EVALUATION OF RICE (*Oryza sativa L.*) GENOTYPES FOR ADAPTABILITY TO HEAT STRESS UNDER CONTROLLED CONDITIONS IN MOROGORO

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN CROP SCIENCE OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

ABSTRACT

A study was conducted in the 2012/13 growing season, at Horticulture unit screen house and heat chamber at African Seed Health Centre in the Department of Crop Science and Production at Sokoine University of Agriculture. Morogoro. The aim of this study was to evaluate rice genotypes for adaptability to heat stress under controlled conditions in Morogoro, whereas, mutant rice genotypes originating from Kihogo red (Local variety), CG 14 (*O.glaberrima*), WAB 56-50 and WAB 56-104 (*O. sativa*) were evaluated. The results from screening of rice mutant lines which were subjected to heat stress at 45°C for different days of exposure showed variation in survival among genotypes tested. The survived rice seedlings were laid out as pot experiments in a completely randomized Design with three replications in the screen house. Data collected included plant survived from heat chamber, Days to 50% flowering, Tiller number per plant, panicle number per plant, plant height, panicle length, number of spikelets per plant, percentage sterility, 1000 grain weight, and grain yield per plant. Data were subjected to the analysis of variance (ANOVA). The results revealed that there were significant differences among the genotypes for all traits studied. In this study the effects of temperature were observed in plant height, Days to 50% flowering, panicle length, number of spikelets per panicle, 1000 grain weight, in almost all mutants whereas, grain yield of WAB 45-104 and 56-50 mutants were affected significantly. Also the following traits were favored by high temperature; Percent sterility, number of panicles per plant, number of tillers per plant and grain yield per plant for Kihogo red and CG 14. The phenotypic screen revealed the following mutants lines to be heat tolerant; KR 37, CG-14-7, CG 14-13,

CG 14-16, WAB 56-104-36, WAB 56-104-43, WAB 56-104-82, WAB 56-104-40, WAB 56-104-12, WAB 56-104-123, WAB 56-104-181, WAB 56-50-82 and WAB 56-50-132. Therefore these lines could be grown in the area where temperature exceeded the normal range for rice cultivation.

DECLARATION

I, **RAJABU VITTA MASANCHE** do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

19. 11. 2014

RAJABU VITTA MASANCHE **Date**

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The above declaration is confirmed by;

19/11/2014

Dr. Ashura Luzi- Kihupi **Date**

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This study is dedicated to my late mother for sending me to school. To my wife Jamila Issa, my daughters Jaalia and Laina for their love, moral support and endurance throughout the duration of my study.

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LIST OF SYMBOLS AND ABBREVIATIONS

ANOVA	Analysis of variance
Cntrl	Control
CO_2	Carbon dioxide
CRD	Completely randomized design
CV	Coefficient of variance
DES	Diethyl sulphate
Df	Degree of freedom
DMRT	Duncan's multiple range tests
DNA	Deoxyribonucleic acid
EMS	Ethyl methane sulphonate
FAO	Food and Agriculture Organization of United Nation
FAOSTAT	Food and Agriculture Organization Statistics
g	grammes
GWT	Grain weight
GY	Grain yield
IRRI	International Rice Research Institute
K	Potassium
KR	Kihogo Red
MAFC	Ministry of Agriculture Food security and Coo- operative
MSTATC	Michigan State University Computer Software
N/ha	Nitrogen/hectare
NP	Number of panicle
NS	Number of spikelets

CHAPTER ONE

1.0 INTRODUCTION

Rice (*Oryza sativa L.*) is an annual grass which belongs to the genus *Oryza*, family *Graminae*. There are about 23 species of the genus oryza, out of which only two species are cultivated. These are *Oryza sativa* L. and *Oryza glaberima.* Stend. The later which is indigenous to West Africa is being replaced by the introduced Asian species of rice, *O. sativa* which is the most commonly grown species throughout the world, (IRRI, 1988; FAO, 1994).

