.00 | 18.33 | 1.00 | 4.77 |
| KCE($o_2o_2$)$C_o$ | 56.11 | 381.33 | 12.00 | 18.33 | 1.13 | 5.27 |
| KCE($o_2o_2$)mod. | 74.15 | 444.67 | 12.00 | 19.67 | 1.00 | 5.20 |
| KCE($br_2br_2$)$C_o$ | 80.50 | 401.67 | 13.67 | 18.67 | 1.13 | 4.97 |
| KCE($br_2o_2$)$C_o$ | 82.06 | 401.33 | 14.33 | 20.33 | 1.13 | 5.07 |
| KCE($br_2o_2$)mod. | 73.89 | 420.33 | 13.33 | 20.00 | 1.07 | 5.10 |
| KCE($br_2o_2su_2$)$C_o$ | 73.63 | 366.00 | 13.67 | 18.00 | 1.20 | 5.20 |

Continued

*Table 1 Continued.*

| | | | | | | |
|---|---|---|---|---|---|---|
| KCBtm/S/$C_1$ | 69.62 | 402.00 | 12.00 | 17.00 | 0.93 | 5.33 |
| KCBtm/R/$C_1$ | 65.72 | 356.00 | 11.33 | 16.67 | 1.47 | 5.10 |
| KCEtm/S/$C_1$ | 59.63 | 349.33 | 13.67 | 17.67 | 1.07 | 4.83 |
| KCEtm/R/$C_1$ | 75.84 | 347.00 | 14.67 | 18.67 | 1.07 | 4.87 |
| KCBtm/$C_o$×KCEtm/$C_o$ | 66.63 | 334.00 | 14.00 | 17.67 | 1.13 | 5.40 |
| KCBtm/S/$C_1$×KCEtm/S/$C_1$ | 87.50 | 410.00 | 15.67 | 18.67 | 0.73 | 5.03 |
| KCBtm/R/$C_1$×KCEtm/R/$C_1$ | 103.71 | 427.67 | 13.67 | 21.33 | 0.93 | 4.93 |
| H 614 C | 97.35 | 459.67 | 12.67 | 22.67 | 1.33 | 4.97 |
| H 512 | 84.13 | 446.67 | 12.67 | 20.00 | 1.07 | 5.13 |
| Kensed | 84.65 | 480.00 | 11.33 | 18.33 | 1.00 | 5.13 |
| Katumani Composite B | 49.65 | 359.33 | 11.67 | 14.67 | 1.07 | 5.23 |
| Mean | 76.59 | 394.31 | 13.09 | 18.85 | 1.10 | 5.07 |
| Range | 49.65-103.71 | 334.00-480.00 | 11.33-15.67 | 14.67-22.67 | 0.73-1.47 | 4.63-5.40 |
| LSD(P=0.05) | 6.53 | 10.42 | 1.89 | 2.22 | NS | NS |
| CV % | 11.0 | 4.5 | 6.0 | 5.0 | 1.0 | 4.0 |
| F-ratio | 3.40** | 5.18** | 2.15** | 3.15** | 1.00 | 0.91 |

* Significant at P = 0.05.

** Significant at P = 0.01.

Table 2. Mean grain yield (q/ha), weight of 1000 grains (gm), number of rows per ear, ear length (cm), ear per plant and ear diameter (cm) of 25 maize populations in Katumani (b)

| Population | Yield q/ha | wt. of 1000 grains (gm) | No. of rows per ear | ear length (cm) | ears per plant | ear diameter (cm) |
|---|---|---|---|---|---|---|
| KCB(++)$C_o$ | 110.06 | 503.67 | 14.00 | 20.00 | 1.33 | 5.07 |
| KCB($o_2o_2$)$C_o$ | 81.41 | 399.00 | 12.30 | 20.33 | 1.20 | 4.87 |
| KCB($o_2o_2$)mod. | 75.06 | 446.67 | 13.00 | 20.67 | 1.07 | 4.77 |
| KCB($br_2br_2$)$C_o$ | 90.48 | 449.33 | 14.67 | 23.00 | 1.20 | 4.93 |
| KCB($br_2o_2$)$C_o$ | 77.91 | 397.33 | 12.67 | 19.67 | 1.13 | 5.43 |
| KCB($br_2o_2$)mod. | 106.43 | 509.67 | 12.67 | 20.67 | 1.27 | 5.27 |
| KCB($br_2o_2su_2$)$C_o$ | 60.29 | 368.10 | 15.00 | 18.33 | 1.00 | 5.13 |
| KCE(++)$C_o$ | 93.98 | 427.00 | 13.00 | 18.33 | 1.33 | 5.10 |
| KCE($o_2o_2$)$C_o$ | 77.65 | 459.00 | 13.33 | 20.33 | 1.20 | 4.83 |
| KCE($o_2o_2$)mod. | 79.99 | 490.33 | 13.00 | 20.00 | 1.07 | 5.43 |
| KCE($br_2br_2$)$C_o$ | 104.74 | 505.67 | 13.33 | 21.00 | 1.20 | 5.50 |
| KCE($br_2o_2$)$C_o$ | 90.61 | 438.00 | 13.67 | 21.00 | 1.27 | 5.20 |
| KCE($br_2o_2$)mod. | 112.13 | 488.00 | 13.33 | 19.00 | 1.33 | 4.93 |
| KCE($br_2o_2su_2$)$C_o$ | 76.09 | 385.67 | 14.00 | 20.00 | 1.07 | 5.07 |

Continued..

*Table 2 Continued.*

| | | | | | | |
|---|---|---|---|---|---|---|
| KCBtm/S/$C_1$ | 71.56 | 441.67 | 13.67 | 18.00 | 1.13 | 5.00 |
| KCBtm/R/$C_1$ | 70.00 | 460.33 | 12.67 | 18.67 | 1.07 | 4.87 |
| KCEtm/S/$C_1$ | 63.78 | 337.67 | 13.67 | 17.33 | 1.20 | 4.83 |
| KCEtm/R/$C_1$ | 81.54 | 429.33 | 14.67 | 18.00 | 1.00 | 5.03 |
| KCBtm/$C_o$ x KCEtm/$C_o$ | 77.65 | 426.67 | 13.67 | 18.00 | 1.07 | 4.91 |
| KCBtm/S/$C_1$ x KCEtm/S/$C_1$ | 109.54 | 469.67 | 14.67 | 21.33 | 1.20 | 5.43 |
| KCBtm/R/$C_1$ x KCEtm/R/$C_1$ | 118.09 | 449.67 | 14.00 | 20.33 | 1.20 | 5.23 |
| H 614 | 107.08 | 495.33 | 12.30 | 21.33 | 1.27 | 4.80 |
| H 512 | 84.65 | 511.00 | 11.67 | 21.33 | 1.07 | 5.30 |
| Kensed | 113.17 | 536.67 | 12.33 | 21.33 | 1.20 | 5.40 |
| Katumani Composite B | 52.11 | 390.00 | 11.67 | 15.33 | 0.93 | 4.98 |
| Mean | 87.44 | 448.61 | 13.32 | 19.73 | 1.16 | 5.09 |
| Range | 52.11-118.09 | 337.67-536.67 | 11.67-15.00 | 15.33-23.00 | 0.93-1.33 | 4.77-5.50 |
| LSD (P = 0.05) | 6.99 | 10.40 | 1.75 | 2.05 | NS | NS |
| CV % | 11.0 | 5.0 | 5.0 | 4.0 | 9.0 | 3.0 |
| F-ratio | 2.55** | 5.18** | 2.36** | 3.78** | 1.33 | 1.08 |

**Significant at P = 0.01

Table 3. Mean grain yield (q/ha), weight of 1000 grains (gm), number of rows per ear, ear length (cm), ear per plant, and ear diameter (cm) of 25 maize populations in Njoro.

| Population | Yield q/ha | wt. of 1000 grains (gm) | No. of rows per ear | ear length (cm) | ears per plant | ear diameter (cm) |
|---|---|---|---|---|---|---|
| KCB(++)$C_o$ | 63.00 | 449.67 | 11.33 | 19.67 | 1.13 | 4.33 |
| KCB($o_2o_2$)$C_o$ | 39.67 | 376.67 | 12.65 | 18.00 | 1.00 | 4.67 |
| KCB($o_2o_2$)mod. | 36.30 | 363.00 | 12.33 | 18.00 | 1.13 | 4.67 |
| KCB($br_2br_2$)$C_o$ | 37.20 | 344.33 | 13.65 | 17.33 | 1.00 | 4.67 |
| KCB($br_2o_2$)$C_o$ | 54.05 | 311.33 | 13.00 | 18.33 | 1.00 | 4.67 |
| KCB($br_2o_2$)mod. | 66.11 | 434.67 | 13.00 | 17.33 | 1.33 | 5.00 |
| KCB($br_2o_2su_2$)$C_o$ | 43.30 | 299.00 | 15.00 | 13.00 | 1.00 | 5.00 |
| KCE(++)$C_o$ | 75.57 | 371.67 | 13.00 | 17.00 | 1.53 | 4.67 |
| KCE($o_2o_2$)$C_o$ | 49.65 | 305.33 | 12.67 | 18.00 | 1.27 | 5.00 |
| KCE($o_2o_2$)mod. | 38.76 | 316.33 | 13.67 | 17.00 | 1.07 | 4.00 |
| KCE($br_2br_2$) | 55.74 | 364.67 | 13.33 | 17.33 | 1.20 | 5.00 |
| KCE($br_2o_2$)$C_o$ | 69.48 | 317.00 | 13.33 | 18.67 | 1.13 | 5.00 |
| KCE($br_2o_2$)mod. | 74.54 | 346.33 | 13.33 | 18.00 | 1.40 | 4.67 |
| KCE($br_2o_2su_2$)$C_o$ | 48.35 | 280.33 | 15.00 | 17.00 | 1.13 | 4.67 |

Continued .....

*Table 3 Continued*

| | | | | | | |
|---|---|---|---|---|---|---|
| KCBtm/S/$C_1$ | 33.44 | 367.67 | 13.00 | 15.00 | 0.87 | 4.33 |
| KCBtm/R/$C_1$ | 30.98 | 415.33 | 13.33 | 16.33 | 0.80 | 4.00 |
| KCEtm/S/$C_1$ | 34.48 | 281.00 | 13.67 | 15.67 | 1.00 | 4.67 |
| KCEtm/R/$C_1$ | 35.26 | 271.33 | 14.00 | 15.00 | 1.13 | 4.33 |
| KCBtm/$C_o$ x KCEtm/$C_o$ | 48.22 | 292.67 | 13.33 | 15.33 | 1.07 | 5.00 |
| KCBtm/S/$C_1$xKCEtm/S/$C_1$ | 73.11 | 326.00 | 14.33 | 18.33 | 1.60 | 5.00 |
| KCBtm/R/$C_1$xKCEtm/R/$C_1$ | 84.13 | 402.33 | 14.33 | 19.00 | 1.20 | 5.00 |
| H 614 C | 81.41 | 397.33 | 13.00 | 19.67 | 1.47 | 5.00 |
| H 512 | 62.74 | 324.00 | 12.33 | 18.67 | 1.33 | 4.67 |
| Kensed | 51.21 | 519.38 | 12.33 | 19.00 | 1.00 | 4.67 |
| Katumani Composite B | 25.28 | 274.33 | 11.00 | 14.00 | 1.13 | 4.00 |
| Mean | 52.48 | 350.06 | 13.20 | 17.21 | 1.16 | 4.67 |
| Range | 25.28-84.13 | 271.33-519.33 | 11.00-15.00 | 14.00-19.67 | 0.80-160 | 4.00-5.00 |
| LSD ( P = 0.05) | 5.72 | 13.20 | 1.57 | 2.24 | NS | NS |
| CV % | 13.0 | 10.0 | 4.0 | 6.0 | 11.0 | 5.0 |
| F-ratio | 6.67** | 3.70** | 3.63** | 2.79** | 1.40 | 1.73 |

** Significant at P = 0.01.

*Table 4.* *Mean grain yield (q/ha), weight of 1000 grains (gm), number of rows per ear, ear length (cm), ear per plant and ear diameter (cm) of 25 maize populations in Kitale.*

| Population | Yield q/ha | wt. of 1000 grains (gm) | No. of rows per ear | ear length (cm) | ears per plant | ear diameter (cm) |
|---|---|---|---|---|---|---|
| KCB(++)$C_o$ | 52.63 | 463.33 | 12.00 | 18.33 | 1.20 | 3.57 |
| KCB($o_2o_2$)$C_o$ | 46.67 | 360.00 | 14.57 | 17.13 | 1.13 | 3.63 |
| KCB($o_2o_2$)mod. | 42.91 | 383.33 | 14.33 | 18.00 | 1.40 | 4.13 |
| KCB($br_2br_2$)$C_o$ | 48.22 | 333.33 | 12.67 | 19.37 | 1.07 | 3.20 |
| KCB($br_2o_2$)$C_o$ | 41.09 | 336.67 | 13.67 | 15.87 | 1.20 | 3.67 |
| KCB($br_2o_2$)mod. | 56.91 | 370.00 | 13.00 | 16.13 | 1.33 | 3.40 |
| KCB($br_2o_2su_2$)$C_o$ | 57.56 | 290.67 | 13.33 | 13.80 | 1.27 | 3.00 |
| KCE(++)$C_o$ | 29.82 | 298.67 | 11.00 | 14.47 | 1.33 | 2.87 |
| KCE($o_2o_2$)$C_o$ | 66.11 | 270.67 | 12.33 | 17.53 | 1.20 | 3.30 |
| KCE($o_2o_2$)mod. | 50.82 | 440.00 | 11.67 | 16.00 | 1.40 | 2.90 |
| KCE($br_2br_2$)$C_o$ | 53.54 | 460.00 | 14.00 | 14.93 | 1.33 | 3.63 |
| KCE($br_2o_2$)$C_o$ | 51.59 | 342.67 | 11.33 | 15.20 | 1.40 | 3.27 |
| KCE($br_2o_2$)mod. | 48.61 | 336.67 | 13.33 | 15.97 | 1.33 | 3.27 |
| KCE($br_2o_2su_2$)$C_o$ | 41.87 | 244.00 | 13.13 | 15.63 | 1.33 | 3.00 |

Continued....

*Table 4 Continued.*

| | | | | | | |
|---|---|---|---|---|---|---|
| KCBtm/S/$C_1$ | 43.04 | 380.00 | 13.00 | 16.10 | 1.00 | 2.83 |
| KCBtm/R/$C_1$ | 49.65 | 250.00 | 10.33 | 11.30 | 1.00 | 2.50 |
| KCEtm/S/$C_1$ | 39.15 | 328.00 | 15.33 | 15.97 | 1.07 | 3.33 |
| KCEtm/R/$C_1$ | 63.65 | 280.00 | 14.00 | 15.83 | 1.20 | 3.27 |
| KCBtm/$C_o$ x KCEtm/$C_o$ | 47.19 | 320.00 | 13.67 | 15.30 | 1.07 | 3.53 |
| KCBtm/S/$C_1$ xKCEtm/S/$C_1$ | 51.34 | 403.33 | 13.00 | 16.70 | 1.07 | 3.23 |
| KCBtm/R/$C_1$ xKCEtm/R/$C_1$ | 50.43 | 380.00 | 14.67 | 17.70 | 1.13 | 3.50 |
| H 614 C | 48.87 | 510.00 | 14.00 | 19.40 | 1.20 | 3.77 |
| H 512 | 47.06 | 420.00 | 12.33 | 18.33 | 1.20 | 3.37 |
| Kensed | 49.26 | 430.00 | 12.00 | 13.27 | 1.33 | 3.67 |
| Katumani Composite B | 47.32 | 250.00 | 11.33 | 15.50 | 1.00 | 2.87 |
| Mean | 49.01 | 355.17 | 12.97 | 16.15 | 1.21 | 3.32 |
| Range | 29.28-66.11 | 210.00-510.00 | 10.33-15.33 | 11.30-1940 | 1.00-1.40 | 2.50-413 |
| LSD(P = 0.05) | 5.63 | 13.59 | 2.34 | 2.93 | NS | NS |
| CV % | 13.0 | 11.0 | 9.0 | 11.0 | 11.0 | 10.0 |
| F-ratio | 2.35* | 3.77** | 1.74* | 2.13* | 1.00 | 1.33 |

*Significant at P = 0.05
**Significant at P = 0.01

whereas at Njoro, it ranged between 25.28 (Katumani Composite B) and 84.13 q/ha (KCB tm/R/$C_1$ x KCE tm/R/$C_1$) (Table 3). In Kitale the range was between 29.32 (KCE (++) $C_o$) and 66.11 q/ha (KCE ($O_2$ $O_2$) $C_o$) (Table 4). Katumani Composite B had the lowest yield in 3 out of 4 locations. Similarly KCB tm/R/$C_1$ x KCE tm/R/$C_1$ had the highest. At Kitale, KCE ($o_2$ $o_2$)$C_o$ outyielded KCE (++) $C_o$. In general grain yield levels at Katumani were higher than those at Njoro and Kitale (Table 5). The difference among genotypes were highly significant while genotype and environment interacted significantly (Table 6).

4.1.2. 1000-grain weight

At Katumani site (a) (Table 1) the weight of 1000 grains of KCB tm/$C_o$ x KCE tm/$C_o$ was 334.00 gm. compared to Kensed's weight of 480.00 gm. On site (b) (Table 2) in the same location the range was between 337.67 (KCE tm/S/$C_1$) and 536.67 gm of Kensed. KCE tm/R/$C_1$ gave the lowest weight (271.33 gm) at Njoro (Table 3) and Kensed gave the highest weight (519.33 gm). In Kitale (Table 4) Katumani Composite B weighed 250.00 gm compared to H 614 C that weighed 510.00 gm. The weight of 1000 grains was in general heavier at Katumani than in

Table 5. Combined mean grain yield (q/ha), weight of 1000 grains (gm), number of rows per ear, ear length (cm), ear per plant and ear diameter (cm) of 25 maize populations in 4 environments in Kenya.

| Population | Yield q/ha | wt.of 1000 grains (gm) | No. of rows per ear | ear length (cm) | ears per plant | ear diameter (cm) |
|---|---|---|---|---|---|---|
| KCB(++)$C_o$ | 81.92 | 470.00 | 12.15 | 19.83 | 1.27 | 4.48 |
| KCB($o_2o_2$)$C_o$ | 56.39 | 372.50 | 13.13 | 18.12 | 1.08 | 4.58 |
| KCB($o_2o_2$)mod. | 58.59 | 393.67 | 13.25 | 19.34 | 1.18 | 4.67 |
| KCB($br_2br_2$)$C_o$ | 64.39 | 372.42 | 13.67 | 20.09 | 0.10 | 4.36 |
| KCB($br_2o_2$)$C_o$ | 62.57 | 359.58 | 13.00 | 18.05 | 1.10 | 4.74 |
| KCB($br_2o_2$)mod. | 80.40 | 429.25 | 12.92 | 18.45 | 1.32 | 4.71 |
| KCB($br_2o_2su_2$)$C_o$ | 56.03 | 319.75 | 14.50 | 15.53 | 1.09 | 4.53 |
| KCE(++)$C_o$ | 68.80 | 371.75 | 12.50 | 17.03 | 1.30 | 4.35 |
| KCE($o_2o_2$)$C_o$ | 62.38 | 354.08 | 12.58 | 18.55 | 1.20 | 4.60 |
| KCE($o_2o_2$)mod. | 60.93 | 422.83 | 12.59 | 18.17 | 1.14 | 4.38 |
| KCE($br_2br_2$)$C_o$ | 73.63 | 433.00 | 13.58 | 17.98 | 1.22 | 4.78 |
| KCE($br_2o_2$)$C_o$ | 73.43 | 374.75 | 13.17 | 18.80 | 1.23 | 4.64 |
| KCE($br_2o_2$)mod. | 77.29 | 397.83 | 13.30 | 18.24 | 1.28 | 4.52 |
| KCE($br_2o_2su_2$)$C_o$ | 59.98 | 344.00 | 14.00 | 17.66 | 1.18 | 4.49 |

Continued....

Table 5 Continued.

| | | | | | | |
|---|---|---|---|---|---|---|
| KCBtm/S/$C_1$ | 54.41 | 397.84 | 12.92 | 16.53 | 0.98 | 4.37 |
| KCBtm/R/$C_1$ | 54.09 | 370.42 | 11.92 | 15.74 | 1.09 | 4.12 |
| KCEtm/S/$C_1$ | 49.26 | 324.00 | 14.09 | 16.66 | 1.09 | 4.42 |
| KCEtm/R/$C_1$ | 64.07 | 356.92 | 14.34 | 16.88 | 1.10 | 4.38 |
| KCBtm/$C_o$ x KCEtm/$C_o$ | 59.92 | 343.34 | 13.67 | 16.58 | 1.09 | 4.71 |
| KCBtm/S/$C_1$ x KCEtm/S/$C_1$ | 80.37 | 402.25 | 14.42 | 18.76 | 1.15 | 4.67 |
| KCBtm/R/$C_1$ x KCEtm/R/$C_1$ | 89.09 | 414.92 | 14.17 | 19.58 | 1.12 | 4.67 |
| H 614.C | 83.68 | 465.58 | 12.97 | 20.77 | 1.32 | 4.64 |
| H 512 | 69.64 | 425.42 | 12.25 | 19.58 | 1.17 | 4.67 |
| Kensed | 74.57 | 491.50 | 12.00 | 17.98 | 1.13 | 4.72 |
| Katumani Composite B | 43.59 | 318.43 | 11.42 | 14.88 | 1.03 | 4.26 |
| Mean | 66.38 | 389.04 | 13.14 | 17.80 | 1.16 | 4.54 |
| Range | 43.59-89.09 | 318.43-491.50 | 11.42-14.50 | 14.88-20.77 | 0.98-1.32 | 4.12-4.78 |
| LSD (P = 0.05) | 6.30 | 12.18 | 1.06 | 2.42 | NS | NS |
| F-ratio | 8.26** | 10.38** | 4.54** | 5.92** | 1.50 | 1.29 |

**Significant at P = 0.01.

Table 6. Combined analysis of variance for grain yield in maize

| Source of variation | df | ss | ms | F |
|---|---|---|---|---|
| Location | 3 | 78190.00 | 26063.30 | 131.32** |
| Replication | 2 | 2620.12 | 1310.66 | 6.60** |
| Replication/ Environment | 8 | 80810.00 | 10101.25 | 50.89** |
| Genotype | 24 | 39367.00 | 1640.29 | 8.26** |
| Genotype x Environment | 72 | 24450.06 | 339.58 | 1.71** |
| Pooled error | 190 | 37709.92 | 198.47 | |

** significant at P = 0.01

other locations. Kensed was consistently heavier than the other varieties, however Katumani Composite B was the lightest. The genotypes were highly significantly different in all the locations, but the genotype by environment interaction was also significant (Table 7).