Rice is very important staple food in Tanzania and ranks second after Maize (Kanyeka, 1996) and in recent years it is becoming a cash crop. The demand of rice has substantially increased over the years due to increase in human population, change in eating habits as well as the rapid urbanization (Ching'ang'a, 1985). However rice production has decreased due to global climatic change, especially heat stress (Kanyeka, 1996). According to MAFC (2010) the current average yield in Tanzania is still low, ranging from 1-2.33 t/ha, compared to the average yield in the world which is 4.5 t/ha. There are many factors which hinder production of rice in Tanzania, these include biotic and abiotic constraints, The biotic factors are pest and diseases, while abiotic factors include, drought, soil (salinity), lack of improved varieties and temperature (Cold and heat stresses) (Ashwa and Sundhir, 2010).

Based on climatic changes, temperature becomes the most environmental factor which contributes much in reduction of rice production, due to its effect on the different growth stages of rice (Kanyeka, 1996) The optimum temperatures for rice growth at different stages, ranges from 20 ^{0}C to 33 ^{0}C. Above that it may cause spikelet sterility, which leads to low rice yield (Peng *et al.*, 2004). Global warming has significant effect on crop production including rice, whereby increase in temperature and drought conditions has been observed.

It has been estimated that by the year 2100, average temperature will increase between 1.4-5.8^{0}C especially in tropical region, such as Tanzania (URT, 1989). High temperature is a constraint to rice production because rising temperature during the past 25 years has cut down the yield growth and rate of rice by 10-20% in several locations (FAO, 2012). Two reproductive development stages in rice viz anthesis and microsporogenesis are very sensitive to high temperature above 33^{0}C, whereby extreme temperatures affect anther dehiscence, pollination and pollen germination, leading to spikelet sterility. The most damaging effect of high temperature is increase in pollen sterility and poor seed set. Just one or two hours of abnormal high temperature at anthesis a days before heading and at heading, result in a large percentage of sterility (Thangapandian *et al.,* 2010). It is therefore imperative that new rice varieties that can withstand higher temperatures are developed in order to avoid reduction of rice production over the next few decades as days and night get hotter (FAO, 2012). There is a need to develop an approach to increase rice production in the face of climate change. One of the techniques is to develop rice varieties that can cope with challenges of climatic change. Another technique is to improve crop management by developing more resilient rice production system, this will include mutation induction, where by there are some agents which induce genetic variation, and this have been used since the early part of the 20th century to assist in the development of new rice cultivars by increasing genetic diversity of rice germplasms in the breeding programs. Two types of mutagens have been used to induce genetic variation these are; ionizing radiation (e.g. X-rays and gamma rays) and mutagenic chemicals (e.g. Ethyl Methane Sulphonate (EMS), Diethyl sulphate (DES) and Ethyleneimine (EI). In this study the type of mutagen which was used to induce genetic variation was gamma rays from Cobalt 60. Kihogo red, CG 14 and WAB56-50 seeds, were irradiated with 150 GY while WAB 56-104 seeds were irradiated with 200 GY of gamma rays.

1.1 Objectives

1.1.1 Overall objective

The overall objective of the study was to identify and recommend rice genotypes that can adapt to heat stress condition in order to increase rice production.

1.1.2 Specific objectives

i. To determine recovery of rice plants which are subjected to high temperature

ii. To screen and identify mutant lines of rice which are heat tolerant using morphological traits

iii. To study the yield and yield component variation among the mutant lines which are tolerant to heat stress

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Rice Production

Rice (*Oryza sativa L.*) originated from South-East Asian, particularly India and Indo-China, where the richest diversity of cultivated forms, has been recorded. About 90 percent of the rice production takes place in the tropical/sub-tropical Asia where more than 60 percent of the world population lives. It is the major staple for more than half of the world's population (FAO, 2013), accounting for approximately 30 percent of the total dietary intake, globally and in South Asia (Lobell *et al.*, 2008). In the world, major producing countries are China, India, Indonesia, Bangladesh, Vietnam, Thailand, Philippines and Brazil. In Africa, rice is suggested to have been introduced by the Indian and Portuguese traders who visited the Coastal area in the early times (Kaung zan *et al.*, 1985). In Africa, production has grown rapidly. West Africa is the main producing sub region, accounting for more than 45% of African production in 2008-10. In terms of individual countries, the leading producers of paddy between 2008-10 are; Egypt (5.7 million t), Nigeria (3.6 million t), and Madagascar (4.4 million t). (FAOSTAT, 2012).