4.1.3. Number of rows per ear

Number of rows per ear ranged from 11.33 (Kensed) to 15.67 in (KCB tm/S/$C_1$ x KCE tm/S/$C_1$) (Table 1) at Katumani site (a) while on site (b) (Table 2) Katumani Composite B had 11.67 rows per ear and both (KCB tm/S/$C_1$ x KCE tm/S/$C_1$) and KCB ($br_2$ $br_2$) $C_o$ had 14.67 rows per ear. At Njoro (Table 3) the number of rows ranged between 11.00 (Katumani Composite B) and 15.00 (KCB tm/$C_o$). But in Kitale (Table 4), KCB tm/R/$C_1$) had the least number of rows per ear (10.33) while KCE tm/S/$C_1$ had the highest number of rows per ear (15.33). In general Katumani Composite B had the lowest number of rows (11.42) while KCB tm/$C_o$ had the highest (14.50) (Table 5). Triple mutant materials had consistently higher number of rows, compared to Kensed which had the heaviest grain weight and lower number of rows. As a whole genotypes were

Table 7. Combined analysis of variance for weight of 1000 grains in maize

| Source of variation | df | ss | ms | F |
|---|---|---|---|---|
| Environment | 3 | 466995.00 | 155665.00 | 56.08** |
| Replication | 2 | 17829.00 | 8914.50 | 3.21* |
| Environment/ Replication | 8 | 484823.00 | 60602.80 | 21.83** |
| Genotype | 24 | 691350.00 | 28806.25 | 10.38** |
| Genotype x Environment | 72 | 274367.00 | 3810.65 | 1.37* |
| Pooled error | 190 | 527389.00 | 2775.73 | |

* significant at P = 0.05.

**significant at P = 0.01.

significantly different in number of rows. The genotypes and environment did not interact significantly (Table 8).

4.1.4. Ear length

In Table 1, H 614 C had the longest ear length at Katumani site (a) (22.67 cm) and KCB ($br_2$ $br_2$) $C_o$ (23.00) in site (b) (Table 2). Or the other hand Katumani Composite B had the shortest length in both sites: 14.67 cm in site (a) and 15.33 cm in site (b). At Njoro (Table 3) Katumani Composite B had the shortest ears (14.00 cm) and KCB (++) $C_o$ had the longest ears (19.67 cm). But in Kitale (Table 4) KCB tm/R/$C_1$ realised the least length (11.30 cm) while H 614 had the most (19.40 cm). In general Katumani Composite B had short ears on average (14.88 cm) whereas H 614 C had longer ears averaging 20.77 cm (Table 5). Genotypes showed significant differences on ear length in all locations, however, there was no genotype by environment interaction (Table 9).

Table 8. Combined analysis of variance for number of rows per ear in maize

| Source of variation | df | ss | ms | F |
|---|---|---|---|---|
| Environment | 3 | 4.94 | 1.65 | 0.89 |
| Replication | 2 | 15.58 | 7.79 | 4.19* |
| Environment/ Replication | 8 | 20.51 | 2.56 | 1.38 |
| Genotype | 24 | 202.88 | 8.45 | 4.54** |
| Genotype x Environment | 72 | 103.88 | 1.44 | 0.77 |
| Pooled error | 190 | 353.76 | 1.86 | |

* significant at P = 0.05.

**significant at P = 0.01.

Table 9. Combined analysis of variance for ear length in maize

| Source of variance | df | ss | ms | F |
|---|---|---|---|---|
| Environment | 3 | 582.81 | 194.27 | 43.56** |
| Replication | 2 | 52.98 | 26.49 | 5.94** |
| Environment/ Replication | 8 | 635.77 | 79.47 | 17.82** |
| Genotype | 24 | 634.16 | 26.42 | 5.92** |
| Genotype x Environment | 72 | 260.94 | 3.62 | 0.81 |
| Pooled error | 190 | 847.39 | 4.46 | |

**significant at P = 0.01.

4.1.5. Ears per plant

In terms of ears per plant, there were significant differences in both Katumani sites and Kitale except at Njoro where KCB tm/R/$C_1$ with 0.80 ear per plant was not statistically different from KCB tm/S/$C_1$ x KCE tm/S/$C_1$ which had 1.60 ears per plant. KCB tm/S/$C_1$ tended to have low number of ears per plant (0.98) while both H 614 and KCB ($br_2$ $o_2$) modified had the highest number of ears per plant (1.32). Genotypes showed significant differences at Njoro. However, genotype by environment interaction was not significant (Table 10).

4.1.6. Ear diameter

There were no significant differences in ear diameter in other locations except at Kitale, where KCB tm/R/$C_1$ tended to have slender ears (4.12 cm) and KCB ($br_2$ $br_2$)$C_o$ had thick ears (4.78 cm). Genotypes exhibited significant differences at Kitale only, however, there was no genotype and environment interaction over all the locations (Table 11).

4.1.5. Ears per plant

In terms of ears per plant, there were significant differences in both Katumani sites and Kitale except at Njoro where KCB tm/R/$C_1$ with 0.80 ear per plant was not statistically different from KCB tm/S/$C_1$ x KCE tm/S/$C_1$ which had 1.60 ears per plant. KCB tm/S/$C_1$ tended to have low number of ears per plant (0.98) while both H 614 and KCB ($br_2$ $o_2$) modified had the highest number of ears per plant (1.32). Genotypes showed significant differences at Njoro. However, genotype by environment interaction was not significant (Table 10).

4.1.6. Ear diameter

There were no significant differences in ear diameter in other locations except at Kitale, where KCB tm/R/$C_1$ tended to have slender ears (4.12 cm) and KCB ($br_2$ $br_2$)$C_o$ had thick ears (4.78 cm). Genotypes exhibited significant differences at Kitale only, however, there was no genotype and environment interaction over all the locations (Table 11).

Table 10. Combined analysis of variance for ear per plant in maize

| Source of variation | df | ss | ms | F |
|---|---|---|---|---|
| Environment | 3 | 0.40 | 0.13 | 1.30 |
| Replication | 2 | 0.78 | 0.39 | 3.90** |
| Environment/ Replication | 8 | 1.17 | 0.19 | 1.90* |
| Genotype | 24 | 2.36 | 0.15 | 1.50** |
| Genotype/ Environment | 72 | 2.47 | 0.03 | 0.03 |
| Pooled error | 190 | 19.19 | 0.10 | |

*significant at P = 0.05.

**significant at P = 0.01.

Table 11. Combined analysis of variance for ear diameter in maize

| Source of variation | df | ss | ms | F |
|---|---|---|---|---|
| Environment | 3 | 156.6 | 52.20 | 193.33** |
| Replication | 2 | 4.79 | 2.39 | 8.85** |
| Environment/ Replication | 8 | 161.38 | 20.17 | 74.70** |
| Genotype | 24 | 8.50 | 0.35 | 1.29 |
| Genotype x Environment | 72 | 15.26 | 0.21 | 0.78 |
| Pooled error | 190 | 51.30 | 0.27 | |

**significant at P = 0.01.

## 4.2. Plant characteristics

The mean values of crop index, ear height, plant height, number of leaves, days to 50 percent silking and lodging percentage for 25 varieties grown in 4 locations are given in Tables 12, 13, 14 and 15.

### 4.2.1. Crop index

Crop index at Katumani site (a) (Table 12) ranged between 37.47 (KCE ($br_2$ $br_2$)$C_o$) and 54.77 (Katumani Composite B) while on site (b) (Table 13) it ranged from 32.20 (KCE ($br_2$ $br_2$) $C_o$) to 53.10 (Katumani Composite B). At Njoro (Table 14) crop index for KCB tm/R/$C_1$ was 30.57 and 45.93 for Katumani Composite B. In Table 16 combined data over the locations indicated that Katumani Composite B had the highest value (51.27) followed by KCB tm/R/$C_1$ x KCE tm/R/$C_1$ (45.10) and KCB ($br_2$ $br_2$) $C_o$ had the lowest value (35.31). Genotypes were significantly different, but there was no genotype by environment interaction (Table 17).

### 4.2.2. Ear height (cm)

The ear height of H 614 C at Katumani site (a) (Table 12) was 144 cm and in site (b) (Table 13) the

## 4.2. Plant characteristics

The mean values of crop index, ear height, plant height, number of leaves, days to 50 percent silking and lodging percentage for 25 varieties grown in 4 locations are given in Tables 12, 13, 14 and 15.

### 4.2.1. Crop index

Crop index at Katumani site (a) (Table 12) ranged between 37.47 (KCE ($br_2$ $br_2$)$C_o$) and 54.77 (Katumani Composite B) while on site (b) (Table 13) it ranged from 32.20 (KCE ($br_2$ $br_2$) $C_o$) to 53.10 (Katumani Composite B). At Njoro (Table 14) crop index for KCB tm/R/$C_1$ was 30.57 and 45.93 for Katumani Composite B. In Table 16 combined data over the locations indicated that Katumani Composite B had the highest value (51.27) followed by KCB tm/R/$C_1$ x KCE tm/R/$C_1$ (45.10) and KCB ($br_2$ $br_2$) $C_o$ had the lowest value (35.31). Genotypes were significantly different, but there was no genotype by environment interaction (Table 17).

### 4.2.2. Ear height (cm)

The ear height of H. 614 C at Katumani site (a) (Table 12) was 144 cm and in site (b) (Table 13) the

Table 12. Mean crop index, ear height (cm), plant height (cm), number of leaves, days to 50 percent silking and lodging percentage of 25 maize populations in Katumani (a)

| Populations | Crop index | Ear height (cm) | Plant height (cm) | No. of leaves per plant | Days to 50 % silking | Lodging percentage |
|---|---|---|---|---|---|---|
| KCB(++)$C_o$ | 38.27 | 133.33 | 285.00 | 16.33 | 100.00 | 35.47 |
| KCB($o_2o_2$)$C_o$ | 42.17 | 108.00 | 233.67 | 15.00 | 95.00 | 10.00 |
| KCB($o_2o_2$)mod. | 46.83 | 101.33 | 254.67 | 14.67 | 94.67 | 26.67 |
| KCB($br_2br_2$)$C_o$ | 37.83 | 90.67 | 233.00 | 15.67 | 105.33 | 10.00 |
| KCB($br_2o_2$)$C_o$ | 44.37 | 95.00 | 231.33 | 15.33 | 103.33 | 22.27 |
| KCB($br_2o_2$)mod. | 45.97 | 94.33 | 226.67 | 15.00 | 102.33 | 27.40 |
| KCB($br_2o_2su_2$)$C_o$ | 51.77 | 69.33 | 203.00 | 13.33 | 93.00 | 20.63 |
| KCE(++)$C_o$ | 45.13 | 134.33 | 274.00 | 15.33 | 95.67 | 20.00 |
| KCE($o_2o_2$)$C_o$ | 45.73 | 110.00 | 241.67 | 14.67 | 99.67 | 27.67 |
| KCE($o_2o_2$)mod. | 40.60 | 99.67 | 236.67 | 14.67 | 94.67 | 15.00 |
| KCE($br_2br_2$)$C_o$ | 37.47 | 108.00 | 225.00 | 14.67 | 99.67 | 16.57 |
| KCE($br_2o_2$)$C_o$ | 47.17 | 112.33 | 246.00 | 14.67 | 91.67 | 37.77 |
| KCE($br_2o_2$)mod. | 42.83 | 110.00 | 227.00 | 14.00 | 93.67 | 13.70 |
| KCE($br_2o_2su_2$) | 44.27 | 73.00 | 214.00 | 13.67 | 91.00 | 17.03 |

Continued

Table 12. Continued

| | | | | | | |
|---|---|---|---|---|---|---|
| KCBtm/S/$C_1$ | 39.67 | 97.33 | 236.33 | 14.33 | 95.33 | 12.27 |
| KCBtm/R/$C_1$ | 42.27 | 79.67 | 206.33 | 13.67 | 98.00 | 27.58 |
| KCEtm/S/$C_1$ | 48.77 | 87.67 | 223.67 | 14.33 | 96.00 | 24.07 |
| KCEtm/R/$C_1$ | 47.37 | 108.00 | 240.33 | 15.00 | 96.00 | 17.77 |
| KCBtm/$C_o$ × KCEtm/$C_o$ | 46.80 | 69.67 | 207.67 | 12.67 | 83.67 | 13.33 |
| KCBtm/S/$C_1$ × KCEtm/S/$C_1$ | 49.23 | 95.67 | 245.33 | 13.67 | 91.33 | 24.30 |
| KCBtm/R/$C_1$ × KCEtm/R/$C_1$ | 50.90 | 94.38 | 251.33 | 14.33 | 91.00 | 16.20 |
| H 614 C | 40.33 | 144.00 | 281.61 | 17.00 | 97.67 | 23.70 |
| H 512 | 46.47 | 90.33 | 218.00 | 13.67 | 80.33 | 10.37 |
| Kensed | 45.57 | 103.67 | 240.67 | 13.67 | 90.67 | 25.73 |
| Katumani Composite B | 54.77 | 60.67 | 156.00 | 9.33 | 70.67 | 10.00 |
| Mean | 44.90 | 98.81 | 233.56 | 14.35 | 94.01 | 19.98 |
| Range | 37.47-54.77 | 60.67-144.00 | 156.00-285.00 | 9.33-17.00 | 70.67-105.33 | 10.00-32.77 |
| LSD (P = 0.05) | 3.69 | 5.67 | 6.79 | 1.57 | 3.07 | 5.91 |
| CV % | 6.0 | 7.9 | 4.0 | 3.0 | 2.0 | 62.0 |
| F-ratio | 1.92* | 9.42** | 8.06** | 7.99** | 14.26** | 2.15* |

*significant at P = 0.05
**significant at P = 0.01.

*Table 13. Mean crop index, ear height (cm), plant height (cm), number of leaves and days to 50 percent silking of 25 maize population in Katumani (b)*

| Population | Crop index | Ear height (cm) | Plant height (cm) | No. of leaves per plant | Days to 50 percent silking |
|---|---|---|---|---|---|
| KCB(++)$C_o$ | 41.47 | 152.33 | 293.00 | 17.33 | 117.33 |
| KCB($o_2o_2$)$C_o$ | 37.80 | 106.00 | 243.00 | 13.68 | 108.00 |
| KCB($o_2o_2$)mod. | 36.37 | 114.00 | 262.33 | 14.67 | 108.00 |
| KCB($br_2br_2$)$C_o$ | 34.00 | 117.67 | 280.33 | 15.67 | 117.00 |
| KCB($br_2o_2$)$C_o$ | 33.97 | 101.33 | 224.67 | 15.00 | 115.67 |
| KCB($br_2o_2$)mod. | 35.63 | 130.33 | 241.33 | 15.33 | 116.00 |
| KCB($Br_2o_2su_2$($C_o$ | 35.37 | 69.67 | 214.33 | 12.00 | 101.67 |
| KCE(++)$C_o$ | 38.27 | 152.33 | 277.00 | 15.33 | 110.33 |
| KCE($o_2o_2$)$C_o$ | 38.93 | 119.67 | 260.33 | 14.67 | 107.67 |
| KCE($o_2o_2$)mod. | 42.27 | 107.67 | 239.33 | 15.00 | 108.33 |
| KCE($br_2br_2$)$C_o$ | 32.20 | 110.67 | 254.00 | 15.67 | 115.00 |
| KCE($br_2o_2$)$C_o$ | 40.90 | 119.67 | 242.00 | 14.33 | 104.00 |
| KCE($br_2o_2$)mod. | 40.00 | 116.33 | 244.00 | 14.00 | 110.00 |
| KCE($br_2o_2su_2$)$C_o$ | 30.80 | 91.00 | 247.00 | 13.33 | 102.33 |

Continued..

Table 13 Continued

| | | | | | |
|---|---|---|---|---|---|
| KCBtm/S/$C_1$ | 41.40 | 100.00 | 233.67 | 14.33 | 107.33 |
| KCBtm/R/$C_1$ | 37.93 | 93.67 | 217.33 | 13.00 | 110.67 |
| KCEtm/S/$C_1$ | 39.00 | 113.33 | 285.67 | 14.00 | 108.00 |
| KCEtm/R/$C_1$ | 42.17 | 125.00 | 247.67 | 14.33 | 107.00 |
| KCBtm/$C_o$ x KCEtm/$C_o$ | 41.80 | 74.00 | 219.00 | 13.00 | 108.00 |
| KCBtm/S/$C_1$ x KCEtm/S/$C_1$ | 42.00 | 107.67 | 262.00 | 14.33 | 106.33 |
| KCBtm/R/$C_1$ x KCEtm/R/$C_1$ | 39.53 | 115.33 | 262.00 | 14.00 | 104.33 |
| H 614 C | 38.63 | 140.00 | 286.67 | 16.00 | 112.00 |
| H 512 | 41.47 | 108.67 | 240.00 | 12.00 | 98.00 |
| Kensed | 41.47 | 121.33 | 259.33 | 15.33 | 99.33 |
| Katumani Composite B | 53.10 | 66.00 | 174.00 | 10.00 | 99.33 |
| Mean | 39.42 | 110.95 | 246.40 | 14.25 | 108.06 |
| Range | 32.20-53.10 | 60.00-152.33 | 174.00-293.00 | 10.00-17.33 | 98.00-117.33 |
| LSD (P = 0.05) | 3.78 | 6.43 | 8.49 | 1.47 | 4.15 |
| CV % | 7.0 | 8.0 | 6.0 | 3.0 | 3.0 |
| F-ratio | 2.55** | 6.61** | 3.05** | 11.51** | 2.45** |

**significant at P = 0.01.

*Table 14. Mean crop index, ear height (cm) plant length (cm), number of leaves and days to 50 percent silking of 25 maize populations in Njoro.*

| Population | Crop index | Ear height (cm) | Plant height (cm) | No. of leaves per plant | Days to 50 percent silking |
|---|---|---|---|---|---|
| KCB(++)$C_o$ | 39.66 | 151.33 | 295.00 | 17.67 | 133.00 |
| KCB($o_2o_2$)$C_o$ | 33.40 | 131.00 | 272.00 | 16.00 | 123.67 |
| KCB($o_2o_2$)mod. | 31.97 | 125.67 | 268.33 | 15.67 | 126.00 |
| KCB($br_2br_2$) | 34.10 | 129.67 | 270.00 | 16.67 | 139.67 |
| KCB($br_2o_2$)$C_o$ | 38.40 | 115.00 | 247.00 | 17.00 | 137.00 |
| KCB($br_2o_2$) mod. | 40.13 | 130.00 | 259.00 | 18.00 | 137.33 |
| KCB($br_2o_2su_2$)$C_o$ | 41.60 | 78.00 | 212.67 | 15.67 | 122.67 |
| KCE(++)$C_o$ | 34.23 | 185.67 | 311.67 | 17.33 | 129.67 |
| KCE($o_2o_2$)$C_o$ | 38.43 | 123.33 | 224.67 | 16.33 | 125.33 |
| KCE($o_2o_2$)mod. | 32.33 | 126.00 | 267.00 | 16.67 | 134.38 |
| KCE($br_2br_2$) | 36.70 | 120.33 | 271.33 | 18.00 | 137.00 |
| KCE($br_2o_2$)$C_o$ | 45.30 | 115.67 | 251.67 | 16.00 | 123.00 |
| KCE($br_2o_2$)mod. | 41.90 | 129.00 | 239.33 | 16.33 | 128.67 |
| KCE($br_2o_2su_2$($C_o$ | 42.53 | 101.00 | 243.33 | 15.33 | 116.33 |

*Table 14. Continued*

| | | | | | |
|---|---|---|---|---|---|
| KCBtm/S/$C_1$ | 43.53 | 96.67 | 221.33 | 15.67 | 136.67 |
| KCBtm/R/$C_1$ | 30.57 | 99.67 | 226.33 | 15.67 | 133.00 |
| KCEtm/S/$C_1$ | 34.23 | 114.67 | 243.67 | 15.33 | 127.00 |
| KCEtm/R/$C_1$ | 38.67 | 134.67 | 249.33 | 16.33 | 128.00 |
| KCBtm/$C_o$ x KCEtm/$C_o$ | 45.53 | 84.00 | 213.67 | 15.00 | 119.67 |
| KCBtm/S/$C_1$ x KCEtm/S/$C_1$ | 41.97 | 129.33 | 270.33 | 16.33 | 126.00 |
| KCBtm/R/$C_1$ x KCEtm/R/$C_1$ | 44.87 | 120.33 | 269.67 | 15.67 | 119.67 |
| H 614 C | 45.70 | 169.69 | 316.00 | 18.33 | 130.33 |
| H 512 | 42.37 | 116.67 | 256.33 | 14.33 | 120.67 |
| Kensed | 36.40 | 137.67 | 274.33 | 16.33 | 126.00 |
| Katumani Composite B | 45.93 | 84.00 | 179.00 | 13.67 | 79.00 |
| Mean | 39.22 | 121.96 | 254.13 | 16.21 | 126.39 |
| Range | 30.57-45.93 | 78.00-155.67 | 179.00-316.00 | 13.67-18.33 | 79.00-139.67 |
| LSD (P = 0.05) | 4.44 | 6.39 | 5.07 | 1.78 | 3.60 |
| CV% | 10.0 | 7.0 | 5.0 | 4.0 | 2.0 |
| F-ratio | 2.43** | 8.66** | 5.48** | 2.98** | 13.79** |

**significant at P = 0.01.

*Table 15. Mean ear height (cm) plant height (cm), number of leaves per plant and days to 50 percent silking in Kitale.*

| Population | Ear height (cm) | Plant height (cm) | No. of leaves per plant | Days to 50 percent silking |
|---|---|---|---|---|
| KCB(++)$C_o$ | 189.00 | 325.00 | 13.00 | 92.67 |
| KCB($o_2o_2$)$C_o$ | 184.67 | 327.33 | 14.00 | 87.67 |
| KCB($o_2o_2$)mod. | 190.67 | 323.33 | 13.33 | 87.67 |
| KCB($br_2br_2$)$C_o$ | 156.33 | 294.33 | 13.33 | 98.33 |
| KCB($br_2o_2$)$C_o$ | 178.67 | 298.33 | 14.00 | 94.33 |
| KCB($br_2o_2$)mod. | 190.00 | 329.67 | 14.00 | 96.33 |
| KCB($br_2o_2su_2$)$C_o$ | 121.67 | 260.33 | 13.33 | 88.00 |
| KCE(++)$C_o$ | 208.33 | 330.33 | 9.67 | 91.00 |
| KCE($o_2o_2$)$C_o$ | 185.67 | 320.67 | 15.33 | 90.67 |
| KCE($o_2o_2$)mod. | 172.67 | 283.33 | 13.33 | 91.00 |
| KCE($br_2br_2$)$C_o$ | 180.33 | 294.00 | 13.00 | 94.33 |
| KCE($br_2o_2$)$C_o$ | 193.00 | 321.67 | 12.67 | 80.00 |
| KCE($br_2o_2$)mod. | 183.67 | 294.67 | 14.00 | 86.33 |
| KCE($br_2o_2su_2$)$C_o$ | 140.67 | 269.33 | 12.67 | 99.33 |

Continued....

*Table 15. Continued*

| | | | | |
|---|---|---|---|---|
| KCBtm/S/$C_1$ | 150.00 | 292.67 | 12.33 | 90.67 |
| KCBtm/R/$C_1$ | 136.67 | 233.00 | 14.00 | 90.33 |
| KCEtm/S/$C_1$ | 153.67 | 285.00 | 11.67 | 86.67 |
| KCEtm/R/$C_1$ | 178.67 | 292.67 | 13.33 | 87.67 |
| KCBtm/$C_o$ × KCEtm/$C_o$ | 120.33 | 295.33 | 13.67 | 87.33 |
| KCBtm/S/$C_1$ × KCEtm/S/$C_1$ | 169.00 | 322.67 | 13.00 | 88.33 |
| KCBtm/R/$C_1$ × KCEtm/R/$C_1$ | 170.33 | 325.33 | 13.33 | 87.33 |
| H 614 C | 231.33 | 354.00 | 13.67 | 92.67 |
| H 512 | 145.67 | 256.67 | 12.33 | 108.67 |
| Kensed | 175.67 | 307.00 | 12.67 | 86.00 |
| Katumani Composite B | 95.67 | 208.67 | 11.67 | 85.33 |
| Mean | 168.21 | 296.05 | 13.13 | 90.75 |
| Range | 95.67-208.33 | 208.67-354.00 | 9.67-15.33 | 80.00-108.67 |
| LSD (P = 0.05) | 5.17 | 8.77 | 2.53 | 4.04 |
| CV % | 7.0 | 5.0 | 10.0 | 4.0 |
| F-ratio | 7.07** | 4.54** | 1.76* | 2.95** |

* significant at P = 0.05

**significant at P = 0.01.

Table 16. Combined mean crop index, ear length (cm) plant height (cm), number of leaves and days to 50 percent silking of 25 maize populations in 4 environments in Kenya.

| Population | Crop index | Ear height (cm) | Plant height (cm) | No. of leaves per plant | Days to 50 percent silking |
|---|---|---|---|---|---|
| KCB(++)$C_o$ | 39.80 | 156.50 | 299.50 | 16.08 | 110.75 |
| KCB($o_2o_2$)$C_o$ | 37.79 | 132.42 | 269.00 | 14.67 | 103.58 |
| KCB($o_2o_2$)mod. | 38.39 | 132.92 | 271.17 | 14.59 | 104.08 |
| KCB($br_2br_2$)$C_o$ | 35.31 | 123.59 | 269.42 | 15.34 | 115.08 |
| KCB($br_2o_2$)$C_o$ | 38.91 | 122.50 | 250.33 | 15.33 | 112.58 |
| KCB($br_2o_2$)mod. | 40.58 | 136.17 | 264.17 | 15.58 | 113.00 |
| KCB($br_2o_2su_2$)$C_o$ | 42.91 | 84.67 | 222.58 | 13.58 | 101.33 |
| KCE(++)$C_o$ | 39.21 | 170.17 | 298.25 | 14.42 | 106.67 |
| KCE($o_2o_2$)$C_o$ | 41.03 | 134.67 | 263.34 | 15.25 | 105.83 |
| KCE($o_2o_2$)mod. | 38.40 | 126.50 | 256.58 | 14.92 | 107.08 |
| KCE($br_2br_2$)$C_o$ | 35.45 | 129.83 | 261.08 | 15.34 | 111.50 |
| KCE($br_2o_2$)$C_o$ | 44.45 | 135.17 | 265.34 | 14.42 | 99.67 |
| KCE($br_2o_2$)mod. | 41.60 | 134.75 | 251.25 | 14.58 | 104.67 |
| KCE($br_2o_2su_s$)$C_o$ | 42.20 | 101.42 | 243.42 | 13.75 | 102.25 |

Continued...

Table 16. Continued

| | | | | | |
|---|---|---|---|---|---|
| KCBtm/S/$C_1$ | 41.50 | 111.75 | 245.83 | 14.42 | 107.50 |
| KCBtm/R/$C_1$ | 36.92 | 102.42 | 220.75 | 14.09 | 108.00 |
| KCEtm/S/$C_1$ | 40.67 | 117.34 | 247.00 | 13.83 | 104.42 |
| KCEtm/R/$C_1$ | 42.73 | 136.59 | 257.50 | 14.75 | 104.67 |
| KCBtm/$C_o$xKCEtm/$C_o$ | 44.71 | 87.00 | 233.92 | 13.59 | 99.67 |
| KCBtm/S/$C_1$ x KCEtm/S/$C_1$ | 44.40 | 125.42 | 275.08 | 14.33 | 103.00 |
| KCBtm/R/$C_1$ x KCEtm/R/$C_1$ | 45.10 | 125.08 | 277.10 | 14.33 | 100.58 |
| H 614 C | 38.58 | 170.75 | 309.59 | 16.25 | 108.17 |
| H 512 | 43.43 | 115.34 | 242.75 | 13.08 | 101.92 |
| Kensed | 41.14 | 134.59 | 270.33 | 14.50 | 100.50 |
| Katumani Composite B | 51.27 | 76.59 | 179.42 | 11.17 | 83.58 |
| Mean | 41.18 | 124.96 | 258.03 | 14.49 | 104.80 |
| Range | 35.31-51.27 | 76.59-170.75 | 179.42-309.59 | 11.17-16.25 | 83.58-115.08 |
| LSD (P = 0.05) | 4.01 | 6.52 | 8.07 | 1.97 | 3.79 |
| F-ratio | 3.26** | 27.18** | 16.10** | 6.59** | 17.77** |

**significant at P = 0.01.

Table 17. Combined analysis of variance for crop index in maize

| Sources of variation | df | ss | ms | F |
|---|---|---|---|---|
| Environment | 2 | 1559.14 | 779.57 | 23.68** |
| Replications | 2 | 237.73 | 118.86 | 3.61* |
| Environment/ Replication | 6 | 1815.19 | 302.53 | 9.19** |
| Genotype | 24 | 2579.31 | 107.47 | 3.26** |
| Genotype x Environment | 48 | 1690.76 | 35.22 | 1.07 |
| Pooled error | 142 | 4675.03 | 32.92 | |

*significant at P = 0.05.

**significant at P = 0.01.

ear height of KCB (++) $C_o$ was 152.33 cm. The shortest ear height in both sites was Katumani Composite B (60.67 cm) in (a) and 60.00 cm in site (b). At Njoro (Table 14) KCB tm/$C_o$ was the shortest (78.00 cm) while KCE (++) $C_o$ had the tallest ear height (185.67 cm). In Kitale (Table 15) the ear height ranged from 95.67 (Katumani Composite B) to 208.33 cm (KCE (++) $C_o$). Katumani Composite B was the shortest variety in general, while KCE (++)$C_o$ and H 614C were the tallest varieties. Triple mutant (KCB tm/Co) was next to Katumani Composite B in ear height. As a whole, ear placement was higher in Kitale than at both Katumani and Njoro. Genotypes were significantly different in ear height but there was no genotype and environment interaction (Table 18).

4.2.3. Plant height (cm)

The plant height of Katumani Composite B was 156.00 cm and 174.00 cm at Katumani sites (a) (Table 12) and (b) (Table 13) respectively. KCB (++) $C_o$ was the tallest in both sites: in (a) 285.00 cm and in (b) 293.00 cm. In Njoro (Table 14) plant height of Katumani Composite B was 179.00 cm

Table 18. Combined analysis of variance for ear height in maize

| Source of variation | df | ss | ms | F |
|---|---|---|---|---|
| Environment | 3 | 206990.30 | 68996.77 | 293.61** |
| Replication | 2 | 5464.85 | 2732.42 | 11.63** |
| Environment/ Replication | 8 | 212455.10 | 26556.88 | 113.01** |
| Genotype | 24 | 153294.60 | 6387.27 | 27.18** |
| Genotype x Environment | 72 | 17611.51 | 244.60 | 1.04 |
| Pooled error | 190 | 44649.74 | 234.99 | |

**significant at P = 0.01.

and H 614 C plant height was 316.00 cm. H 614 C in Kitale (Table 15) attained the height of 354.00 cm and Katumani Composite B stood at 208.00 cm. Although Katumani Composite B was in general the shortest, it tended to increase its height at sites with higher rainfall. At Katumani, Katumani Composite B was on average 165 cm, at Njoro it was 179.00 cm and at Kitale it was 208.00 cm. H 614C and KCB (++) $C_0$ were in general the tallest varieties (Table 16). As a whole, varieties were taller in Kitale than in both Njoro and Katumani. Combined data analysis showed that genotypes were significantly different in plant height, however, there was no interaction between genotypes and environment (Table 19).

4.2.4. Number of leaves

Taller plants tended to have more leaves. Katumani Composite B had 9.33 leaves per plant and H 614 C had 17.00 leaves per plant at Katumani site (a) while on site (b) Katumani Composite B had 10.00 leaves per plant and KCB (++)$C_0$ had 17.33 leaves per plant. In Njoro the number of leaves per plant differed significantly with H 614 C having 18.33 leaves per plant and Katumani Composite B having only

Table 19. Combined analysis of variance for plant height in maize

| Sources of variation | df | ss | ms | F |
|---|---|---|---|---|
| Environment | 3 | 176332.00 | 58777.33 | 106.51** |
| Replication | 2 | 12059.74 | 6029.87 | 10.93** |
| Environment/ Replication | 8 | 188392.00 | 23549.00 | 42.67** |
| Genotype | 24 | 213307.00 | 8887.79 | 16.10** |
| Genotype x Environment | 72 | 38720.66 | 537.79 | 0.97 |
| Pooled error | 190 | 104849.60 | 551.84 | |

** significant at P = 0.01.

13.67 leaves per plant. In Kitale the number of leaves per plant were as low as what was recorded at Katumani. KCE (++)$C_0$ had 9.67 while KCE($o_2$ $o_2$) $C_0$ had 15.33 leaves per plant. Over the four locations, Katumani Composite B had the lowest number of leaves (11.17) while H 614 C had most (16.25) leaves per plant, followed by KCB(++)$C_0$ that had 16.08 leaves. Combined analysis for the number of leaves in Table 20 indicates that there were significant differences among the genotypes. Genotype and environment interacted for leaf number.

4.2.5. Days to 50 percent silking

Early maturing varieties tend to grow short with a low number of leaves. For instance, Katumani Composite B that had the least number of leaves reached 50 percent silking in 70.67 days compared to KCB($br_2$ $br_2$)$C_0$ that reached 50 percent silking in 105.33 days in site (a) at Katumani. In site (b) H 512, 50 percent silking was 98.0 days while KCB(++)$C_0$ was 117.33 days. At Njoro, Katumani Composite B matured in 79.00 days while KCB ($br_2$ $br_2$) $C_0$ took 139.67 days. In Kitale 50 percent silking

Table 20. Combined analysis of variance for the number of leaves per plant in maize

| Source of variation | df | ss | ms | F |
|---|---|---|---|---|
| Environment | 3 | 366.52 | 122.17 | 62.65** |
| Replication | 2 | 9.88 | 4.94 | 2.53 |
| Environment/ Replication | 8 | 376.39 | 47.05 | 24.13** |
| Genotype | 24 | 308.65 | 12.86 | 6.59** |
| Genotype x Environment | 72 | 202.14 | 2.81 | 1.44* |
| Pooled error | 190 | 370.76 | 1.95 | |

* significant at P = 0.05.

** significant at P = 0.01.

ranged between 80.00 (KCE ($br_2$ $br_2$)$C_o$) and 108.67 days for H 512. Combined data showed that Katumani Composite B reached 50 percent silking earlier (83.58 days) while KCB ($br_2$ $br_2$) $C_o$ comparatively reached 50 percent silking later (115.08 days. In general it took longer period for materials at Njoro to reach 50 percent silking (97.00 - 139.67 days) than both Kitale (80.00 - 108.67 days) and Katumani (a) (70.67 - 105.33 days) and Katumani (b) (98.00 - 117.33 days). Over the four locations, genotypes were significantly different in maturity and genotype and environment interaction was significant (Table 21).

4.2.6. Lodging percentage

Lodging percentage was only recorded at Katumani site (a). It ranged between 10.00 (Katumani Composite B) and 37.77 percent for both KCB($br_2$ $br_2$)$C_o$ and KCE ($br_2$ $o_2$)$C_o$. Varieties were significantly different. However, the coefficient of variation proved very high (62.0%).

Table 21. Combined analysis of variance for days to 50 percent silking in maize

| Sources of variation | df | ss | ms | F |
|---|---|---|---|---|
| Environment | 3 | 59287.7 | 19762.57 | 760.39** |
| Replication | 2 | 413.24 | 206.62 | 7.95** |
| Environment/ Replication | 8 | 59701.00 | 7462.62 | 287.13** |
| Genotype | 24 | 11086.30 | 461.93 | 17.77** |
| Genotype x Environment | 72 | 7334.74 | 101.87 | 3.92** |
| Pooled error | 190 | 4939.42 | 25.99 | |

**significant at P = 0.01.

## 4.3. Grain quality

The mean values of protein, lysine, tryptophane and moisture content of grains for 25 genotypes grown in 4 locations are given in Tables 22, 23, 24 and 25.

### 4.3.1. Protein content

Protein content of KCB tm/$C_0$ at Katumani site (a) (Table 22) was 8.33 percent while H 512 was 14.37 percent. In site (b) (Table 23) KCB ($br_2$ $br_2$)$C_0$ registered 9.33 percent whereas KCB ($o_2o_2$) modified had 13.57 percent. In Njoro (Table 24) it ranged between 8.07 (KCE(++)$C_0$) and 12.47 percent (KCB($br_2$ $o_2$)$C_0$). At Kitale (Table 25) protein percentage was much lower comparatively since KCE($o_2$ $o_2$) modified had 6.73 percent and KCE ($br_2$ $o_2$) $C_0$ (10.10 percent). The KCE (++)$C_0$ on the average had the lowest protein (8.86 percent) while H 512 had the highest 11.25 percent (Table 26). Combined analysis over the four locations showed that genotypes were significantly different, but they did not interact with the environment (Table 27).

Table 22. Mean percent protein, percent lysine, per cent tryptophane and moisture content of 25 maize populations in Katumani (a).

| Population | Protein percent | Lysine percent of protein | Tryptophane percent of protein | Moisture content |
|---|---|---|---|---|
| KCB(++)$C_o$ | 11.43 | 2.71 | 0.68 | 12.27 |
| KCB($o_2o_2$)$C_o$ | 11.27 | 3.47 | 0.86 | 12.20 |
| KCB($o_2o_2$)mod. | 10.60 | 3.47 | 0.86 | 12.07 |
| KCB($nr_2br_2$)$C_o$ | 9.77 | 2.04 | 0.51 | 12.07 |
| KCB($br_2o_2$)$C_o$ | 8.80 | 3.96 | 0.98 | 12.00 |
| KCB($br_2o_2$)mod. | 8.53 | 3.49 | 0.87 | 11.93 |
| KCB($br_2o_2su_2$)$C_o$ | 8.33 | 4.48 | 1.12 | 11.70 |
| KCE(++)$C_o$ | 9.83 | 2.10 | 0.52 | 11.90 |
| KCE($o_2o_2$)$C_o$ | 10.83 | 3.99 | 0.90 | 12.30 |
| KCE($o_2o_2$)mod. | 11.20 | 4.33 | 1.08 | 12.10 |
| KCE($br_2br_2$)$C_o$ | 10.47 | 2.15 | 0.54 | 12.57 |
| KCE($br_2o_2$)$C_o$ | 10.27 | 3.56 | 0.89 | 12.43 |
| KCE($br_2o_2$)mod. | 12.83 | 3.82 | 0.96 | 12.17 |
| KCE($br_2o_2su_2$)$C_o$ | 9.47 | 4.57 | 1.14 | 12.27 |

Continued.

*Table 22. Continued*

| | | | | |
|---|---|---|---|---|
| KCBtm/S/$C_1$ | 11.83 | 4.59 | 0.87 | 12.12 |
| KCBtm/R/$C_1$ | 12.07 | 4.07 | 1.01 | 12.00 |
| KCEtm/S/$C_1$ | 13.80 | 4.60 | 1.15 | 11.70 |
| KCEtm/R/$C_1$ | 11.17 | 4.79 | 1.19 | 11.70 |
| KCBtm/$C_o$ x KCEtm/$C_o$ | 10.83 | 4.56 | 1.14 | 11.57 |
| KCBtm/S/$C_1$ x KCEtm/S/$C_1$ | 10.27 | 4.68 | 1.17 | 11.93 |
| KCBtm/R/$C_1$ x KCEtm/R/$C_1$ | 10.03 | 4.84 | 1.21 | 12.37 |
| H 614 C | 12.97 | 1.91 | 0.47 | 12.20 |
| H 512 | 14.37 | 2.27 | 0.56 | 12.60 |
| Kensed | 8.60 | 2.54 | 0.63 | 11.90 |
| Katumani Composite B | 8.40 | 2.33 | 0.58 | 12.17 |
| Mean | 10.72 | 3.57 | 0.89 | 12.09 |
| Range | 8.33-14.37 | 1.91-4.84 | 0.47-1.21 | 11.70-12.60 |
| LSD (P = 0.05) | 2.38 | 1.37 | 0.70 | NS |
| CV % | 11.0 | 12.0 | 11.0 | 2.0 |
| F-ratio | 2.01* | 2.11* | 2.00* | 0.78 |

*significant at P = 0.05.

*Table 23. Mean percent protein, percent lysine, percent tryptophane and moisture content of 25 maize populations in Katumani (b)*

| Population | Protein percent | Lysine percent of protein | Tryptophane percent of protein | Moisture content |
|---|---|---|---|---|
| KCB(++)$C_o$ | 11.00 | 2.51 | 0.62 | 12.20 |
| KCB($o_2o_2$)$C_o$ | 11.73 | 4.30 | 1.01 | 12.80 |
| KCB($o_2o_2$)mod. | 13.57 | 3.77 | 0.94 | 12.77 |
| KCB($br_2br_2$)$C_o$ | 9.33 | 2.52 | 0.63 | 12.80 |
| KCB($br_2o_2$)$C_o$ | 11.90 | 3.92 | 0.98 | 12.40 |
| KCB($br_2o_2$)mod. | 10.40 | 3.93 | 0.98 | 12.67 |
| KCB($br_2o_2su_2$)$C_o$ | 11.77 | 4.39 | 1.09 | 12.77 |
| KCE(++)$C_o$ | 10.23 | 2.62 | 0.65 | 12.77 |
| KCE($o_2o_2$)$C_o$ | 12.67 | 4.34 | 1.08 | 12.30 |
| KCE($o_2o_2$)mod. | 12.92 | 3.53 | 1.08 | 12.33 |
| KCE($br_2br_2$)$C_o$ | 11.93 | 2.28 | 0.57 | 12.43 |
| KCE($br_2o_2$)$C_o$ | 13.30 | 3.99 | 1.00 | 12.30 |
| KCE($br_2o_2$)mod. | 13.07 | 3.93 | 0.98 | 12.70 |
| KCE($br_2o_2su_o$)$C_o$ | 11.30 | 3.79 | 0.98 | 13.17 |

Continued

*Table 23. Continued*

| | | | | |
|---|---|---|---|---|
| KCBtm/S/$C_1$ | 13.03 | 3.97 | 0.99 | 12.73 |
| KCBtm/R/$C_1$ | 11.23 | 3.99 | 0.99 | 12.33 |
| KCEtm/S/$C_1$ | 12.23 | 4.15 | 1.03 | 12.27 |
| KCEtm/R/$C_1$ | 11.73 | 4.26 | 1.06 | 12.90 |
| KCBtm/$C_o$ x KCEtm/$C_o$ | 12.30 | 4.32 | 1.08 | 12.80 |
| KCBtm/S/$C_1$ x KCEtm/S/$C_1$ | 11.67 | 3.96 | 0.99 | 12.03 |
| KCBtm/R/$C_1$ x KCEtm/R/$C_1$ | 10.00 | 4.22 | 1.05 | 12.93 |
| H 614 C | 11.00 | 2.38 | 0.59 | 12.93 |
| H 512 | 12.90 | 2.21 | 0.55 | 12.83 |
| Kensed | 12.90 | 2.18 | 0.55 | 12.80 |
| Katumani Composite B | 11.20 | 2.48 | 0.62 | 12.70 |
| Mean | 11.81 | 3.51 | 0.87 | 13.18 |
| Range | 9.33-13.57 | 2.18-4.39 | 0.55-1.08 | 12.03-25.97 |
| LSD (P = 0.5) | NS | 1.00 | 0.40 | NS |
| CV % | 11.0 | 10.00 | 11.0 | 2.1 |
| F-ratio | 0.94 | 2.57** | 2.20** | 0.96 |

**significant at P = 0.01.

*Table 23. Continued*

| | | | | |
|---|---|---|---|---|
| KCBtm/S/$C_1$ | 13.03 | 3.97 | 0.99 | 12.73 |
| KCBtm/R/$C_1$ | 11.23 | 3.99 | 0.99 | 12.33 |
| KCEtm/S/$C_1$ | 12.23 | 4.15 | 1.03 | 12.27 |
| KCEtm/R/$C_1$ | 11.73 | 4.26 | 1.06 | 12.90 |
| KCBtm/$C_o$ x KCEtm/$C_o$ | 12.30 | 4.32 | 1.08 | 12.80 |
| KCBtm/S/$C_1$ x KCEtm/S/$C_1$ | 11.67 | 3.96 | 0.99 | 12.03 |
| KCBtm/R/$C_1$ x KCEtm/R/$C_1$ | 10.00 | 4.22 | 1.05 | 12.93 |
| H 614 C | 11.00 | 2.38 | 0.59 | 12.93 |
| H 512 | 12.90 | 2.21 | 0.55 | 12.83 |
| Kensed | 12.90 | 2.18 | 0.55 | 12.80 |
| Katumani Composite B | 11.20 | 2.48 | 0.62 | 12.70 |
| Mean | 11.81 | 3.51 | 0.87 | 13.18 |
| Range | 9.33-13.57 | 2.18-4.39 | 0.55-1.08 | 12.03-25.97 |
| LSD (P = 0.5) | NS | 1.00 | 0.40 | NS |
| CV % | 11.0 | 10.00 | 11.0 | 2.1 |
| F-ratio | 0.94 | 2.57** | 2.20** | 0.96 |

**significant at P = 0.01.

*Table 24.* Mean percent protein, percent lysine, percent tryptophane and moisture content of 25 maize populations in Njoro

| Population | Protein percent | Lysine percent of protein | Tryptophane percent of protein | Moisture content |
|---|---|---|---|---|
| KCB(++)$C_o$ | 10.23 | 2.29 | 0.57 | 12.67 |
| KCB($o_2o_2$)$C_o$ | 10.53 | 4.13 | 1.03 | 13.00 |
| KCB($o_2o_2$)mod. | 10.33 | 4.00 | 1.00 | 12.67 |
| KCB($br_2br_2$)$C_o$ | 10.57 | 2.27 | 0.56 | 13.33 |
| KCB($br_2o_2$)$C_o$ | 10.60 | 4.17 | 1.04 | 13.33 |
| KCB($br_2o_2$)mod. | 12.47 | 3.91 | 0.97 | 13.00 |
| KCB($br_2o_2su_2$)$C_o$ | 8.33 | 4.14 | 1.03 | 12.67 |
| KCE(++)$C_o$ | 8.07 | 2.65 | 0.66 | 13.00 |
| KCE($o_2o_2$)$C_o$ | 11.73 | 4.37 | 1.09 | 12.67 |
| KCE($o_2o_2$)mod. | 10.47 | 3.98 | 0.99 | 13.33 |
| KCE($br_2br_2$)$C_o$ | 8.53 | 2.64 | 0.66 | 12.67 |
| KCE($br_2o_2$)$C_o$ | 10.63 | 4.13 | 1.03 | 12.67 |
| KCE($br_2o_2$)mod. | 10.77 | 4.16 | 1.04 | 13.00 |
| KCE($br_2o_2Su_2$) | 9.53 | 4.13 | 1.03 | 12.33 |

Continued..