Rice is a staple food in many countries of Africa and constitutes a major part of the diet in many others. During the past three decades the crop has seen consistent increases in demand and its growing importance is evident in the strategic food security planning policies of many countries. With the exception of a few countries that have attained self-sufficiency in rice production, rice demand exceeds production and large quantities of rice are imported to meet demand at a huge cost in hard currency. Africa consumes a total of 15.27 million tonnes of milled rice per year (FAO, 2013), of which 6.12 million tonnes is imported. As many as 21 of the 39 rice-producing countries in Africa import between 50 and 99 percent of their rice requirements. The distribution of rice importation on a regional basis appears skewed, with the North and Central Africa regions setting the lower (1.7 %) and upper (71.7%) limits, respectively (World rice production, 2010).

In Tanzania rice has been grown since the early 1900' s. Rice farming was introduced in Tanzania during the period of German colonization of 1884-1918. Over time, rice has become an important staple food for about 60% of the population. An estimated 18% of agricultural families grow rice and it contributes to 2.66% of national GDP (FAO, 2013). Rice is grown under three major ecosystems, namely rain-fed lowlands, uplands and the irrigated systems. Virtually all rice (99%) is grown by smallholders in Tanzania who operate on farm sizes of 0.5-3 hectares. However, some of them are part of large – scale rice irrigation schemes that were formerly state managed farms. Tanzania is the second largest rice producer in Eastern, Central and Southern Africa after Madagascar, with production level of 1 104 890 tones (FAOSTAT, 2011). The most rice producing Regions in Tanzania are Tabora Morogoro, Mbeya Mwanza, Arusha, Shinyanga, Kigoma and Rukwa (MAFC, 2012).

Table 1: Leading Paddy Production Regions in Tanzania

Regions	Paddy production in metric tonnes '000.
Tabora	158
Morogoro	138
Mbeya	138
Mwanza	119
Arusha	111
Shinyanga	96
Kigoma	65
Rukwa	62

Source: FAO 2012.World rice statistic report.

Table 2: Annual Rice Production trends in Tanzania (2005-2011)

Year	Area (ha)	Production in metric ton '000	Yieldon/ha.
2005	701.99	778.46	1.66
2006	633.77	804.1	1.90
2007	557.98	894.57	2.40
2008	896.02	947.05	1.59
2009	805.63	889.87	1.66
2010	1 136.29	1 766.75	2.33
2011	1 119.32	1 498.88	2.01

Source: FAO 2012 World Rice statistics

2.2 Climatic Requirements

Rice crop is best suited to tropical and sub-tropical humid climate but it is grown in variety of climate except extreme cold temperate. The climatic factors that affect rice production are temperature, day length and humidity.

2.2.1 Temperature

The average temperature required throughout the life period of the crop ranges from 21 to 37^{0}C. At the time of tillering the crop requires a higher temperature than for growth. Temperature requirement for blooming is in the range of 26.5 to 29.5^{0}C. At the time of ripening the temperature should be between 20-25^{0}C. Photoperiodically, rice is a short-day plant. However, there are varieties which are non-sensitive to photoperiodic conditions (IRRI, 2007).

2.2.2 Soil

Rice can be grown in all type of soils like light to heavy soil, except very sandy. Clay, silt clay, silt clay loam, textures of soil are best for Paddy crop cultivation due to its high water holding capacity. It grows well in soils having a pH range between 5.5 and 6.5. Flat fields having smooth surface are better for rice cultivation as it facilitates even and equal distribution of water.