*Table 24. Continued*

| | |
|---|---|
| $KCBtm/S/C_1$ | 8.97 |
| $KCBtm/R/C_1$ | 9.67 |
| $KCEtm/S/C_1$ | 11.90 |
| $KCEtm/R/C_1$ | 9.13 |
| $KCBtm/C_o \times KCEtm/C_o$ | 10.73 |
| $KCBtm/S/C_1 \times KCEtm/S/C_1$ | 9.23 |
| $KCBtm/R/C_1 \times KCEtm/R/C_1$ | 11.23 |
| H 614 C | 9.27 |
| H 512 | 9.70 |
| Kensed | 10.30 |
| Katumani Composite B | 9.53 |
| Mean | 10.10 |
| Range | 8.07-12.47 |
| LSD (P = 0.05) | NS |
| CV % | 16.0 |
| F-ratio | 0.79 |

*significant at P = 0.05.

| | | |
|---|---|---|
| 4.12 | 1.03 | 13.33 |
| 4.26 | 1.06 | 12.00 |
| 4.11 | 1.02 | 13.33 |
| 4.08 | 1.02 | 13.33 |
| 3.89 | 0.97 | 13.00 |
| 4.26 | 1.06 | 12.67 |
| 4.19 | 1.05 | 13.00 |
| 2.48 | 0.62 | 13.33 |
| 2.19 | 0.54 | 13.67 |
| 2.29 | 0.57 | 13.00 |
| 2.29 | 0.57 | 13.67 |
| 3.57 | 0.87 | 12.99 |
| 2.19-4.37 | 0.54-1.09 | 12.00-13.67 |
| 1.45 | 0.75 | NS |
| 14.5 | 13.0 | 4.0 |
| 1.74* | 2.00* | 0.71 |

*Table 25. Mean percent protein, percent lysine, percent tryptophane and moisture content of 25 maize populations in Kitale*

| Population | Protein percent | Lysine percent of protein | Tryptophane percent of protein | Moisture content |
|---|---|---|---|---|
| KCB(++)$C_o$ | 6.90 | 2.62 | 0.65 | 14.07 |
| KCB($o_2o_2$)$C_o$ | 8.43 | 4.07 | 1.02 | 14.13 |
| KCB($o_2o_2$)mod. | 8.43 | 4.06 | 1.02 | 13.63 |
| KCB($br_2br_2$)$C_o$ | 7.17 | 2.47 | 0.61 | 11.40 |
| KCB($br_2o_2$)$C_o$ | 8.07 | 4.12 | 1.03 | 13.93 |
| KCB($br_2o_2$)mod. | 7.63 | 4.01 | 1.00 | 14.10 |
| KCB($br_2o_2su_2$($C_o$ | 8.40 | 4.11 | 1.03 | 13.00 |
| KCE(++)$C_o$ | 7.30 | 2.66 | 0.66 | 11.90 |
| KCE($o_2o_2$)$C_o$ | 7.80 | 3.98 | 0.99 | 14.53 |
| KCE($o_2o_2$(mod. | 6.73 | 3.86 | 0.97 | 12.93 |
| KCE($br_2br_2$)$C_o$ | 7.03 | 2.39 | 0.59 | 14.27 |
| KCE($br_2o_2$)$C_o$ | 10.10 | 3.99 | 0.99 | 15.63 |
| KCE($br_2o_2$)mod. | 7.30 | 3.98 | 0.99 | 12.40 |
| KCE($br_2o_2su_o$)$C_o$ | 7.30 | 3.98 | 0.99 | 13.77 |

Continued

*Table 25. Continued*

| | | | | |
|---|---|---|---|---|
| KCBtm/S/$C_1$ | 6.90 | 3.83 | 0.96 | 13.13 |
| KCBtm/R/$C_1$ | 7.37 | 4.09 | 1.02 | 11.97 |
| KCEtm/S/$C_1$ | 6.97 | 4.45 | 1.11 | 14.33 |
| KCEtm/R/$C_1$ | 7.97 | 4.32 | 1.08 | 13.77 |
| KCBtm/$C_o$ x KCEtm/$C_o$ | 7.93 | 3.96 | 0.99 | 13.73 |
| KCBtm/S/$C_1$ x KCEtm/S/$C_1$ | 7.77 | 4.34 | 1.09 | 14.83 |
| KCBtm/R/$C_1$ x KCEtm/R/$C_1$ | 9.31 | 4.16 | 1.04 | 13.93 |
| H 614 C | 7.80 | 2.27 | 0.57 | 14.87 |
| H 512 | 8.03 | 2.61 | 0.56 | 14.27 |
| Kensed | 7.07 | 2.36 | 0.59 | 14.13 |
| Katumani Composite B | 8.30 | 2.49 | 0.62 | 13.67 |
| Mean | 7.76 | 3.56 | 0.89 | 13.69 |
| Range | 6.73-10.10 | 2.27-4.45 | 0.56-1.11 | 11.40-15.63 |
| LSD (P = 0.05) | NS | 1.03 | 0.63 | NS |
| CV % | 9.0 | 8.0 | 9.0 | 7.0 |
| F-ratio | 1.41 | 1.80* | 2.01* | 0.99 |

*significant at P = 0.05.

*Table 26.* Combined mean percent protein, percent lysine, percent tryptophane and moisture content of 25 maize populations in 4 environments in Kenya.

| Population | Protein percent | Lysine percent of protein | Tryptophane percent of protein | Moisture content |
|---|---|---|---|---|
| KCB(++)$C_o$ | 9.89 | 2.53 | 0.63 | 12.20 |
| KCB($o_2c_2$)$C_o$ | 10.49 | 3.93 | 0.98 | 13.03 |
| KCB($o_2o_2$)mod. | 10.73 | 3.82 | 0.95 | 12.78 |
| KCB($br_2br_2$)$C_o$ | 9.21 | 2.32 | 0.58 | 12.40 |
| KCB($br_2o_2$)$C_o$ | 9.84 | 4.04 | 1.01 | 12.92 |
| KCB($br_2o_2$)mod. | 9.76 | 3.83 | 0.95 | 12.92 |
| KCB($br_2o_2su_2$)$C_o$ | 9.21 | 4.28 | 1.07 | 12.53 |
| KCE(++)$C_o$ | 8.86 | 2.51 | 0.62 | 12.39 |
| KCE($o_2o_2$)$C_o$ | 10.76 | 4.17 | 1.04 | 12.39 |
| KCE($o_2o_2$)mod. | 10.33 | 3.92 | 0.98 | 12.67 |
| KCE($br_2br_2$)$C_o$ | 9.41 | 2.36 | 0.59 | 12.98 |
| KCE($br_2o_2$)$C_o$ | 11.07 | 3.91 | 0.98 | 13.26 |
| KCE($br_2o_2$)mod. | 10.99 | 3.97 | 0.99 | 12.57 |
| KCE($br_2su_2$)$C_o$ | 9.40 | 4.12 | 1.03 | 12.88 |

*Continued*

Table 26. Continued

| | | | | |
|---|---|---|---|---|
| KCBtm/S/$C_1$ | 10.18 | 4.13 | 1.03 | 12.85 |
| KCBtm/R/$C_1$ | 10.08 | 4.10 | 1.02 | 12.07 |
| KCEtm/S/$C_1$ | 11.22 | 4.32 | 1.08 | 12.91 |
| KCEtm/R/$C_1$ | 10.00 | 4.36 | 1.09 | 12.92 |
| KCBtm/$C_o$ x KCEtm/$C_o$ | 10.45 | 4.18 | 1.04 | 12.77 |
| KCBtm/S/$C_1$ x KCEtm/S/$C_1$ | 9.73 | 4.31 | 1.08 | 12.87 |
| KCBtm/R/$C_1$ x KCEtm/R/$C_1$ | 10.16 | 4.35 | 1.09 | 13.06 |
| H 614 C | 10.26 | 2.26 | 0.56 | 13.33 |
| H 512 | 11.25 | 2.31 | 0.58 | 13.34 |
| Kensed | 9.72 | 2.34 | 0.58 | 14.07 |
| Katumani Composite B | 9.36 | 2.40 | 0.60 | 13.05 |
| Mean | 10.10 | 3.55 | 0.88 | 12.85 |
| Range | 8.86-11.25 | 2.26-4.36 | 0.56-1.09 | 12.07-14.07 |
| LSD (P = 0.05) | NS | 1.35 | 0.79 | NS |
| F-ratio | 1.51 | 2.33** | 2.52** | 0.96 |

**significant at P = 0.01.

Table 27. Combined analys-s of variance for protein in maize

| Sources of variation | df | ss | MS | F |
|---|---|---|---|---|
| Environment | 3 | 658.60 | 219.53 | 62.54** |
| Replication | 2 | 111.88 | 55.94 | 15.93** |
| Environment/ Replication | 8 | 783.27 | 97.91 | 27.89** |
| Genotype | 24 | 127.14 | 5.30 | 1.51 |
| Genotype x Environment | 72 | 301.76 | 4.19 | 1.19 |
| Pooled error | 190 | 667.05 | 3.51 | |

**significant at P = 0.01.

4.3.2. Lysine content

At Katumani site (a) (Table 22) lysine content for H 614 C was 1.91 percent and for KCB tm/R/$C_1$ x KCE tm/R/$C_1$ it was 4.84 percent. In site (b) (Table 23) Kensed had 2.18 percent and KCB tm/$C_o$ showed a high value of 4.39 percent. In Njoro (Table 24) H 512 came last with 2.19 percent while KCE($br_2$ or $_2$) $C_o$) was at the top with lysine content of 4.37 percent. At Kitale (Table 25) it varied from 2.27 percent (H 614 C) to 4.45 percent (KCE tm/S/$C_1$). In general H 614 C had the lowest lysine content (2.27 percent) while KCE tm/R/$C_1$ had the highest value of 4.36 percent (Table 26). Triple mutant populations showed higher lysine content with lower protein content whereas the normal populations had higher protein content and lower lysine content (Table 26). Although genotypes were statistically different in respect of both lysine and tryptophane content (Tables 28 and 29) the two quality characters did not interact with environments.

4.3.3. Moisture content

The moisture content of the grains were not significantly different in all locations. At Katumani site (b) due to sampling error one of the three replications of KCB ++ $C_o$ was discarded. Then the remaining two replications conformed with the general trend. In general moisture

Table 28. Combined analysis of variance for lysine percent of protein in maize

| Sources of variation | df | ss | ms | F |
|---|---|---|---|---|
| Environment | 3 | 0.20 | 0.07 | 0.16 |
| Replication | 2 | 9.63 | 4.82 | 11.21** |
| Environment/ Replication | 8 | 1.32 | 0.16 | 0.37 |
| Genotype | 24 | 206.68 | 8.61 | 20.02** |
| Genotype x Environment | 72 | 35.04 | 0.49 | 1.14 |
| Pooled error | 190 | 81.39 | 0.43 | |

**significant at P = 0.01.

Table 29. Combined analysis of variance for tryptophane percent of protein in maize

| Sources of variation | df | ss | ms | F |
|---|---|---|---|---|
| Environment | 3 | 9.01 | 3.00 | 100.00** |
| Replication | 2 | 0.65 | 0.32 | 10.67** |
| Environment/ Replication | 8 | 0.08 | 0.01 | 0.33 |
| Genotype | 24 | 12.57 | 0.52 | 17.33** |
| Genotype x Environment | 72 | 1.67 | 0.02 | 0.67 |
| Pooled error | 190 | 5.48 | 0.03 | |

** significant at P = 0.01.

did respond highly to the environmental changes (Table 30). Later maturing populations such as H 614 C and KCB (++) $C_o$ tended to have higher moisture content than the early maturing varieties such as Katumani Composite B, triple mutant populations and their crosses.

## 4.4. Reaction to pests and diseases

The mean values of rust rating, blight rating, stem borer infestation and diseased ears for 25 populations evaluated in 4 locations are given in Tables 31, 32, and 33.

### 4.4.1. Rust rating

No rust was recorded on Katumani Composite B while Kensed recorded a heavy attack at Katumani location (3.33)(Table 31). At Njoro (Table 32) KCB tm/R/$C_1$ x KCEtm/R/$C_1$ recorded the lowest disease incidence (0.67) while KCEtm/$C_o$ was moderately affected (2.6). Rust ratings varied from 0.43 (H 614 C) to 2.77 (KCEtm/$C_o$) in Kitale (Table 33). In general, KCE (++)$C_o$ had the lowest attack of rust (0.89) and Kensed had a moderate score (2.23)

Table 30. Combined analysis of variance for moisture content of grains in maize

| Sources of variation | df | ss | ms | F |
|---|---|---|---|---|
| Environment | 3 | 100.57 | 33.52 | 4.94** |
| Replication | 2 | 50.42 | 25.21 | 3.72* |
| Environment/ Replication | 8 | 150.99 | 18.87 | 2.78** |
| Genotype | 24 | 157.05 | 6.54 | 0.96 |
| Genotype x Environment | 72 | 99594.76 | 503.00 | 74.19** |
| Pooled error | 190 | 1289.31 | 6.78 | |

* significant at P = 0.05.

**significant at P = 0.01.

Table 31. Mean rust rating and blight rating of 25 maize populations in Katumani

| Populations | Rust score | Blight score |
|---|---|---|
| KCB(++)$C_o$ | 0.67 | 0.67 |
| KCB($o_2o_2$)$C_o$ | 1.33 | 2.33 |
| KCB($o_2o_2$)mod. | 0.67 | 1.67 |
| KCB($br_2br_2$)$C_o$ | 1.33 | 2.67 |
| KCB($br_2o_2$)$C_o$ | 1.00 | 2.00 |
| KCB($br_2o_2$)mod. | 1.33 | 1.33 |
| KCB($br_2o_2su_2$)$C_o$ | 1.00 | 0.67 |
| KCE(++)$C_o$ | 0.33 | 1.33 |
| KCE($o_2o_2$)$C_o$ | 1.33 | 2.33 |
| KCE($o_2o_2$)mod. | 0.67 | 2.33 |
| KCE($br_2br_2$)$C_o$ | 0.67 | 1.33 |
| KCE($br_2o_2$)$C_o$ | 0.67 | 1.33 |
| KCE($br_2o_2$)mod. | 1.00 | 2.67 |
| KCE($br_2o_2su_2$)$C_o$ | 1.00 | 2.00 |

Continued

*Table 31. Continued*

| | | |
|---|---|---|
| KCBtm/S/$C_1$ | 0.67 | 1.67 |
| KCBtm/R/$C_1$ | 1.00 | 1.67 |
| KCEtm/S/$C_1$ | 1.00 | 1.67 |
| KCEtm/R/$C_1$ | 0.33 | 2.00 |
| KCBtm/$C_o$ × KCEtm/$C_o$ | 0.33 | 2.00 |
| KCBtm/S/$C_1$ × KCEtm/S/$C_1$ | 1.33 | 1.67 |
| KCBtm/R/$C_1$ × KCEtm/R/$C_1$ | 0.67 | 1.00 |
| H 614 C | 1.00 | 1.00 |
| H 512 | 1.00 | 2.33 |
| Kensed | 3.33 | 3.33 |
| Katumani Composite B | 0.00 | 0.33 |
| Mean | 0.95 | 1.73 |
| Range | 0.00-3.33 | 0.33-3.33 |
| LSD (P = 0.05) | 1.49 | 1.45 |
| CV % | 48.0 | 25.0 |
| F-ratio | 1.82* | 2.73** |

* significant at P = 0.05

** significant at P = 0.01.

*Table 32. Mean diseased ears, rust rating, blight rating and response to pest of 25 maize populations in Njoro.*

| Population | Diseased ear | Rust score | Blight score | Pest response |
|---|---|---|---|---|
| KCB(++)$C_o$ | 26.67 | 1.67 | 0.00 | 25.63 |
| KCB($o_2o_2$)$C_o$ | 30.00 | 2.00 | 1.00 | 44.97 |
| KCB($o_2o_2$)mod. | 40.00 | 1.67 | 1.00 | 56.67 |
| KCB($br_2br_2$($C_o$ | 16.67 | 1.33 | 0.33 | 52.13 |
| KCB($br_2o_2$)$C_o$ | 40.00 | 1.67 | 1.00 | 65.33 |
| KCB($br_2o_2$)mod. | 26.67 | 2.33 | 0.38 | 61.27 |
| KCB($br_2o_2su_2$)$C_o$ | 10.00 | 1.67 | 1.00 | 43.90 |
| KCE(++)$C_o$ | 10.00 | 1.00 | 0.00 | 36.40 |
| KCE($o_2o_2$)$C_o$ | 16.67 | 2.33 | 0.67 | 67.47 |
| KCE($o_2o_2$)mod. | 16.67 | 1.00 | 0.00 | 71.37 |
| KCE($br_2br_2$)$C_o$ | 10.00 | 1.33 | 1.00 | 32.07 |
| KCE($br_2o_2$)$C_o$ | 30.00 | 2.00 | 0.00 | 58.77 |
| KCE($br_2o_2$)mod. | 30.00 | 1.67 | 0.67 | 37.40 |
| KCE($br_2o_2su_o$)$C_o$ | 10.00 | 2.67 | 2.33 | 53.43 |

Continued

Table 32. Continued

| | | | | |
|---|---|---|---|---|
| KCBtm/S/$C_1$ | 10.00 | 1.33 | 0.33 | 68.33 |
| KCBtm/R/$C_1$ | 33.33 | 2.33 | 1.00 | 61.77 |
| KCEtm/S/$C_1$ | 46.67 | 1.67 | 1.00 | 42.10 |
| KCEtm/R/$C_1$ | 16.67 | 1.00 | 0.33 | 53.70 |
| KCBtm/$C_o$ × KCEtm/$C_o$ | 10.00 | 2.00 | 1.33 | 44.33 |
| KCBtm/S/$C_1$ × KCEtm/S/$C_1$ | 20.00 | 1.33 | 0.00 | 43.33 |
| KCBtm/R/$C_1$ × KCEtm/R/$C_1$ | 13.33 | 0.67 | 0.00 | 34.63 |
| H 614 C | 13.33 | 1.67 | 0.33 | 31.07 |
| H 512 | 10.00 | 1.67 | 0.00 | 33.30 |
| Kensed | 20.00 | 1.67 | 1.37 | 39.47 |
| Katumani Composite B | 10.00 | 1.67 | 0.67 | 45.90 |
| Mean | 20.67 | 1.65 | 0.63 | 48.19 |
| Range | 10.00-46.67 | 0.67-2.67 | 0.00-2.33 | 25.63-68.33 |
| LSD (P = 0.05) | 6.29 | NS | 1.00 | 6,69 |
| CV % | 68.0 | 28.0 | 67.0 | 44.0 |
| F-ratio | 1.91* | 1.08 | 1.94* | 2.06* |

* significant at P = 0.05.

Table 33. Mean rust rating, blight rating and response to pest of 25 maize populations in Kitale

| Population | Rust score | Blight score | Pest response |
|---|---|---|---|
| KCB(++)$C_o$ | 1.63 | 1.10 | 65.70 |
| KCB($o_2o_2$)$C_o$ | 1.00 | 1.07 | 62.27 |
| KCB($o_2o_2$)mod. | 1.27 | 0.80 | 53.50 |
| KCB($br_2br_2$)$C_o$ | 0.87 | 0.93 | 75.60 |
| KCB($br_2o_2$)$C_o$ | 1.30 | 0.70 | 72.90 |
| KCB($br_2o_2$)mod. | 1.13 | 0.90 | 56.73 |
| KCB($br_2o_2su_2$)$C_o$ | 2.43 | 1.47 | 63.10 |
| KCE(++)$C_o$ | 1.33 | 0.80 | 48.50 |
| KCE($o_2o_2$)$C_o$ | 2.20 | 1.70 | 57.33 |
| KCE($o_2o_2$)mod. | 1.47 | 1.07 | 50.60 |
| KCE($br_2br_2$)$C_o$ | 1.10 | 0.60 | 49.03 |
| KCE($br_2o_2$)$C_o$ | 1.70 | 0.43 | 68.00 |
| KCE($br_2o_2$)mod. | 1.87 | 0.47 | 50.07 |
| KCE($br_2o_2su_2$)$C_o$ | 2.77 | 1.97 | 50.13 |

Continued

Table 33. Continued

| | | | |
|---|---|---|---|
| KCBtm/S/$C_1$ | 1.67 | 0.60 | 38.17 |
| KCBtm/R/$C_1$ | 1.97 | 1.50 | 54.00 |
| KCEtm/S/$C_1$ | 2.20 | 1.20 | 42.87 |
| KCEtm/R/$C_1$ | 1.70 | 1.17 | 56.03 |
| KCBtm/$C_o$ x KCEtm/$C_o$ | 1.57 | 1.30 | 63.67 |
| KCBtm/S/$C_1$ x KCEtm/S/$C_1$ | 1.63 | 0.37 | 51.23 |
| KCBtm/R/$C_1$ x KCEtm/R/$C_1$ | 1.43 | 0.47 | 42.73 |
| H 614 C | 0.43 | 0.27 | 69.33 |
| H 512 | 1.10 | 1.30 | 47.97 |
| Kensed | 1.70 | 1.10 | 55.10 |
| Katumani Composite B | 2.73 | 2.00 | 60.03 |
| Mean | 1.61 | 1.01 | 56.18 |
| Range | 0.43-2.77 | 0.27-2.00 | 38.17-75.60 |
| LSD (P = 0.05) | 1.00 | 1.26 | 6.64 |
| CV % | 26.0 | 32.0 | 50.0 |
| F-ratio | 1.79* | 2.23** | 2.14* |

* significant at P = 0.05

** significant at P = 0.01.

(Table 34). Genotypes significantly ciffered in all the locations, however, combined analysis showed that the genotypes did not interact with the environment in respect of rust ratings (Table 35).