2.2.3 Rainfall

Rice cultivation is possible only in areas with good rainfall, as the crop requires standing water for growth. A monthly rainfall of 100-200 mm is a must and about 125 cm is required during vegetative season, while there should be no water at ripening stage (Pattanayak and Kumar, 2013). Most rice is currently grown in regions where current temperatures are already close to optimum for rice production. Therefore, any further increases in mean temperatures or of short episodes of high temperatures during sensitive stages may be supra-optimal and reduce grain yield (Shah *et al.*, 2011). It has been estimated that yield of rice will be reduced by 41% by the end of the 21st Century (Ceccarelli *et al.*, 2010). There is sufficient evidence that increasing night-time temperature has been the main cause of increases in global mean temperatures since the middle of the 20th Century and is thus the main factor contributing to the yield decrease (Kukla and Karl, 1993; Zisks and Manalo 1996; Peng *et al*., 2004; Sheehy *et al*., 2005).

2.3 Rice Growth Stages

The growth of a rice plant can be broadly divided into three phases: vegetative, reproductive and ripening phase (grain filling) (Maclean *et al.,* 2002). The vegetative phase starts at seed establishment (germination) and ends at the onset of panicle initiation during the late vegetative phase. The number of days in this phase varies in different varieties. For example, the 120-day rice variety will have 55 days in the vegetative phase, while the 150-day variety may take 85 days. Further, low temperature or long day length can increase the duration of the vegetative phase. The reproductive phase begins at panicle initiation and ends at flowering, usually taking 35 days. At this phase, the plant is most sensitive to stresses such as low and high temperatures, and drought. The number of days in the reproductive phase and the ripening phase are the same among most rice varieties. The ripening phase starts at flowering and ends at maturity. This stage usually takes 30 days. Rainy days or low temperatures may lengthen the ripening phase, while sunny and warm days may shorten it. Dingkuhn and Kropff, (1996) reported that the genotype of the rice plant largely defines the characteristics of each phase, although the growth environment of the plant also contributes to the overall source sink dynamics of the plant.

2.4 Effects of High Temperatures

High temperature stress is one of the most important environmental factors influencing crop growth, development, and yield processes. High temperature stress is defined as the rise in temperature beyond a critical threshold for a period of time sufficient to cause irreversible damage to plant growth and development (Shah *et al.*, 2011). Heat stress is considered to be one of the major environmental factors limiting crop growth and yield. The high temperatures during sensitive growth phases are changing rice morphology as well as influencing yield. This stress induces biochemical, molecular, and physiological changes and responses that influence various cellular and whole plant processes that affect crop yield and quality. Heat stress affects plants on various physiological growths, development, and yield processes. It causes detrimental effects on growth, yield, and quality of the rice crop by affecting its phenology, physiology, and yield components (Singh 2001; Sheehy *et al.* 2005; Peng *et al.* 2004). Moreover, the vegetative and reproductive stages are greatly affected by heat stress. A high day temperature can damage leaf gas exchange properties during the vegetative stage. According to Shrivastava *et al.* (2012) the sensitivity of rice to high temperature varies with growth phase, an increase in day/night temperature and genotype.

2.4.1 High temperature in relation to growth and development of the rice plant

Temperature along with photoperiod is the main driving force for crop development (Kropff *et al.*, 1995). The optimum temperature for the normal development of rice ranges from 27-32°C (Yin *et al.*, 1996). High temperature above these ranges affects almost all the growth stages of rice, i.e. from emergence to ripening and harvesting. Moderately high temperatures increase the rate of plants development and reduce its rate of growth. The number and formation of spikelets and florets as well as, grain filling, are reduced, resulting in lower yields. The late-boot and seed-set stages are especially vulnerable and in many areas, high temperatures are more likely to occur during these later stages of plant development.

2.4.1.1 Heat stress at different ontogenetic stages

2.4.1.2 Vegetative phase

During vegetative stage, rice can tolerate relatively high temperatures (35/25°C; expressing day/night temperature regime). Temperatures beyond this critical level could reduce plant height, tiller number and total dry weight (Yoshida *et al.*, 1981). Rice is relatively more tolerant of high temperatures during the vegetative phase but is highly susceptible during the reproductive phase, particularly at the flowering stage (Jagadish *et al.*, 2010).

In a temperature gradient chamber study, rice exposed to 3.6°C and 7.0° C higher temperature than ambient, from heading to middle ripening stage, reduced photosynthesis by 11.2–35.6%, respectively (Oh-e *et al.*, 2007). This decline in the photosynthesis can be attributed to structural changes in the organization of thylakoids (Karim *et al.*, 1997) and more particularly due to loss of stacking of grana in the chloroplast or its ability to swell (Wahid *et al.*, 2007). Moreover, membranes that house these cell organelles are extremely important as high temperatures increase the kinetic energy, in turn the molecular movements to loosen the bonds between biological membranes, Such rapid movements will lead to increase in fluidity of lipid layer (Savchenko *et al.*, 2002) resulting in increased solute leakage and membrane instability.

2.4.1.3 Reproductive phase

Reproductive stage in rice is more sensitive to heat than the vegetative stage (Yoshida *et al.*, 1981). Anthesis/flowering, identified with the appearance of the anthers, is the most sensitive process during reproductive stage to high temperature (Nakagawa *et al.*, 2002; Satake and Yoshida,1978) followed by microgametogenesis. High temperatures (35° C) during microsporogenesis resulted in 34% decline in spikelet fertility. Heat stress during anthesis leads to an irreversible effect with stagnation in panicle dry weight even with subsequent improvement in the environment (Oh-e *et al.*, 2007).

Lower relative humidity of 60% at 38° C leads to a higher vapor pressure deficit of 2.65 facilitating the plant to exploit its transpiration cooling ability (Jagadish, 2007; Jagadish *et al.*, 2007). Similarly, Abeysiriwardena *et al.* (2002) recorded a 1.5°C increase in spikelet temperature by increasing RH from 55–60% to 85–90% at a constant temperature regime of 35/30° C. Increased heat tolerance is most needed in *Oryza sativa* species, compared to *Oryza glaberrima* species, which exhibit peak anthesis during late morning till mid-afternoon (Yoshida *et al.*, 1981). Exposing the heat sensitive reproductive organs to high temperatures invariably leading to increased spikelet sterility (Jagadish *et al.*, 2008; Prasad *et al.*, 2006). Moreover, O. sativa species rice is exponentially grown in the African continent as compared to O.glaberrima.

High temperatures induce sterility if the sensitive physiological processes such as anther dehiscence, pollen germination on the stigma, pollen tube growth are affected.

Anthesis in rice is extremely sensitive to high temperature whereas spikelets opening on any flowering day during the flowering period (5–7 days) could be affected differently depending on the duration of exposure.

2.4.1.4 Ripening phase

High temperature affects cellular and developmental processes leading to reduced fertility and grain quality (Barnabas *et al.*, 2008). Decreased grain weight, reduced grain filling, higher percentage of white chalky rice and milky white rice are common effects of high temperature exposure during ripening stage in rice (Osada *et al.*, 1973; Yoshida *et al.,* 1981). In addition, increased temperature causes serious reduction in grain size and amylose content (Zhu *et al.*, 2005) further reducing the potential economic benefits farmers can derive from rice cultivation due to depression in farm-gate and/or milled grain prices. High temperature during grain-filling period accelerates the demand for more assimilates to avoid milky white kernels (Kobata and Uemuki, 2004).

The reduced grain weight under high temperature is attributed to excessive energy consumption to meet the respiratory demand of the seeds (Tanaka *et al.*, 1995). Alternatively, the reduction in grain weight is attributed to higher grain dry matter accumulation rate together with a shortened grain-filling period (Kobata and Uemuki, 2004). High temperature during grain-filling period is a critical factor to reduce grain filling/ripening but this effect could be magnified by lower assimilate supply (Kobata and Uemuki, 2004).

Table 3: Symptoms of heat stress in rice plants, in the different growth stages

Growth stage	Threshold Temperature(°C)	Symptoms	References
Emergence	40	Delay &decrease in emergence	Yoshida(1978) Akman (2009)
Seedling	35	Poor growth of the seedling	Yoshida(1978)
Tillering	32	Reduce tillering &height.	Yoshida(1978)
Booting	-	Decrease number of pollen grains	Shimaraki *et al.*, 1964)
Anthesis	33	Poor anther dehiscence &sterility	Jagadish *et al.* (2007)
Flowering	35	Floret sterility	Satake and Yoshida (1978)
Grain formation	34	Yield reduction	Morita *et al.* (2004)
Grain ripening	39	Reduced grain filling	Yoshida(1981)