4.4.2. Blight rating

Katumani Composite B had traces of blight attack (0.33) in Katumani (Table 31) while Kensed was heavily infested with blight (3.33). At Njoro (Table 32) KCBtm/R/$C_1$ x KCEtm/R/$C_1$ showed no sign of blight attack while KCBtm/$C_o$ was affected (2.33). In Kitale (Table 33) on the contrary Katumani Composite B was moderately affected while H 614 C had traces of blight attack. In general, KCBtm/R/$C_1$ x KCEtm/R/$C_1$ realised the least attack of blight (0.49) while KCEtm/$C_o$ was moderately affected (2.10). Genotypes differed significantly in all the locations. The genotype by environment interaction was highly significant (Table 36).

4.4.3. Stem borer infestation

Stem borer attack was observed at Njoro, Kitale and one of the Katumani sites only. At Katumani, stem borer population was too low to allow

Table 34. Combine mean rust rating, blight rating and response to pest of 25 maize populations in 3 environments in Kenya.

| Populations | Rust score | Blight score | Pest response |
|---|---|---|---|
| KCB(++)$C_o$ | 1.32 | 0.59 | 45.67 |
| KCB($o_2o_2$)$C_o$ | 1.44 | 1.47 | 53.62 |
| KCB($o_2o_2$)mod. | 1.20 | 1.16 | 55.04 |
| KCB($br_2br_2$)$C_o$ | 1.18 | 1.31 | 63.87 |
| KCB($br_2o_2$)$C_o$ | 1.32 | 1.23 | 69.12 |
| KCB($br_2o_2$)mod. | 1.60 | 0.85 | 59.00 |
| KCB($br_2o_2su_2$)$C_o$ | 1.70 | 1.05 | 53.50 |
| KCE(++)$C_o$ | 0.89 | 0.71 | 42.45 |
| KCE($o_2o_2$)$C_o$ | 1.95 | 1.57 | 62.40 |
| KCE($o_2o_2$)mod. | 1.05 | 1.13 | 60.99 |
| KCE($br_2br_2$)$C_o$ | 1.03 | 0.98 | 40.55 |
| KCE($br_2o_2$)$C_o$ | 1.46 | 0.59 | 63.39 |
| KCE($br_2o_2$)mod. | 1.51 | 1.27 | 43.74 |
| KCE($br_2o_2su_2$)$C_o$ | 2.15 | 2.10 | 51.78 |

Continued

*Table 34. Continued*

| | | | |
|---|---|---|---|
| KCBtm/S/$C_1$ | 1.22 | 0.87 | 53.25 |
| KCBtm/R/$C_1$ | 1.77 | 1.39 | 57.89 |
| KCEtm/S/$C_1$ | 1.62 | 1.29 | 42.49 |
| KCEtm/R/$C_1$ | 1.01 | 1.17 | 54.87 |
| KCBtm/$C_o$ × KCEtm/$C_o$ | 1.30 | 1.54 | 54.00 |
| KCBtm/S/$C_1$ × KCEtm/S/$C_1$ | 1.43 | 0.68 | 47.28 |
| KCBtm/R/$C_1$ × KCEtm/R/$C_1$ | 0.92 | 0.49 | 38.68 |
| H 614 C | 1.03 | 0.53 | 50.20 |
| H 512 | 1.26 | 1.21 | 40.64 |
| Kensed | 2.23 | 1.93 | 47.29 |
| Katumani Composite B | 1.46 | 2.00 | 52.97 |
| Mean | 1.40 | 1.13 | 52.18 |
| Range | 0.89-2.23 | 0.49-2.10 | 36.68-69.12 |
| LSD (P = 0.05) | NS | 1.39 | 7.03 |
| F-ratio | 1.45 | 4.73** | 3.32** |

**significant at P = 0.01.

Table 35. Combined analysis of variance for rust rating in maize

| Sources of variation | df | ss | ms | F |
|---|---|---|---|---|
| Environment | 2 | 22.47 | 11.73 | 19 55** |
| Replication | 2 | 22.87 | 11.43 | 19.04** |
| Environment/ Replication | 6 | 46.33 | 7.72 | 12.87** |
| Genotype | 24 | 34.73 | 1.45 | 2.42** |
| Genotype x Environment | 48 | 31.49 | 0.66 | 1.10 |
| Pooled error | 142 | 85.44 | 0.60 | |

** significant at P = 0.01.

Table 36. Combined analysis of variance for blight rating in maize

| Sources of variation | df | ss | ms | F |
|---|---|---|---|---|
| Environment | 2 | 47.36 | 23.68 | 51.48** |
| Replication | 2 | 5.67 | 2.83 | 6.15** |
| Environment/ Replication | 6 | 53.03 | 8.84 | 19.22** |
| Genotype | 24 | 38.58 | 1.61 | 3.50** |
| Genotype x Environment | 48 | 38.14 | 0.79 | 1.72** |
| Pooled error | 142 | 66.16 | 0.46 | |

** significant at P = 0.01.

for an evaluation of different varieties. The infestation in Kitale was higher than that at Njoro. At Njoro the infestation ranged from 25.63 (KCB (++) $C_o$) to 68.33 percent (KCBtm/S/$C_1$) while in Kitale the range was between 38.17 (KCBtm/S/$C_1$) and 75.6 percent (KCB($br_2$ $br_2$)$C_o$). When the locations were pooled together, KCBtm/R/$C_1$ x KCEtmER/$C_1$ had the least attack (38.68 percent) and KCB ($br_2$ $o_2$) $C_o$ was the most susceptible cultivar (69.12 percent). Genotypes were different in their response to the attack by the stem borer complex. However, there was no interaction between genotypes and the environment in respect of attack by stem borers (Table 37).

4.4.4. Diseased ears

This character was only recorded at Njoro. Although H 512, KCBtm/$C_o$ x KCEtm/$C_o$, KCBtm/S/$C_1$, KCEtm/$C_o$, KCE($o_2$ $o_2$) $C_o$ and KCBtm/$C_o$ showed a good level of resistance (10.00 percent), KCEtm/S/$C_1$ in turn showed a high level of sensitivity to ear rot (46.67 percent). Next in infestation were KCB($o_2$ $o_2$) mod. $C_o$ with 40.00 percent, KCB($br_2$ $o_2$)$C_o$ (40.00 percent) and KCE ($br_2$ $o_2$)$C_o$ (30.00 percent).

Table 37. Combined analysis of variance for stem borer infestation in maize

| Sources of variation | df | ss | ms | F |
|---|---|---|---|---|
| Environment | 1 | 2399.19 | 2399.19 | 9.53** |
| Replication | 2 | 253.53 | 126.65 | 0.50 |
| Environment/ Replication | 4 | 2652.73 | 663.18 | 2.63* |
| Genotype | 24 | 9836.48 | 409.84 | 1.63* |
| Genotype/ Environment | 24 | 6536.61 | 272.36 | 1.08 |
| Pooled error | 94 | 23672.29 | 251.83 | |

* significant at P = 0.05.

** significant at P = 0.01.

Genotypes were significantly different in numbers of diseased ears, however, the coefficient of variation was very high (68.00 percent).

## 4.5. Gene effect

### 4.5.1. The effect of brachytic-2 gene ($br_2br_2$)

Yield and yield components

As given in Table 5 brachytic-2 gene affected a number of yield characters. It significantly reduced grain yield (from 81.92 to 64.39 q/ha) and weight of 1000 grains (from 470.0 to 372.42 gm) of KCB, but did not influence ear length, number of ears per plant and ear diameter. It, however, improved the number of rows per ear (from 12.15 to 13.67). In KCE grain yield was not reduced significantly (from 73.43 to 68.80 q/ha). This was probably due to low grain yield of KCE ++ (29.82 q/ha) in Kitale. Weight of 1000 grains and number of rows per ear showed significant differences. In fact 1000 grain weight was improved in KCE (from 371.75 to 433.0 gm). Brachytic-2 gene did affect the grain yield of KCB but not of KCE, this could be attributed to their difference in genetic background.

Plant characteristics

As far as plant characters were concerned both KCB and KCE were equally influenced (Table 16). KCB showed significant differences in maturity, lodging percentage, ear length and plant height (Table 8) but not in leaf numbers and crop index. Brachytic-2 did not interfere with the number of leaves nor did it influence crop index. It reduced plant height from 299.5 to 269.42 cm in KCB and from 298.25 to 261.08 cm in KCE; ear height was reduced from 156.5 to 123.5 cm in KCB and from 170.17 to 129.83 cm in KCE. It is the shortening of internode (Fig. 2) that brought about height reduction (Fig. 1). As a result of short stature the stalks became stronger hence reduction in lodging percentage from 35.47 to 10.00 percent in KCB and from 20.00 to 16.57 percent in KCE. However, it celayed days to 50 percent silking from 110.75 to 115.08 days in KCB and from 106.67 to 111.50 days in KCE. In the case of KCE population there were no significant differences in leaf number, lodging percentage and crop index.

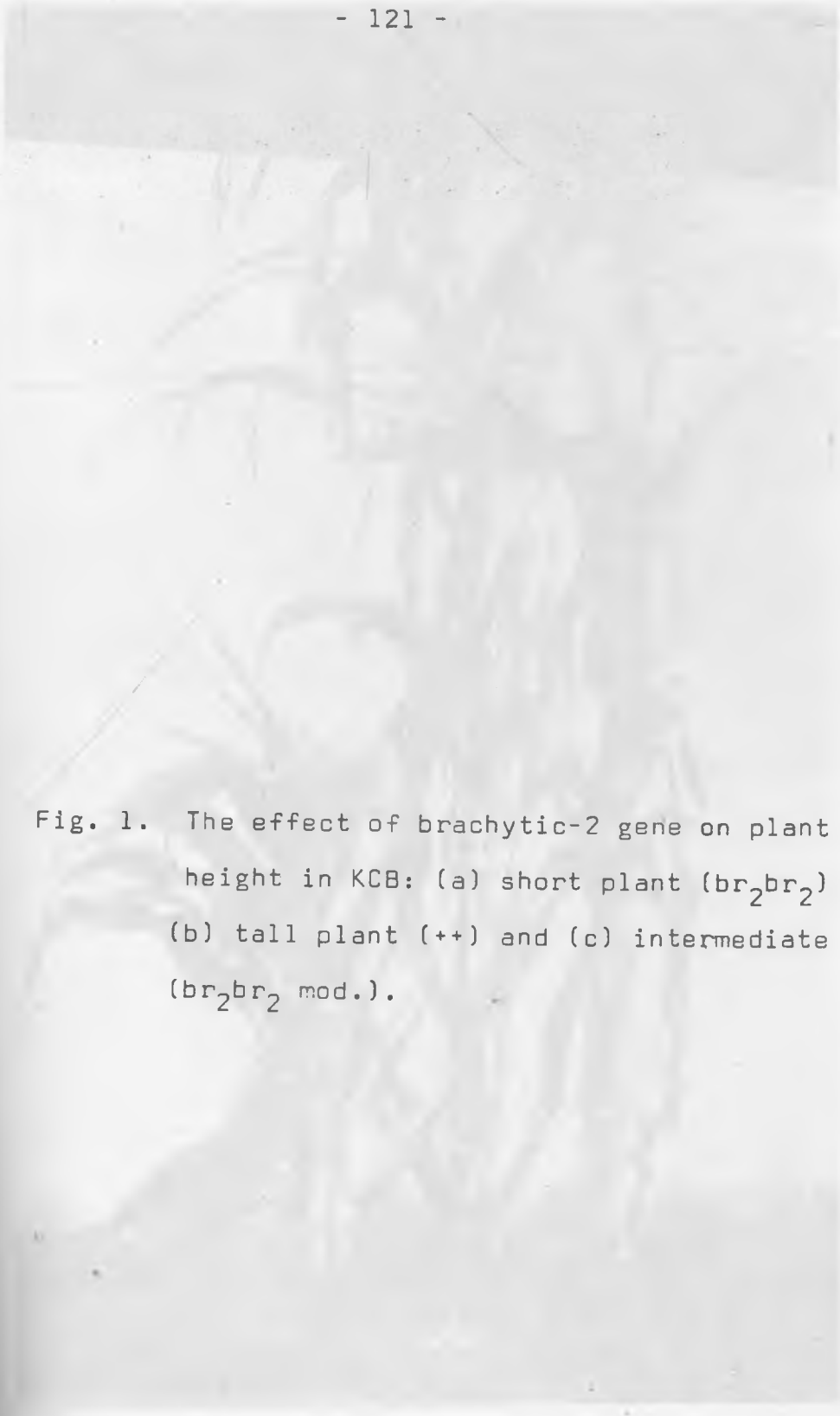


Fig. 1. The effect of brachytic-2 gene on plant height in KCB: (a) short plant ($br_2br_2$) (b) tall plant (++) and (c) intermediate ($br_2br_2$ mod.).

(a) (b) (c)

Fig. 2. The effect of brachytic-2 gene on internodes of KCB (a) shortened internode ($br_2br_2$) (b) long internode (++) and (c) intermediate internode ($br_2br_2$ mod.).

(a) (b) (c)

Grain quality

Brachytic-2 gene as such had no influence on protein, lysine, tryptophane and moisture content in either KCB or KCE populations (Table 26).

Pests and diseases

Brachytic-2 gene did not affect blight or rust but it increased stem borer incidence in both populations (Table 34).

4.5.2. The effect of opaque-2 gene ($o_2$ $o_2$)

Yield and yield components

Opaque-2 gene brought about significant differences, in both KCB and KCE populations for grain yield and weight of 1000 grains but not in the number of rows per ear, ear length, ear per plant and ear diameter (Table 5). Opaque-2 gene reduced both grain yield from 81.92 to 56.39 q/ha in KCB , from 68.80 to 62.38 q/ha in KCE and weight of 1000 grains from 470.00 to 372.50 gm in KCB and from 371.75 to 354.08 in KCE. It did not interfere with other yield components. It reduced the grain yield of KCB populations by 31.11

percent and KCE populations by 9.32 percent. Similarly the weight of 1000 grains of KCB population was reduced by 20.76 percent and in the case of KCE populations by 4.75 percent.

Grain quality

Both KCB and KCE populations with opaque-2 gene showed significant difference on lysine and tryptophane percentage with the normal populations but not in protein content (Table 26). significant difference was observed in moisture percentage of KCB and KCE. Opaque-2 gene increased tryptophane in the grains from 0.63 to 0.98 percent and lysine from 2.53 to 3.93 percent for KCB populations. For KCE populations tryptophane content was raised from 0.62 to 1.04 percent and lysine content from 2.51 to 4.17 percent. Opaque-2 gene had no effect on protein content. Opaque-2 grains showed soft endosperm and opaqueness as opposed to the hard and translucent endosperm of the normal maize (Figure 3).

Plant characteristics

Opaque-2 gene had no influence on a number of

Fig. 3. Grain characteristics of normal grains (a) opaque-2 grains (b) and modified opaque-2 grains (c) in KCE.

(c)

(b)

(a)

plant characters such as plant and ear height, leaf number and maturity periods or even crop index.

Pests and diseases

KCB and KCE opaque populations were more susceptible to both stem borer and ear rot than their normal counterparts (Table 34). The two populations did not differ in their response to either rust or blight attack. Opaque-2 ears of KCB populations were much more diseased than the normal counterparts: KCB (++)$C_o$ (26.67 percent), KCB ($o_2$ $o_2$)$C_o$ (30.00 percent), KCE (++)$C_o$ (10.00 percent), KCE ($o_2$ $o_2$)$C_o$ (16.67 percent (Table 32). Similarly stem borer infestation was much more in opaque populations than the normal counterparts: KCB (++)$C_o$ (45.67 percent), KCB ($o_2$ $o_2$) (53.62 percent), KCE (++)$C_o$ (42.45 percent) and KCE ($o_2$ $o_2$)$C_o$ (62.40 percent).

4.5.3. The effect of modifying opaque-2 gene by selection

Yield and yield components

The results in Table 5 indicate that, selection for the unknown modifiers or modifying factors of

opaque-2 gene did not rectify fully the defects caused by opaque-2 gene in both populations. In KCB populations ear length, ear per plant, ear diameter, number of rows per ear and grain yield did not show significant differences except weight of 1000 grains ($KCB_{o_2o_2}$ and $KCB_{o_2o_2mod.}$ 393.67 gm) Similarly in KCE population only weight of 1000 grains showed significant differences ($KCE_{o_2o_2}$ 354.08 gm and $KCE_{o_2o_2mod.}$ 422.83 gm). The grains selected for modifiers failed to improve yield but did resemble the normal grains in appearance (Fig. 3). Grains selected out of opaque-2 on the basis of the unknown modifiers hereafter are referred to as modified opaque-2 grains.

Grain quality

There were no significant differences between modified opaque populations of KCB and KCE and opaque populations in protein, tryptophane and moisture content (Table 26). However, there were differences between modified opaque populations and normal counterparts for lysine content in both

populations: $KCB_{o_2o_2mod.}$ (3.82 percent), KCB++ (2.53 percent), $KCE_{o_2o_2mod.}$ (3.92 percent) and KCE++ (2.51 percent).

Plant characteristics

Opaque-2 modified population of KCB anc KCE did not differ significantly from KCB opaque-2 and KCE opaque-2 in most of the plant characters. However, the modified KCB opaque lodged much more (26.67 percent) than the KCB opaque (10.00 percent) and KCE opaque modified lodged less (15.00 percent) than KCE opaque (27.60 percent) in Table 12.

Pests and diseases

Results presented in Table 34 showed that the modified opaque populations of KCB and KCE and opaque populations of KCB and KCE showed no significant differences in stem borer infestation: $KCB_{o_2o_2mod.}$ (55.04 percent), $KCB_{o_2o_2}$ (53.62 percent) and $KCE_{o_2o_2mod.}$ (60.99 percent), $KCE_{o_2o_2}$ (62.40 percent). Both rust and blight did not respond to modifying factors of opaque-2. It may be noted that at the individual gene level modification of opaque-2 did not reduce the infestation of diseases

and pests.

4.5.4. The effect of combining brachytic-2 and opaque-2 genes (double mutant ($br_2o_2$)

Yield and yield components

KCB $br_2o_2$ (62.57 q/ha) showed no difference in grain yield with KCB $br_2br_2$ (64.39 q/ha) but was better than KCB$o_2o_2$ (56.39 q/ha), and worse than KCB++ (81.92 q/ha) (Table 5). For 1000 grains, KCB$br_2o_2$ (359.58 gm) was significantly lower than both KCB $br_2br_2$ (372.42 gm), KCB $o_2o_2$ (372.50 gm) and even KCB(++) (470.00 gm). There were no differences in ear length, number of ears per plant, ear diameter and number of rows per ear. The double mutant grains have combined both opaqueness and translucence as compared to the opaque-2 grains (Fig. 4). As far as grain yield and weight of 1000 grains were concerned there was no improvement. KCE $br_2o_2$ had (73.43 q/ha) and (374.75 gm) while KCE (++) had (68.80 q/ha) and (371.75 gm) respectively. However, KCE $br_o o_2$ was significantly better than KCE $o_2o_2$ which had grain yield of 62.38 q/ha and 1000 grain weight of 354.08 gm. At least in both

Fig. 4. Grain characteristics of normal (a) brachytic (b) opaque (c) and double mutant ($br_2o_2$) (d) in KCE.

(d)
(c)
(b)
(a)

populations double mutant rectified loss in grain yield and weight of 1000 grains.

Grain quality

It has been shown that opaque-2 gene improved lysine and tryptophane percentage but not protein content (Table 26). It has also been indicated that brachytic-2 gene as such did not have any influence on lysine, tryptophane, protein and moisture content. It is therefore interesting to note that double mutant populations maintained protein quality levels closer to that of the opaque populations: KCB $o_2o_2$ (3.93 percent lysine) KCB $br_2o_2$ (4.04 percent lysine) KCE $o_2o_2$ (4.17 percent lysine) and KCE $br_2o_2$ (3.91 percent lysine). It appears that brachytic-2 and opaque-2 genes interacted favourably for grain quality characters.

Plant characteristics

In Table 16 both KCB and KCE double mutants matured significantly earlier than brachytic-2 populations. For example KCB $br_2br_2$ took 115.08 days, as compared to 112.58 days of KCB $br_2o_2$,

KCE $br_2br_2$ took 111.50 days as compared to 99.67 days KCE $br_2o_2$. This means that by combining the opaque-2 and brachytic-2 genes the lateness of brachytic-2 was no longer effective. For leaf number, ear height and plant height, double mutant populations were similar to the brachytic-2 populations. The crop index of KCB $br_2o_2$ (38.91) showed some improvement over KCB $br_2br_2$ (35.31) and KCE $br_2o_2$ (44.45) was significantly higher than KCE $br_2br_2$ (35.34)

Pests and diseases

KCB and KCE double mutant populations suffered significantly more from stem borer infestation than either of the single mutant populations or normal counterparts: KCB++ (45.67 percent), KCB $br_2br_2$ (63.87 percent), KCB $o_2o_2$ (53.62 percent) and KCB $br_2o_2$ (69.12 percent), KCE++ (42.25 percent), KCE $br_2br_2$ (40.55 percent), KCE $o_2o_2$ (62.40 percent) and KCE $br_2o_2$ (63.39 percent) (Table 34). Double mutant populations showed no difference in rust and blight attack. This meant that the attack of rust and blight was

not influenced by the combination of brachytic-2 and opaque-2. However, KCB and KCE double mutants had more diseased ears, than their counterparts: KCB $br_2br_2$ (16.67 percent), KCB ++ (26.67 percent), KCB $o_2o_2$ (30.00 percent) and KCB $br_2o_2$ (40.00 percent). KCE $br_2br_2$ (10.00 percent), KCE ++ (10.00 percent), KCE $o_2o_2$ (16.67 percent) and KCE $br_2o_2$ (30.00 percent). This could be associated with the presence of opaque-2 that exhibited a higher percent of diseased ears.

4.5.5. The effect of modifying double mutant populations by selection

Yield and yield components

Both KCB and KCE modified double mutant populations were significantly higher than either opaque-2 or brachytic-2 populations in grain yield and weight of 1000 grains: KCB $br_2br_2$ (64.39 q/ha), KCB $o_2o_2$ (56.39 q/ha), KCB $br_2o_2$ (mod.) (80.40 q/ha) and KCB ++ (81.92 q/ha), KCE $br_2br_2$ (73.63 q/ha), KCE $o_2o_2$ (60.93 q/ha), KCE $br_2o_2$ (mod.) (77.29 q/ha and KCE ++ (68.80 q/ha). For weight of 1000 grains, KCB $br_2br_2$ (372.42 gm), KCB $o_2o_2$ (372.50 gm),

KCB $br_2o_2$ mod. (393.67 gm) and KCB ++ (470.00 gm), KCE $br_2br_2$ (433.00 gm), KCE $o_2o_2$ (422.83 gm), KCE $br_2o_2$ (mod.) (397.83 gm) and KCE++ (371.75 gm). It would appear that modified double mutant populations recovered the grain yield loss that was realised either with opaque-2 or in combination with brachytic-2 in both populations. All the other yield components such as ear length, number of ears per plant, ear diameter and number of rows per ear were not affected by modifiers in double mutant populations.

Grain quality

Modifying factors did not influence protein lysine or tryptophane content of the double mutant populations. Modified double mutant populations maintained the high quality levels of the double mutant: KCB $br_2o_2$ (9.84 percent protein), KCB $br_2o_2$ mod. (9.76 percent protein), KCB $br_2o_2$ (4.04 percent, lysine) KCB $br_2o_2$ (mod.) (3.83 percent lysine) KCE $br_2o_2$ (11.07 percent protein), KCE $br_2o_2$ mod. (10.99 percent protein) KCE $br_2o_2$ (3.97 percent lysine) and KCE $br_2o_2$ mod. (3.97 percent lysine. In appendix 8 protein, tryptophane and lysine contents of these populations are listed.

Plant characteristics

KCB and KCE modified double mutants did not show significant differences in the number of leaves per plant (see table 16). In maturity, the modified populations were just as late as the brachytic-2 populations. However, they lodged significantly less than their normal counterparts: KCB ++ (35.47 percent), KCB $br_2o_2$ mod. (27.40 percent), KCE++ (20.00 percent) and KCE $br_2o_2$ mod. (15.00 percent). Reduction in locging was attributed to the reduced plant height: KCB ++ (299.5 cm), KCB $br_2o_2$ mod. (264.17 cm), KCE ++ (298.25 cm) and KCE $br_2o_2$ mod. (265.34 cm).

Pests and diseases

Both KCB and KCE modified double mutant populations were less infested by stem borer than their double mutant counterparts: KCB $br_2o_2$ (69.12 percent), KCB $br_2o_2$ mod. (59.00 percent), KCE $br_2o_2$ (63.39 percent) and KCE $br_2o_2$ mod. (43.74 percent). It appears that modifiers improved the level of tolerance to stem borer damage in both populations. There were significant differences observed for rust and blight. For rust rating

KCB $br_2o_2$ scored (1.32) while KCB $br_2o_2$ mod had (1.60), KCE $br_2o_2$ had (1.46) and KCE $br_2o_2$ mod (1.50). In the case of blight KCB $br_2o_2$ had (1.23) and KCB $br_2o_2$ mod (0.85) while KCE $br_2o_2$ rated (0.59) and KCE $br_2o_2$ mod (1.27). KCB $br_2o_2$ mod. (26.67 percent) was more tolerant than KCE $br_2o_2$ (40.00 percent) for diseased ears, however there was no difference between KCE $br_2o_2$ mod and KCE $br_2o_2$ as both had 30.00 of their ears diseased.

4.5.6. The effect of sugary-2 gene as a modifier of the double mutant population (triple mutant)

Yield and yield components

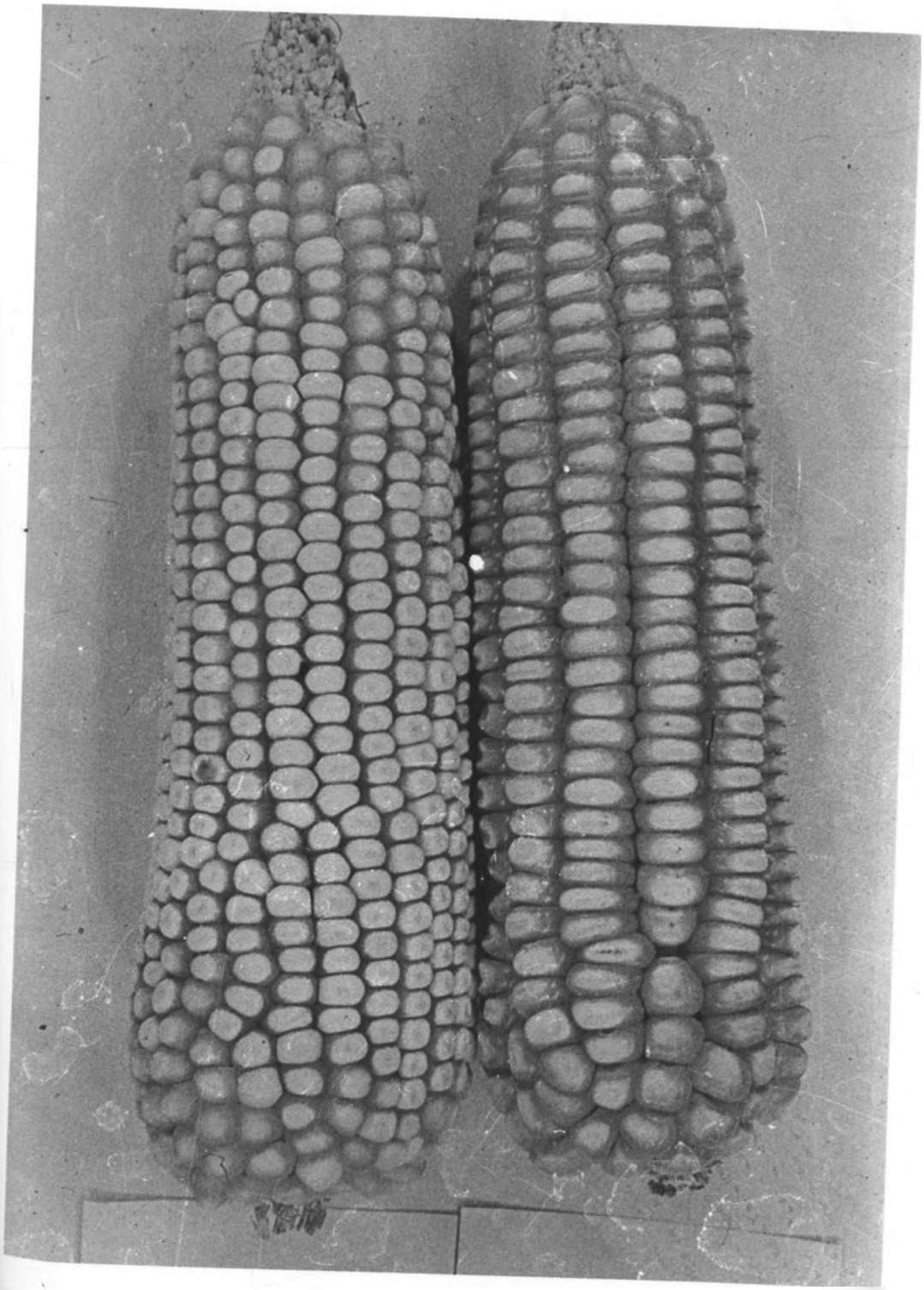
KCB and KCE triple mutant populations registered lower grain yields and weight of 1000 grains than double mutant populations: KCB $br_2o_2su_2$ (56.03 q/ha), KCB $br_2o_2$ (62.57 q/ha) KCE$br_2o_2su_2$ (59.98 q/ha) and KCE $br_2o_2$ (73.43 q/ha). With the weight of 1000 grains the results were: KCB$br_2o_2su_2$ (319.75 gm), KCB$br_2o_2$ (359.38 gm), KCE$br_2o_2su_2$ (397.83 gm) and KCE $br_2o_2$ (374.75 gm). The incorporation of sugary-2 gene in these populations improved the number of rows per ear significantly: KCB$br_2o_2su_2$ (14.5), KCB ++ (12.15), KCE $br_2o_2su_2$

(14.00) and KCE ++ (12.50). However, it reduced the ear length in KCB population only: KCB ++ (19.83 cm), KCB $br_2o_2su_2$ (15.53 cm), KCE ++ (17.03 cm) and KCE $br_2o_2su_2$ (17.66 cm). The weight of 1000 grains of triple mutant populations were lower than their normal counterparts: KCB ++ was 470.00 gm and KCE ++ (371.75 gm) compared to KCB $br_2o_2su_2$ that weighed 319.75 gm while KCE $br_2o_2su_2$ was 344.00 gm. Less weight of 1000 grains suggests reduction in grain size as shown in figure 5.

Grain quality

Data in Table 26 showed that sugary-2 gene did not influence protein percentage but significantly improved both lysine and tryptophane percentage: KCB $br_2o_2su_2$ (9.21 percent protein), KCB ++ (9.89 percent protein), KCE $br_2o_2su_2$ (9.4 percent protein) and KCE ++ 8.86 percent protein). For lysine KCB $br_2o_2su_2$ had 4.28 percent, KCB ++ had only 2.53 percent whereas KCE $br_2o_2su_2$ registered 4.12 percent and KCE ++ (2.51 percent). It appears that sugary-2 gene improved protein quality rather than quantity. Moisture content was not significantly affected.

Fig. 5. The ear of KCB triple mutant ($br_2o_2\ su_2$) (a) shows increased number of rows and small grain size as compared to KCB normal ear (++) (b)



(a) (b)

Plant characteristics

Triple mutants lowered plant and ear heights significantly below that of the double mutant: KCB $br_2br_2$ (269.42, 123.59 cm), KCB $br_2o_2su_2$ (222.58, 84.67 cm), KCE $br_2br_2$ (261.08, 129.83 cm) and KCE $br_2o_2su_2$ (243.42, 101.42 cm). The difference in plant and ear height of double and triple mutants is also shown in Figure 6. The reduction of height in the triple mutant poulations might have accounted for the loss in grain yield. Triple mutants also had a lower number of leaves per plant and shorter maturity periods: KCB++ (110.75 days), KCB$br_2o_2su_2$ (101.33 days), KCE++ (106.67 days) and KCE $br_2o_2su_2$ (102.25 days). Maturity period was similar to that of opaque-2 populations but was significantly earlier than the brachytic-2 populations. KCB$o_2o_2$ (103.58 days), KCB $br_2br_2$ (115.08 days), KCB $br_2o_2su_2$ (101.33 days), KCE$o_2o_2$ (105.83 days), KCE $br_2br_2$ (111.50 days) and KCE $br_2o_2su_2$ (102.25 days). KCB triple mutant population lodged much less than the normal counterparts: KCB ++ (35.47 percent), KCB $br_2o_2su_2$ (20.63 percent), KCE ++ (20.00 percent) and KCE $br_2o_2su_2$ (17.03 percent). Lower lodging percentage is attributed to the reduction in plant and

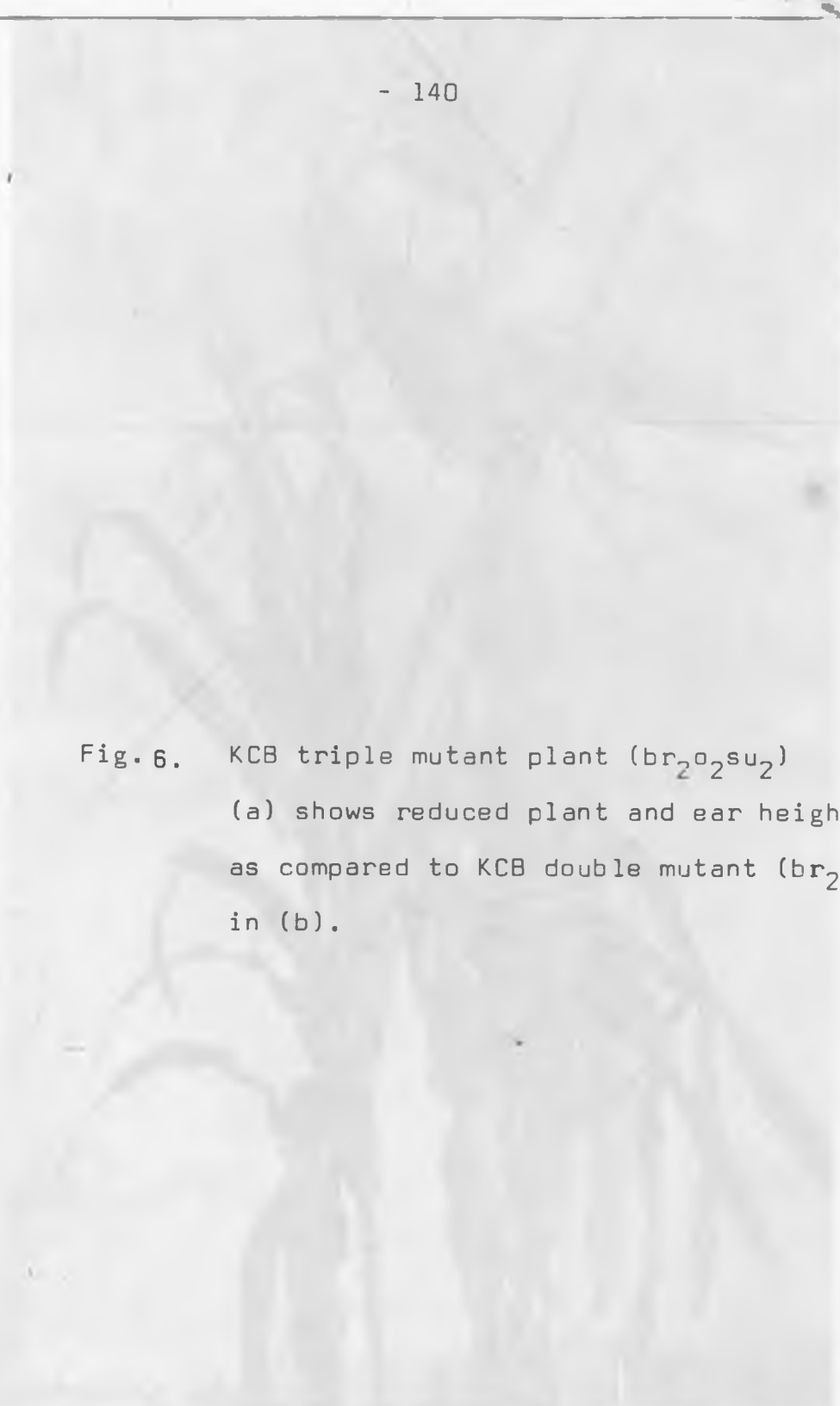


Fig. 6. KCB triple mutant plant ($br_2o_2su_2$) (a) shows reduced plant and ear height as compared to KCB double mutant ($br_2o_2$) in (b).

(a) (b)

ear height. Triple mutant improved crop index that brachytic-2 gene alone failed to accomplish: KCB $br_2br_2$ (35.31), KCB $br_2o_2su_2$ (42.91), KCE $br_2br_2$ (35.45) and KCE $br_2o_2su_2$ (42.20).

Pests and diseases

Sugary-2 as a modifying gene did not improve the rust and blight tolerance nor did it improve the response to stem borer infestation (Table 34). Triple mutant population showed better tolerance to ear rot since in both KCB and KCE triple mutant populations only 10 percent of the harvested ears were rotten in comparison to 26.0 and 16.67 percent in the normal versions of KCB and KCE respectively. In this case, sugary-2 as a modifying gene reduced the defect of opaque-2 gene.

4.5.7. Relationship between yield and protein quality characters

Simple correlation coefficients between yield and quality characters are given in Table 38. For opaque populations correlation coefficient between yield and lysine were either negative but highly significant (r = -0.43** for KCB) or showed no

Table 38. Correlation coefficient between yield and protein quality characters

| Population | Genotype | Yield/lysine | Protein/lysine | Yield/protein |
|---|---|---|---|---|
| KCB | $o_o o_2$ | -0.43** | -0.33* | 0.17 |
| KCE | $o_2 o_2$ | -0.04 | -0.42** | -0.32* |
| KCB | $br_2 o_2 su_2$ | -0.85** | -0.89** | |
| KCE | $br_2 o_2 su_2$ | -0.84** | -0.68** | |

* significant at P = 0.05.

** significant at P = 0.01.

association between these characters (r = -0.04 for KCE). The relationships between protein and lysine proved negative (r = -0.33* for KCB opaque r = -0.42** for KCE). Yield and protein were not associated in KCB (r = 0.17) but negatively related in KCE (r = -0.32*).

In triple mutant populations, relationships between yield and lysine or protein and lysine were highly significant. Correlation coefficients for KCB were r = -0.85** and r = -0.89** respectively and for KCE r = -0.84** and r = -0.68**.

As shown above the relationship between these characters in the opaque populations was not as strong as in the case of triple mutant populations although the association was negatively correlated.

### 4.5.8. Selection experiments

#### $S_1$ progeny testing selection method (S)

Mean performance of the top twenty one high yielding families selected on the basis of $S_1$ progeny tests from two populations are given in Table 39. These family lines in turn formed KCB tm/S/$C_1$ and KCE tm/S/$C_1$. The means of the selected

Table 39. Mean yield data of selected KCB and KCE $S_1$ families

| Rank | KCE tm/S/$C_0$ families | | KCB tm/S/$C_0$ families | |
|---|---|---|---|---|
| | Progeny | yield (q/ha) | Progeny | yield(q/ha) |
| 1 | 5 | 59.0 | 74 | 44.1 |
| 2 | 52 | 59.0 | 150 | 44.0 |
| 3 | 93 | 58.9 | 167 | 44.0 |
| 4 | 86 | 58.9 | 101 | 43.8 |
| 5 | 158 | 58.8 | 13 | 42.7 |
| 6 | 66 | 58.8 | 63 | 42.6 |
| 7 | 92 | 58.7 | 136 | 41.7 |
| 8 | 160 | 58.7 | 45 | 41.1 |
| 9 | 99 | 58.6 | 3 | 41.1 |
| 10 | 55 | 57.6 | 15 | 41.0 |
| 11 | 100 | 57.9 | 27 | 40.9 |
| 12 | 142 | 57.9 | 138 | 40.9 |
| 13 | 96 | 57.8 | 34 | 40.8 |
| 14 | 57 | 56.9 | 36 | 40.8 |
| 15 | 122 | 56.9 | 137 | 40.9 |
| 16 | 83 | 56.8 | 106 | 40.8 |
| 17 | 17 | 56.8 | 70 | 40.8 |
| 18 | 61 | 56.6 | 140 | 40.8 |
| 19 | 145 | 56.7 | 158 | 39.9 |
| 20 | 71 | 56.6 | 155 | 39.8 |
| 21 | 115 | 56.7 | 141 | 39.8 |
| Mean | | 57.75 | | 41.82 |
| $\bar{X}$ | | 43.85 | | 29.12 |
| D | | 13.90 | | 12.70 |
| LSD (P=0.05) | | 3.38 | | 3.02 |

$\bar{X}$ = mean of selected families

$\bar{\bar{X}}$ = overall mean

D = selection differential, the difference between $\bar{X}$ and $\bar{\bar{X}}$

lines ($\bar{X}$) were 57.75 q/ha for KCE and 41.82 q/ha for KCB. The mean of all the lines tested (overall mean $\bar{\bar{X}}$) was 43.84 q/ha for KCE and 29.12 q/ha for KCB. The difference between overall mean and mean of the selected (selection differential, D) was 13.90 q/ha for KCE compared to 12.70 q/ha for KCB. Selected families from KCE had higher grain yield than those selected from KCB.

Reciprocal recurrent selection method (R)

Table 40 gives the performance of top twenty two families in KCE and twenty one in KCB which were selected using reciprocal recurrent selection method. The mean of the selected families ($\bar{X}$) was 58.1 a/ha for KCE and 54.4 q/ha for KCB. The overall mean ($\bar{\bar{X}}$) of all families tested for KCE was 37.2 q/ha compared to 43.0 q/ha for KCB. The selection differential for KCE was 20.9 q/ha while for KCB it was 11.4 q/ha. Even under reciprocal recurrent selection procedure the mean of the selected lines from KCE 58.1 q/ha was higher than the mean of the selected lines from KCB 54.4 q/ha.

Table 40. Mean yield data of selected KCB and KCE reciprocal recurrent families

| Yield Rank | KCE tm/R/$C_o$ | | KCB tm/R/$C_o$ | |
|---|---|---|---|---|
| | Progeny | yield (q/ha) | Progeny | yield(q/ha) |
| 1 | 144 | 61.6 | 74 | 63.6 |
| 2 | 194 | 61.4 | 13 | 61.3 |
| 3 | 188 | 61.4 | 60 | 60.8 |
| 4 | 155 | 61.4 | 38 | 60.8 |
| 5 | 151 | 61.2 | 145 | 56.6 |
| 6 | 186 | 61.2 | 77 | 56.6 |
| 7 | 191 | 61.2 | 83 | 54.4 |
| 8 | 86 | 61.2 | 87 | 53.5 |
| 9 | 126 | 61.2 | 78 | 52.5 |
| 10 | 54 | 61.0 | 157 | 52.5 |
| 11 | 34 | 61.0 | 158 | 52.5 |
| 12 | 83 | 60.8 | 195 | 52.5 |
| 13 | 57 | 60.6 | 196 | 52.5 |
| 14 | 42 | 60.6 | 73 | 52.5 |
| 15 | 180 | 60.6 | 129 | 51.5 |
| 16 | 184 | 52.1 | 80 | 51.5 |
| 17 | 80 | 51.9 | 13 | 51.5 |
| 18 | 165 | 51.9 | 65 | 51.5 |
| 19 | 72 | 51.9 | 91 | 51.5 |
| 20 | 173 | 51.9 | 42 | 51.5 |
| 21 | 63 | 51.7 | 52 | 51.5 |
| 22 | 99 | 51.7 | | |
| $\bar{X}$ | | 58.1 | | 54.4 |
| $\bar{\bar{X}}$ | | 37.2 | | 43.00 |
| D | | 20.9 | | 11.4 |
| LSD (P=0.05) | | 2.48 | | 2.32 |

Components of variance

Selection trials of 169 $S_1$ and 196 reciprocal families were conducted using 13 x 13 and 14 x 14 triple lattice designs respectively in two sites at Katumani. One site was irrigated while the other was not. The mean squares ($M_1$, $M_2$ and $M_3$) of the combined yield data over the two sites are presented in Table 41.

The Components of variance given in Table 42 were obtained by solving the equations for mean squares for the analysis of variance table multi-location trial as indicated in Section 3.9.2.

4.5.9. Predicted genetic gains

In Table 42 predicted genetic gain for $S_1$ method was 5.90 q/ha per cycle, or 2.95 q/ha per year for KCE and 1.65 q/ha or 0.83 q/ha per year for KCB. Reciprocal selection method on the other hand gave a predicted gain of 7.31 q/ha per cycle or 3.65 q/ha per year for KCE and 3.48 q/ha per cycle or 1.74 q/ha per year for KCB. The KCE population (6.6 q/ha) had a higher predicted gain than $_{KCB}$ (2.56 q/ha) based on the mean of the two populations. Thus reciprocal recurrent method showed a higher predicted genetic gain (5.93 q/ha) than the $S_1$ method (3.77 q/ha) based

Table 41. Mean square of yield data

| Sources of variations | Populations | | | |
|---|---|---|---|---|
| | KCE tm/S/$C_o$ | KCE tm/R/$C_o$ | KCB tm/S/$C_o$ | KCB tm/R/$C_o$ |
| Genotype (g) | 893.76 | 1015.07 | 170.28 | 579.94 |
| Genotype x Environment (ge) | 133.95 | 298.96 | 125.69 | 227.02 |
| Pooled error (e) | 66.91 | 19.36 | 42.92 | 15.05 |

Table 42. Estimates of variance components: heritabilities (H), selection differential (D) and expected gains of populations improved through $S_1$ testing (S) and reciprocal recurrent method (R)

| Population | Yield | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Selection method | Mean | $S_e^2$ | $S_{ge}^2$ | $S_g^2$ | H | D | $\hat{G}$ | % gains | Predicted yield | Observed yield | differences between obs. and pred. |
| KCE(tm($C_1$ | S | 57.75 | 66.91 | 22.35 | 126.63 | 0.85 | 13.9 | 5.90 (2.95) | 10.2 (5.1) | 63.65 (60.70) | 65.68 | 2.03 (4.98) |
| KCE(tm)$C_1$ | R | 58.10 | 19.36 | 93.20 | 119.35 | 0.70 | 20.9 | 7.31 (3.65) | 12.58 (6.29) | 65.41 (61.75) | 85.43 | 20.02 (23.68) |
| KCB(tm)$C_1$ | S | 41.82 | 42.92 | 27.59 | 7.43 | 0.26 | 12.7 | 1.65 (0.83) | 3.94 (1.97) | 43.47 (42.65) | 72.55 | 29.08 (29.90) |
| KCB(tm)$C_1$ | R | 54.40 | 15.05 | 70.66 | 58.82 | 0.61 | 11.4 | 3.48 (1.74) | 6.40 (3.20) | 58.15 (56.14) | 72.12 | 15.97 (15.98) |

Figures given in parenthesis are gain per year

on the average of the methods over the two populations. The difference between predicted and observed yield was much greater in KCB than it was in KCE population. The mean difference in KCB was 22.52 q/ha and 11.02 q/ha in KCE. But the difference between predicted and observed yield on the basis of breeding methods was similar. For reciprocal recurrent selection the difference was 17.99 q/ha while for $S_1$ method it was 15.55 q/ha.

A simple t-test was carried out to test Ho: Predicted = Observed. From the F-table the tabular value at 5 percent level of significance was greater (9.28) than the calculated F-value (1.45). This meant that the variances were not the same. Pooled variance was therefore calculated. On the basis of that a t-test was done. The t-value at 5 percent level of significance (2.45) was found to be less than the calculated t (2.59). The hypothesis Ho: Predicted = Observed at 5 percent level, was rejected which meant that the predicted gains were differert from the observed gains.

4.5.10. Efficiency of the breeding methods

Population improvement

In Table 43 yield and quality characters of improved populations and their hybrids are given. It may

Table 43. The influence of the two selection methods on yield, grain quality and crop index of in populations *per se*, improved populations and their hybrids.

| Population | selection method | yield | percentage increase | protein | percentage increase | lysine content | percentage increase | crop index | pecentage increase |
|---|---|---|---|---|---|---|---|---|---|
| $KCBtmC_0$ | | 74.71 | 100.00 | 9.21 | 100.00 | 4.28 | 100.00 | 42.91 | 100.00 |
| $KCBtmC_1$ | S | 72.55 | 97.11 | 10.18 | 110.53 | 4.13 | 96.49 | 41.53 | 96.78 |
| $KCBtmC_1$ | R | 72.12 | 96.53 | 10.00 | 108.58 | 4.10 | 95.79 | 36.92 | 86.60 |
| $KCEtmC_0$ | | 79.98 | 100.00 | 9.40 | 100.00 | 4.12 | 100.00 | 42.20 | 100.00 |
| $KCEtmC_1$ | S | 65.68 | 82.12 | 11.22 | 119.36 | 4.32 | 104.85 | 40.67 | 96.37 |
| $KCEtmC_1$ | R | 85.43 | 106.81 | 10.00 | 106.38 | 4.36 | 105.82 | 42.73 | 101.25 |
| $KCBtmC_0$ x $KCEtmC_0$ | | 79.90 | 100.00 | 10.45 | 100.00 | 4.18 | 100.00 | 44.71 | 100.00 |
| $KCBtmC_1$ x $KCEtm/C_1$ | S | 107.16 | 134.12 | 9.73 | 93.11 | 4.31 | 103.11 | 44.40 | 99.31 |
| $KCBtmC_1$ x $KCEtmC_1$ | R | 118.78 | 148.66 | 10.15 | 97.13 | 4.35 | 104.07 | 45.10 | 100.89 |
| Mean | | 84.03 | | 10.02 | | 4.24 | | 42.01 | |
| Range | | 65.68-118.78 | | 9.21-11.22 | | 4.10-4.36 | | 36.92 45.10 | |
| LSD (P = 0.05) | | 4.39 | | 1.60 | | 0.94 | | 2.79 | |

be noted that only KCE population responded to selection significantly particularly when it was improved by reciprocal recurrent selection. In grain yield both KCB tm/S/$C_1$ and KCB tm/R/$C_1$ showed no significant difference from the original KCB tm/$C_o$. But both KCE tm/S/$C_1$ and KCE tm/R/$C_1$ were significantly different from the original KCE tm/$C_o$. On the contrary $S_1$ selection method lowered the grain yield by 18 percent, while reciprocal recurrent selection improved it by 6.81 percent in KCE population.

There was no heterosis response when the original populations were crossed: KCB tm/$C_o$ (74.71 q/ha), KCE tm/$C_o$ (79.98 q/ha) and KCB tm/$C_o$ x KCE tm/$C_o$ (79.90 q/ha). But after one cycle of selection populations resulted in tremendous improvement in yield when crossed: KCB tm/S/$C_1$ x KCE tm/S/$C_1$, (107.16 q/ha) and KCB tm/R/$C_1$ x KCE tm/R/$C_1$, (118.78 q/ha). This indicated that the selection methods applied were efficient in improving respective populations. Expressed as percentage over the original cross, $S_1$ selection made an improvement of 34.21 percent compared to the reciprocal recurrent method that realised 48.66 percent. There were no significant differences in protein and lysine. Both selection methods reduced crop index slightly but after the cross the hybrids were improved.

Breeding methods

Both methods did not make any improvement in grain yield in the KCB population. On the contrary $S_1$ method reduced grain yield in the KCE population by 18.0 percent. This reduction was due to inbreeding depression. Reciprocal recurrent selection increased grain yield by 6.81 percent in the case of KCE population *per se*. In hybrids of these populations, $S_1$ method improved grain yield of KCB tm/S/$C_1$ x KCE tm/S/$C_1$ by 34.12 percent over the original cross of KCB tm/$C_o$ x KCE tm/$C_o$. Similarly, reciprocal recurrent selection technique improved grain yield of KCB tm/R/$C_1$ x KCE tm/R/$C_1$ by 48.66 percent over the original KCB tm/$C_o$ x KCE tm/$C_o$. Reciprocal recurrent selection therefore achieved a higher gain than the $S_1$ method within the period of two years.

Effective population size

In Table 44 the effective population size ($\bar{N}$) of the two breeding methods are given. $S_1$ testing method had an effective population of 6.0 compared to 9.23 for the reciprocal recurrent procedure. These values are different and must have contributed to the effectiveness of each method in the improvement of these two populations.

Table 44. Effective population size

| Selection methods | No. of male plants selected | No. of female plants selected | Effective population size |
|---|---|---|---|
| $S_1$ testing | 3 | 3 | 6.0 |
| Reciprocal recurrent | 10 | 3 | 9.23 |

Table 44. Effective population size

| Selection methods | No. of male plants selected | No. of female plants selected | Effective population size |
|---|---|---|---|
| $S_1$ testing | 3 | 3 | 6.0 |
| Reciprocal recurrent | 10 | 3 | 9.23 |

# CHAPTER 5

# DISCUSSION

## Yield and yield components

While yield and weight of 1000 grains varied with locations the number of rows per ear, ear length, number of ears per plant and ear diameter remained unchanged. This indicates that the grain yield and 1000 grain weight are influenced by change in the environments.

Early maturing varieties are generally associated with low grain yield (Johnson 1971). Katumani Composite B reached 50 percent silking in 83.58 days with a grain yield of 43.59 q/ha compared to H 614 that reached 50 percent silking in 108.17 days and a grain yield of 83.68 q/ha in this study. Similarly the normal KCB and KCE populations matured in 110.75 days and 106.67 days, respectively, with grain yields of 81.92 and 68.80 q/ha. When three mutant genes were incorporated the maturity of KCB $br_2o_2su_2$ (101.33 days) and KCE $br_2o_2su_2$ (102.25 days) were reduced and grain yields were also reduced KCB $br_2o_2su_2$ (56.03 q/ha) and KCE $br_2o_2su_2$ 59.98 q/ha. This agrees with the findings of Beauman (1974). However after one cycle of selection using the two

breeding methods, the hybrids of KCB tm/S/$C_1$ x KCE tm/S/$C_1$ (80.37 q/ha) and KCB tm/R/$C_1$ x KCE tm/R/$C_1$ (89.09 q/ha) yielded as well as the best commercial hybrid in Kenya H 614 C (83.68 q/ha) if not better. The high grain yield of the triple mutant hybrids was attributed to the higher number of rows per ear, larger ear diameter and heavier grain weight.

Plant characteristics

Crop index shows the grain producing efficiency of the plant. It is also known as harvest index. Changes in environments did not affect crop index, ear height and plant height. However, the number of leaves per plant and maturity were affected. This means that maturity and number of leaves are sensitive to changes in altitude, rainfall, humidity and other environmental factors - they will, therefore, vary according to the places of selection. Crop index, ear height and plant height are stable and could, therefore, be dependable selection criteria.

Early maturing varieties (Katumani Composite B) tend to be shorter in plant height (179.42 cm) with lower ear placement (76.59 cm) and fewer leaves (11.17) while late maturing populations H 614 C are taller

(309.59 cm) with higher ear placement (170.75 cm) and higher numbers of leaves (16.25).

Grain quality

Both protein and lysine content did not change from one location to another while moisture content did. Therefore selection for protein and lysine quality is not seriously influenced by the ervironment. Normal populations of KCB and KCE had lower lysine content: KCB ++ (2.53 percent), and KCE ++ (2.15 percent). With protein content of KCB ++ (9.89 percent), and KCE ++ (8.86 percent). The triple mutant populations have higher lysine content: KCB $br_2o_2su_2$ (4.28 percent), KCE $br_2o_2su_2$ (4.12 percent) and protein content of 9.21 percent for KCB $br_2o_2su_2$ and 9.4 percent for KCE $br_2o_2su_2$. In this study it is shown that protein percentage remained fairly constant, while lysine content was enhanced by the incorporation of the three mutant genes. This is in agreement with Vasal *et al.* (1979). Selection for lysine will simultaneously improve tryptophane content since there is a very high positive correlation between lysine and tryptophane (Villegas and Mertz 1971).

Reaction to pests and diseases

Rust rating and stem borer infestation did not respond to changes in the environment while blight did. Most of the local material which was incorporated in KCB and to some extent in KCE had a built-in resistance from Storey *et al.* (1958) lines. For stem borer, there has been a blanket use of DDT to control stalk borer in the area for a long time, therefore the population of the pest must have been low. In the case of blight, the level of resistance was low in both KCB and KCE populations. As a result both populations responded highly to blight attack in different environments.

## 5.1. Gene effect

Effect of brachytic-2 gene

Generally brachytic-2 genes when incorporated have reduced plant height and may or may not reduce grain yield (Omolo 1978). Results presented in this study have shown that in KCB population, grain yield was reduced whereas in KCE grain yield was in fact improved. The improvement of KCE $br_2br_2$ over KCE ++ was due to low grain yield reported in Kitale location. Omolo (1977) working with the same population of KCB and KCE, reported that there were

no differences in final grain yield between brachytic-2 and normal counterparts (Appendix 3). Leng (1958) however, reported unfavourable effects of brachytic-2. In his study he worked with corn belt hybrids of medium height. The introduction of brachytic-2 gene in these hybrids lowered the height to the unproductive level. This argument is supported by Johnson (1971) partly when he reported some work that was done at CIMMYT, Mexico, with that very tall tropical material (Tuxpeno) where the dwarfing gene did not affect grain yield adversely.

Brachytic-2 gene was intended to reduce the height, improve lodging resistance and increase crop index. It improved lodging resistance but failed to rectify crop index. It merely compacted the plant, leaving the grain to total dry matter ratio the same. There was no change in leaf number which suggests that the plant had shortened internode and thicker stem. There were also no effects on ears/plant (prolificacy) ear diameter and ear length, except on the number of rows per ear. Selection for reduced plant height as was done by Johnson (1971) has also produced shorter plants with high yields. The advantage of use of brachytic-2 gene over the recurrent selection for reduced plant height is that

once the population is converted it is possible to extract brachytic-2 lines without the necessity of coverting individual lines. Moreover, this trait is highly heritable.

Despite the fact that brachytic-2 may or may not reduce the yield there is still hope that brachytic-2 would improve lodging resistance that may lead to high level of yield recovery at harvest. The plants also being shorter in stature could easily stand higher population (CIMMYT Review 1978). In earlier studies by Omolo (1978) there was no hybrid vigour when KCB and KCE brachytic-2 populations were crossed. The reason for lack of heterosis was not due to brachytic-2 gene but may have been attributed to the introgression of genes from one population to the other that took place at the time of formation of these populations as explained in Section 3.1/3.2. Brachytic-2 gene had no influence on the quality of grains.

Effect of opaque-2 gene

Opaque-2 genes did not affect the protein quantity but improved protein quality of the grain. It has been reported by Mertz,Bates and Nelson (1964)that though opaque-2 improves the overall nutritional quality of

ordinary maize, it has some problems associated with it. Among these are drop in yield, unacceptable appearance due to opaqueness of the grain Fig. 7 that makes the consumers reject it, and susceptibility to diseases and pests. These have been supported in this study as the yield on $KCBo_2o_2$ dropped by 30 percent and $KCEo_2o_2$ by 10 percent. Opaque-2 gene did not interfere with other plant characters such as ear height and plant height, leaf number and days to maturity, but it affected the weight of 1000 grains adversely: KCB ++ (470.0 gm), KCB $o_2o_2$ (372.5 gm), KCE ++ (371.75 gm) and $KCEo_2o_2$ (354.08 gm). Opaque-2 ears were more diseased and plants suffered much more attack by stem borers. The high incidence of disease, low grain weight, few ears per plant must have contributed to the drop in yield.

Effect of modifying factors

It was possible with the populations of opaque-2 to select modified types of grains which had near normal appearance. Modified populations when evaluated earlier by Omolo (1977) (Appendix 7), showed improvement in the grain yield as compared to the original opaque population. In this study a number of grain characters were not significantly

Fig. 7. Grain characteristics of normal (a) opaque (b) double mutant (c) and triple mutant ($br_2o_2su_2$) (d) in KCE.

(a)
(b)
(d)
(c)

interfered with, however grain yield was not significantly improved over the opaque population except in weight of 1000 grains. This is probably due to the instability of the modifying factors. But the level of resistance to diseases and pests was enahanced.

Within a double mutant population selection of the modified grain type was also done. The modified double mutant populations were better than either opaque-2 or brachytic-2 populations in both grain yield and weight of 1000 grains, but were similar to that of KCB ++ and better than KCE ++ populations. This supports the previous findings of Omolo in press (1981) (Appendices 9 and 10). The role played by modifiers was, therefore, realised at double mutant level but not at the individual mutant level. What is still not understood is the role of these modifiers and their inheritance which limits their extensive use (Bauman 1974).

The effect of combining brachytic-2 and opaque-2 genes

Although opaque-2 gene improved nutritional value of the grain, it reduced the grain yield in both populations of KCB and KCE. Their grains were not only lighter in weight but were also much more diseased.

Brachytic-2 gene more or less reduced grain yield, plant and ear height but delayed maturity. When both opaque-2 and brachytic-2 genes were combined grain yield was improved and this improvement could be attributed to the favourable epistatic factors. Protein quality was enhanced and this was definitely due to the presence of opaque-2 gene. Combining the two genes did not improve the resistance to ear rot and stem borer infestation, and this could be explained by the presence of opaque-2 gene. At this level of double mutant, crop index was still just as low as the normal counterparts.

The effect of sugary-2 as a modifier of the double mutant populations

Bauman (1977) working at Purdue, found that double mutant sugary-2 and opaque-2 had several advantages over the ordinary opaque-2 maize. Among these were hard endosperm, good digestibility, good biological value, less ear rot, less damage from storage insect. One disadvantage was small size of the grains that lowered the yield. Similar results have been found in this study. A low yield was realised in KCB ++ (81.92 q/ha), KCB $br_2o_2su_2$ (56.03 q/ha), KCE ++ (68.80 q/ha) and KCE $br_2o_2su_2$

(59.98 q/ha). When the number of rows per ear increased and ear diameter remained constant the grain reduced. The appearance of grains became translucent and shiny due to presence of sugary-2 gene (Fig.7). Weight of 1000 grains was reduced. Sugary-2 gene in combination with brachytic-2 and opaque-2 lowered the height: KCB $br_2br_2$ (269.42 cm), KCB $br_2o_2su_2$ (222.58 cm), KCE $br_2br_2$ (261.08 cm) and KCE $br_2o_2su_2$ (242.42 cm). Crop index was improved: KCB $br_2br_2$ (38.39), KCB $br_2o_2su_2$ (42.91), KCE$br_2br_2$ (35.31) and KCE $br_2o_2su_2$ (42.20). Triple mutant populations showed the next highest values to Katumani Composite B (51.27) particularly when they were crossed KCB $tm/C_o$ x KCE $tm/C_o$ (44.71). After one cycle of selection in each population using the two methods no improvement in grain yield was realised: KCB $tm/S/C_1$ (54.41 q/ha), KCE $tm/S/C_1$ (49.26 q/ha) KCB $tm/R/C_1$ (54.09 q/ha) and KCE $tm/R/C_1$ (64.07 q/ha). However, their hybrids were not only high yielding: KCB $tm/C_o$ x KCE $tm/C_o$ (59.92 q/ha), KCB $tm/S/C_1$ x KCE $tm/S/C_1$ (80.37 q/ha) and KCB $tm/R/C_1$ x KCE $tm/R/C_1$ (89.09 q/ha), but were also much more efficient in partitioning grains to stover (crop index): KCB $tm/C_o$ x KCE $tm/C_o$ (44.71), KCB $tm/S/C_1$ x KCE $tm/S/C_1$ (44.40) and KCB $tm/R/C_1$ x

KCE tm/R/$C_1$ (45.10). The most efficient variety in dry matter accumulation may not necessarily be the highest yielder. This is supported in this study where the triple mutant population realised higher crop index but not higher grain yield unless and until the population had been improved by selection. This finding also agrees with Law„(1974) who reported that H 613 with 1:2 grain to stover ratio gave grain yield of 95 q/ha while Katumani Composite B with 1:1 ratio only had a grain yield of 51.0 q/ha. It indicates that modification using sugary-2 appears more effective than the use of modifiers within the populations of either opaque-2 or double mutants.

## 5.2. Relationship between yield and quality characters

The negative association between yield and quality characters in both opaque-2 and triple mutant populations was noted (Table 38 ). It is therefore not practical to improve both characters in the same population. In this study selection for lysine and yield were carried out separately, first on the basis of high lysine and then based on grain yield. It was found that lines with higher mean yields had lower lysine and tryprophane (Appendix 11).

The relationship between yield and protein was low (r = 0.17) in the case of KCB $o_2o_2$ but negative (r =-0.32*) in the case of KCE $o_2o_2$. There was none or very little association between protein and yield. The little that was there, was in fact negatively related. This is supported by Wolfram and Ochieng' (1978) who reported that correlation coefficient in Kitale Synthetic II, and Ecuador 573 of protein to lysine was -0.28 and -0.33 respectively. In their conclusion they noted that such negative association, though low, underlined the importance of care that must be taken in breeding efforts to improve the two.

## 5.3. Predicted genetic gains

When t-test was run to test the null hypothesis Ho: Predicted gains = Observed it was rejected which meant that there were significant differences between the two values.

KCE population had a higher predicted gain (6.6 q/ha) than KCB (2.56 q/ha) while the difference between expected and observed yield was much greater in KCB (22.52 q/ha) than in KCE (11.02 q/ha). It means that selection based on predicted data would give more response to selection with KCE population

than KCB. Reciprocal recurrent selection made much more genetic gains than $S_1$ testing method.

The main difference between the two recurrent selection methods is that $S_1$ testing method is an intrapopulation selection while Reciprocal recurrent method is an interpopulation selection procedure (Darrah, Eberhart and Penny 1972). Later on Darrah, Eberhart and Penny (1976) reported after four years of reciprocal recurrent selection and $S_1$ testing, among other methods, that reciprocal recurrent technique made rapid improvement in Ecuador which was a constituent of KCE. The improved strain of Ec. 573 was used as a male parent of the current Kenya commercial hybrid, H 613.

Population improvement

KCB population did not make any improvement, KCE population on the other hand made a definite improvement through reciprocal recurrent selection. The hybrids between the two populations, developed through $S_1$ testing and Reciprocal selection method, registered a tremendous improvement over their original population cross. Reciprocal recurrent selection made 48.66 percent improvement compared to the 34.12 percent from $S_1$ improved population. KCE made a much bigger improvement than KCB, the

explanation could be the fact that KCE is exotic and much more variable than KCB which has already been selected (mainly locally adapted material). This argument is supported by previous work of Eberhart, Harrison and Ogada (1967) who found that Kitale Synthetic II responded less to the improvement because of adaptability than Ecuador 573 which was unadapted.

Efficiency of the breeding method

Reciprocal recurrent selection was much more efficient than $S_1$ testing. It made a much higher improvement (48.66 percent) compared to 34.12 percent that of $S_1$ method. On genetic gains, reciprocal recurrent selection method made a faster gain (5.39 q/ha) when compared to $S_1$ method (3.77 q/ha). The extreme variation of estimates (Table 41) particularly of genetic variance components, and pooled error variance component showed that reliable estimates could be obtained by multilocation and multiseason experiments because variation among locations and between seasons would even out when all the results are pooled together.

The large amount of heterosis obtained suggest that there existed different gene frequencies at many

loci. $S_1$ testing being an intrapopulation improvement technique must have relied wholly on the exploitation of the additive gene type of action while reciprocal recurrent selection procedure depended on both additive and non-additive gene action.

Effective population size

The difference between the two methods could also be explained by the effective population size which reflects the response to the inbreeding difference observed or the variance of the random deviation of gene frequencies and rate of decay.

In an ideal population, there are N breeding individuals, half of them females and the other half males. Mating at random the variance of the random deviation of gene frequency is q (1-q)2N and the rate of decay is $\frac{1}{2}$N, (Li 1955). The heterozygosity in $S_1$ group of 6 breeding individuals decreased or decayed faster than the decay in the reciprocal recurrent selection where 13 individuals were involved. The 6 individuals in $S_1$ method was in fact 3 because the same three plants were self-pollinated.

## CONCLUSION

1. Brachytic-2 gene may or may not improve grain yield, depending on the background of the population. It definitely reduced plant height, ear height and increased lodging resistance, and maintained the leaf number per plant. It also failed to improve crop index. Opaque-2 gene improved nutritional value, lowered the grain yield, and made grains much more susceptible to pests and diseases. Selections for modifying factors were unstable. The benefit from favourable epistatic factors was realised from double mutant populations, but at triple mutant level tremendous improvement was shown particularly with the hybrids from both selection methods.

2. The relationship between yield and quality traits was negative and low, which underlines the importance of care that must be taken when breeding to improve both in a single population.

3. KCE population made faster genetic gains than KCB. Comparison of genetic gains indicated that reciprocal recurrent selection method was much more efficient than $S_1$ testing method.

4. Introgression of genes from KCB population into KCE and vice versa affected their response to heterosis adversely in original population, however after one cycle of selection in both $S_1$ testing and reciprocal recurrent selection methods the population improved.

5. Programmes geared for the release of open-pollinated varieties, may have a choice between $S_1$ testing and Reciprocal recurrent selection method, depending on the skill of labour and available resources. However, a breeding programme for hybrid production reciprocal recurrent selection method is most appropriate.

6. It would be difficult to encourage the production of high protein quality maize if it yielded less than normal maize. In this project therefore the emphasis was placed on improving protein quality without sacrificing the yield. The results of this study clearly indicate that the yield performance of triple mutant hybrids was equal to the best commercial hybrid grown in Kenya: KCB tm/S/$C_1$ x KCE tm/S/$C_1$ (80.37 q/ha),

KCB tm/R/$C_1$ x KCE tm/R/$C_1$ (89.09 q/ha), H 614 C 83.68 q/ha) and as good as the normal counterparts, KCB ++ (81.92 q/ha) and KCE ++ (81.79 q/ha).

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# APPENDICES

Appendix 1: Production of maize in Kenya from 1963 to 1976.

| Year | Grain handled by Maize & Produce Board (metric tons) | Imports | Exports |
|---|---|---|---|
| 1963 | 200,968 | - | - |
| 1964 | 96,576 | - | - |
| 1965 | 105,332 | 35,801 | - |
| 1966 | 132,690 | 191,766 | - |
| 1967 | 225,772 | - | |
| 1968 | 322,340 | - | 64,530 |
| 1969 | 292,112 | - | 90,000 |
| 1970 | 193,654 | - | - |
| 1971 | 240,108 | 13,318 | - |
| 1972 | 379,022 | 26,815 | 19,269 |
| 1973 | 457,435 | - | 219,348 |
| 1974 | 335,407 | - | - |
| 1975 | 499,230 | 21,600 | - |
| 1976 | 555,668 | - | 118,710 |

Source: Maize & Produce Board

Appendix 2: Performance of different maize composite, hybrids and their parents at Kakamega, West Kanya

| Population | Mean yield (q/ha) | Percent improvement over cycle zero |
|---|---|---|
| KCB $C_o$ | 42.6 | 100 |
| KCB(S) $C_1$ | 47.2 | 111 |
| KCB (F) $C_1$ | 46.3 | 109 |
| KCB (F) $C_2$ | 44.1 | 103 |
| KCE $C_o$ | 46.9 | 100 |
| KCE (S) $C_1$ | 36.3 | 77 |
| KCE (F) $C_1$ | 47.6 | 101 |
| KCE (F) $C_2$ | 49.7 | 106 |
| KCB $C_o$ x KCE $C_o$ | 46.1 | 98 |
| KCB (S) $C_1$ x KCE (S) $C_1$ | 48.3 | 103 |
| KCB (F) $C_1$ x KCE (F) $C_1$ | 47.5 | 101 |
| KCB (F) $C_2$ x KCE (F) $C_2$ | 46.1 | 93 |
| KCB $C_o$ x KCF (M) $C_o$ | 42.0 | 99 |
| KCE $C_o$ x KCF (M) $C_o$ | 44.1 | 94 |
| Kitale Synthetic II $C_o$ | 37.4 | 100 |
| Kitale Synthetic II (E) $C_1$ | 40.6 | 108 |
| Ecuador 573 $C_o$ | 29.0 | 100 |
| Ecuador 573 (E) $C_1$ | 41.7 | 144 |
| Kitale II x Ecuador 573 (H611)$C_o$ | 53.1 | 100 |
| H661 (R) $C_1$ | 61.4 | 116 |
| H661 (R) $C_2$ | 75.1 | 141 |
| H661 (R) $C_3$ | 76.1 | 143 |
| H632 | 43.6 | - |
| Mean | 44.5 | |
| LSD (P = 0.05) | 4.5 | |

Source: National Agricultural Research Station - Kitale Annual Report 1972

Appendix 3: Effect of brachytic-2 gene on yield and other characters in different populations of maize

| Population | Genotype | Yield (q/ha) | %root lodging | usable ears | diseased ears | ear height (cm) |
|---|---|---|---|---|---|---|
| KCB (S) $C_o$ | ++ | 66.1 | 22.1 | 96.4 | 5.2 | 209.7 |
| KCB (F) $C_1$ | ++ | 69.9 | 21.1 | 100.0 | 3.8 | 204.3 |
| KCB $C_o$ | $br_2br_2$ | 72.9 | 17.5 | 100.0 | 3.5 | 166.5 |
| KCB (R) $C_o$ | ++ | 43.4 | 17.5 | 90.5 | 10.5 | 195.6 |
| KCE (F) $C_o$ | ++ | 46.8 | 25.9 | 84.2 | 10.3 | 193.9 |
| KCE $C_o$ | $br_2br_2$ | 52.2 | 24.7 | 87.1 | 5.2 | 178.4 |
| KCE (S) $C_o$ | ++ | 47.6 | 25.9 | 73.9 | 9.3 | 192.7 |
| KCE (R) $C_o$ | ++ | 36.3 | 20.6 | 89.9 | 5.3 | 200.3 |
| KCB (S) KCE (S) | ++ | 61.0 | 18.1 | 88.6 | 11.9 | 189.5 |
| KCB (F) KCE (F) | ++ | 57.1 | 18.2 | 90.9 | 4.5 | 192.9 |
| KCB $C_o$ x KCE | $br_2br_2$ | 57.3 | 17.6 | 99.5 | 4.3 | 179.0 |
| KCB (R) x KCE (R) | ++ | 52.9 | 18.5 | 98.9 | 7.0 | 191.2 |
| H 611 C | ++ | 63.8 | 16.2 | 98.1 | 5.1 | 204.5 |
| Mean | | 57.1 | 20.5 | 93.4 | 6.2 | 194.6 |
| LSD (P = 0.05) | | 11.4 | 10.7 | 10.5 | 2.2 | 17.9 |

Source: Omolo (1978)

Appendix 4: Amino acids in endosperm (E) and whole kernels (K) of normal and high lysine maize grams/100 g protein

| Amino acid | W64A | | W64A (K) | |
|---|---|---|---|---|
| | ++ | $o_2o_2$ | ++ | $o_2o_2$ |
| Lysine | 1.6 | 3.7 | 3.0 | 4.8 |
| Tryptophan | 0.6 | 1.2 | 0.7 | 1.3 |
| Histidine | 2.9 | 3.2 | 2.6 | 3.3 |
| Arginine | 3.4 | 5.2 | 4.9 | 8.5 |
| Aspartic acid | 7.0 | 10.8 | 9.2 | 10.8 |
| Glutanic acid | 26.0 | 19.8 | 22.6 | 17.5 |
| Threonine | 3.5 | 3.7 | 4.1 | 4.0 |
| Serine | 5.6 | 4.8 | 5.6 | 4.8 |
| Proline | 8.6 | 8.6 | 9.6 | 7.6 |
| Glycine | 3.0 | 4.7 | 4.7 | 4.8 |
| Alanine | 10.1 | 7.2 | 9.2 | 6.6 |
| Valine | 5.4 | 5.3 | 5.7 | 5.1 |
| Cystine | 1.8 | 1.8 | 1.7 | 1.7 |
| Methionine | 2.0 | 1.8 | 1.3 | 2.1 |
| Isoleucine | 4.5 | 3.9 | 4.2 | 3.4 |
| Leucine | 18.8 | 11.6 | 14.6 | 9.1 |
| Tyrosine | 5.3 | 3.9 | 5.2 | 4.0 |
| Phenylalanine | 6.5 | 4.9 | 5.8 | 4.5 |
| | | | Percent protein | |
| | 12.7 | 11.1 | 9.0 | 11.6 |

Source: Mertz *et al.* (1964)

Appendix 5: Protein quality of Kitale composite maize

| Population | Genotype | % protein | %improvement | Lysine index | %improvement |
|---|---|---|---|---|---|
| KCB | ++ | 9.7 | 100 | 0.17 | 100 |
| KCB | $o_2o_2$ | 11.3 | 116 | 0.27 | 159 |
| KCE | ++ | 10.2 | 100 | 0.19 | 100 |
| KCE | $o_2o_2$ | 10.1 | 99 | 0.29 | 153 |
| Mean | | 10.3 | | 0.23 | |
| SE $\pm$ | | 0.83 | | 0.06 | |

Source: Omolo (1977)

Appendix 6: Combined mean data of maize composites, varieties and their hybrids

| Variety | Genotype | Yield (q/ha) | % RL | EH cm | % DE | wt. of 1000 grains (gm) |
|---|---|---|---|---|---|---|
| KCB | ++ | 42.6 | 22.9 | 220.0 | 14.7 | 405.5 |
| KCE | ++ | 46.9 | 24.6 | 231.0 | 24.5 | 397.5 |
| KCE x KCE | ++ | 46.1 | 23.9 | 210.0 | 15.4 | 411.2 |
| KCB x KCE | $o_2o_2$ | 34.7 | 30.6 | 212.0 | 35.2 | 315.1 |
| Kitale II | ++ | 37.4 | 17.7 | 225.0 | 21.1 | 380.0 |
| Ec. 573 | ++ | 29.0 | 37.0 | 232.0 | 16.7 | 438.8 |
| Kit. II x Ec. 573 | ++ | 56.0 | 27.0 | 217.0 | 14.8 | 450.3 |
| H 632 (Comm) | ++ | 43.6 | 17.9 | 210.0 | 18.9 | 415.8 |
| Mean | | 44.3 | 25.2 | 219.6 | 20.2 | 401.8 |
| LSD (P = 0.05) | | 4.5 | 8.5 | 9.0 | 10.5 | 59.2 |

Source: Omolo (1977)

RL = root lodging
EH = ear height
DE = discard ear

Appendix 7: Combined mean data of opaque-2 hybrid maize and modified grain

| Hybrids | Genotype | Yield (q/ha) | | Combined |
|---|---|---|---|---|
| | | NARS | Top farm | |
| H 611 | ++ | 84.4 | 93.5 | 89.0 |
| | $o_2o_2$ | 61.2 | 79.1 | 70.1 |
| | $o_2o_2$ (modified) | 86.7 | 89.6 | 88.1 |
| Mean | | 77.4 | 87.4 | 82.4 |
| LSD (P = 0.05) | | 6.7 | 6.9 | 8.2 |

Source: Omolo (1977)

Appendix 8: Protein quality analysis of composite maize populations

| Variety | Genotype | % protein | % tryptophan | | % lysine | |
|---|---|---|---|---|---|---|
| | | | of total dry matter | of protein | of total dry matter | of protein |
| Kitale Composite B | ++ | 8.1 | 0.062 | 0.77 | 0.228 | 2.81 |
| | $o_2o_2$ | 6.5 | 0.078 | 1.20 | 0.305 | 4.69 |
| | $o_2o_2$(m) | 7.6 | 0.107 | 1.41 | 0.282 | 3.71 |
| | $br_2br_2$ | 7.5 | 0.073 | 0.97 | 0.211 | 2.81 |
| | $br_2br_2/o_2o_2$ | 7.1 | 0.107 | 1.51 | 0.258 | 3.63 |
| | $br_2br_2/o_2o_2$(m) | 8.1 | 0.083 | 1.02 | 0.223 | 2.75 |
| Kitale Composite E | ++ | 8.2 | 0.091 | 1.11 | 0.230 | 2.80 |
| | $o_2o_2$ | 5.8 | 0.087 | 1.50 | 0.223 | 3.84 |
| | $o_2o_2$(m) | 7.1 | 0.055 | 0.77 | 0.235 | 3.31 |
| | $br_2br_2$ | 8.8 | 0.082 | 0.93 | 0.230 | 2.61 |
| | $br_2br_2/o_2o_2$ | 8.8 | 0.088 | 1.00 | 0.294 | 3.34 |
| | $br_2br_2/o_2o_2$(m) | 7.7 | 0.080 | 1.04 | 0.235 | 3.05 |
| Mean | | 8.3 | 0.083 | 1.10 | 0.246 | 3.11 |

Source: Omolo (1981)

(m) = modified genotype.

Appendix 9: Combined mean data of double mutant maize composites evaluated over two sites in Kitale - 1974

| Variety | Genotype | NARS | | Top Farm | | Combined | |
|---|---|---|---|---|---|---|---|
| | | Yield (q/ha) | Lod % | Yield (q/ha) | Lod % | Yield (q/ha) | Lod % |
| KCB | ++/++ | 88.9 | 40.5 | 63.9 | 50.3 | 76.4 | 45.4 |
| KCB | $br_2br_2/o_2o_2$ | 64.1 | 43.9 | 42.5 | 49.4 | 53.3 | 46.6 |
| KCB | $br_2br_2/o_2o_2$ (mod) | 78.3 | 24.4 | 65.3 | 71.8 | 39.5 | |
| Mean | | 77.1 | 36.3 | 57.2 | 51.4 | 67.2 | 43.8 |
| LSD (P = 0.05) | | 7.3 | 6.7 | 7.4 | 3.4 | 7.2 | 3.3 |
| KCE | ++/++ | 82.1 | 47.2 | 53.5 | 51.5 | 67.8 | 49.3 |
| KCE | $br_2br_2/o_2o_2$ | 56.2 | 25.0 | 32.8 | 47.1 | 44.5 | 36.1 |
| KCE | $br_2br_2/o_2o_2$ (mod) | 74.0 | 20.2 | 56.4 | 58.0 | 65.2 | 39.1 |
| Mean | | 70.8 | 30.8 | 47.6 | 52.2 | 59.2 | 41.5 |
| LSD (P = 0.05) | | 7.5 | 10.5 | 7.4 | 4.9 | 7.6 | 5.4 |
| Overall mean | | 73.9 | 33.5 | 52.4 | 51.8 | 63.2 | 42.7 |

mod - modified genotype

Source: Omolo, (1981)

Appendix 9: Combined mean data of double mutant maize composites evaluated over two sites in Kitale - 1974

| Variety | Genotype | NARS | | Top Farm | | Combined | |
|---|---|---|---|---|---|---|---|
| | | Yield (q/ha) | Lod % | Yield (q/ha) | Lod % | Yield (q/ha) | Lod % |
| KCB | ++/++ | 88.9 | 40.5 | 63.9 | 50.3 | 76.4 | 45.4 |
| KCB | $br_2br_2/o_2o_2$ | 64.1 | 43.9 | 42.5 | 49.4 | 53.3 | 46.6 |
| KCB | $br_2br_2/o_2o_2$ (mod) | 78.3 | 24.4 | 65.3 | 71.8 | 39.5 | |
| Mean | | 77.1 | 36.3 | 57.2 | 51.4 | 67.2 | 43.8 |
| LSD (P = 0.05) | | 7.3 | 6.7 | 7.4 | 3.4 | 7.2 | 3.3 |
| KCE | ++/++ | 82.1 | 47.2 | 53.5 | 51.5 | 67.8 | 49.3 |
| KCE | $br_2br_2/o_2o_2$ | 56.2 | 25.0 | 32.8 | 47.1 | 44.5 | 36.1 |
| KCE | $br_2br_2/o_2o_2$ (mod) | 74.0 | 20.2 | 56.4 | 58.0 | 65.2 | 39.1 |
| Mean | | 70.8 | 30.8 | 47.6 | 52.2 | 59.2 | 41.5 |
| LSD (P = 0.05) | | 7.5 | 10.5 | 7.4 | 4.9 | 7.6 | 5.4 |
| Overall mean | | 73.9 | 33.5 | 52.4 | 51.8 | 63.2 | 42.7 |

mod - modified genotype

Source: Omolo, (1981)

Appendix 10: Mean data of double mutant maize composite crosses evaluated in Nyanza, Western and Rift Valley Provinces in Kenya during 1975

| Variety | Genotype | Provinces | | | | | | | | | Mean | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Nyanza | | | Western | | | Rift Valley | | | | | |
| | | YL (q/ha) | RL % | EH (cm) | YL (q/ha) | RL (%) | EH (cm) | YL (q/ha) | RL (%) | EH (cm) | YL (q/ha) | RL (%) | EH (cm) |
| KCB × KCE | ++/++ | 39.5 | 34.2 | 176.7 | 67.4 | 70.3 | 228.0 | 65.7 | 31.6 | 222.6 | 57.5 | 45.4 | 209.1 |
| KCB × KCE | $br_2br_2/o_2o_2$ | 36.8 | 37.6 | 134.1 | 69.5 | 70.9 | 195.0 | 55.8 | 35.2 | 198.6 | 54.0 | 47.9 | 175.9 |
| KCB × KCE | $br_2br_2/o_2o_2$ (mod) | 32.3 | 39.2 | 142.3 | 44.5 | 78.8 | 184.3 | 52.2 | 38.6 | 191.9 | 43.0 | 52.2 | 172.8 |
| Mean | | 36.2 | 37.0 | 151.0 | 60.5 | 73.3 | 202.4 | 57.9 | 35.1 | 137.7 | 51.5 | 48.0 | 185.9 |
| LSD (P = 0.05) | | 9.5 | 16.8 | 13.5 | 30.7 | 25.1 | 7.21 | 10.0 | 14.0 | 23.1 | 16.7 | 18.0 | 14.6 |

Source: Omolo, (1981)

YL = Yield
RL = Root lodging
EH = Ear height

Appendix 11: Yield and quality character of KCB and KCE triple mutant population

| Population | Sample no. | Progeny | Lysine content | Yield (q/ha) | Lysine ha (kg) | Rank |
|---|---|---|---|---|---|---|
| KCB tm $C_o$ | 1 | 15 | 4.01 | 42.4 | 172.02 | 5 |
| | 2 | 95 | 4.28 | 28.7 | 122.84 | 9 |
| | 3 | 12 | 4.42 | 40.4 | 178.57 | 4 |
| | 4 | 87 | 3.76 | 15.3 | 57.53 | 10 |
| | 5 | 79 | 4.09 | 31.9 | 130.47 | 8 |
| | 6 | 24 | 2.40 | 58.1 | 139.44 | 6 |
| | 7 | 39 | 3.29 | 42.3 | 139.18 | 7 |
| | 8 | 25 | 2.31 | 92.9 | 214.60 | 3 |
| | 9 | 22 | 2.34 | 99.4 | 232.60 | 1 |
| | 10 | 19 | 2.26 | 101.6 | 229.62 | 2 |
| KCE tm $C_o$ | 1 | 58 | 1.92 | 74.7 | 143.42 | 4 |
| | 2 | 88 | 1.90 | 83.4 | 158.46 | 3 |
| | 3 | 65 | 4.69 | 14.1 | 66.13 | 10 |
| | 4 | 74 | 3.71 | 82.0 | 304.22 | 1 |
| | 5 | 81 | 3.63 | 27.8 | 100.91 | 6 |
| | 6 | 83 | 4.05 | 28.3 | 114.61 | 5 |
| | 7 | 84 | 2.37 | 82.0 | 67.07 | 9 |
| | 8 | 71 | 2.47 | 79.9 | 197.35 | 2 |
| | 9 | 80 | 3.85 | 23.1 | 83.93 | 8 |
| | 10 | 16 | 4.27 | 21.8 | 93.09 | 7 |

Source: Omolo (1981).