The developmental stage at which the plant is exposed to heat stress determines the severity of the possible damage to the crop (Wahid *et al.*, 2007). However, flowering (anthesis and fertilization) and to a lesser extent the preceding stage booting (microsporogenesis) are considered to be the stages of development most susceptible to temperature in rice (Satake and Yoshida 1978; Farrell *et al.*, 2006). Exposure to 41°C for 4 hours at flowering caused irreversible damage and plants become completely sterile. Whereas this high temperature (41°C) had no effect on spikelet fertility at 1 day before or after flowering (Yoshida *et al.*, 1981). In the same study, it was also found that pollination of heat-stressed stigmas with unstressed pollen as well as self-pollination at one hour before heat stress application did not affect spikelet to one hour before and after flowering.

2.4.2 High temperature and spikelet sterility

Temperature higher than optimum, induced floret sterility and thus decreased rice yield (Nakagawa *et al.*, 2003).Similarly, Spikelet sterility was greatly increased at temperature higher than 35°C (Matsui *et al.*, 1997b). In greenhouse experiments with both indica and japonica genotypes, Jagadish *et al.* (2007) found that less than one hour of exposure to temperature above 33.7 °C was sufficient to induce sterility. Enhanced CO_2, levels may further aggravate this problem possibly because of reduced transpiration cooling (Matsui *et al.*, 1997a).

2.5 Mechanism of Heat-Induced Floret Sterility

Eco physiological analysis has revealed the mechanism responsible for heat-induced floret sterility (Matsui *et al.*, 2007). A key mechanism of high-temperature induced floret sterility in rice is the decreased ability of the pollen grain to swell, resulting in poor thecae dehiscence (Matsui *et al.*, 2000). This swelling of pollen grains in the locules is the driving force for anther dehiscence (Matsui *et al.*, 1999). Endo *et al.*, 2009), found that although high-temperature treated pollen showed a normal round shape, some of the tapetum functions such as pollen adhesion to the stigma and its subsequent germination were negatively affected. Endo *et al.* (2009) also identified some temperature-responsive genes in the anther by clustering of micro array data. Some other possible reasons discussed by researchers for decreasing spikelet fertility at high temperature are altered hormonal balance in the floret (Michael and Beringer, 1980), disturbance in the availability and transport of photosynthesis to the kernel (Afuakwa *et al.*, 1984), lack of ability of the floral buds to mobilize Carbohydrates under heat stress (Dinar and Rudich 1985) and changes in the activities of starch and sugar biosynthesis enzymes (Keeling *et al.*, 1994; Singletarry *et al.*, 1994).

Prasad *et al.* (2006) reported that high-temperature stress during rice flowering led to decreased pollen production and pollen shed. The probable reasons were the inhibition of swelling of pollen grains, indehiscence of anthers and poor release of pollen grains (Matsui *et al.*, 2000, 2005) and thus fewer numbers of pollen were available to be intercepted by the stigma. Mackill *et al.* (1982) stated that the proportional fertility was positively correlated with the number of pollen grains shed on the stigma under both high and ambient temperatures. Physiologically, the decreased production of pollens at elevated temperatures may be attributable to impaired cell division of the micro-spore mother cells (Takeoka *et al.*, 1992). Similarly, high temperatures at anthesis or soon after can cause poor pollen germination and retarded pollen tube growth, along with poor anther dehiscence. Different reasons have been discussed for variation of these traits among tolerant and susceptible cultivars. For example, Matsui *et al.* (2001) stated that the occurrence of well-developed cavities in anther, and thick locale walls which enable easy rupture of the septa in response to swelling of pollen resulted in better anther dehiscence and pollen shed in tolerant cultivars.

Exposure of pollen grains to high temperature resulted in a loss of pollen viability within 10 minutes (Song *et al.*, 2001) while it was essential that more than 10 pollen grains germinated on the stigmata to ensure successful fertilization of a rice floret (Satake and Yoshida, 1978). Given that concentrations of 0.50 of the pollen grains on a stigma germinate, there must be over 20 pollen grains on a stigma to ensure fertilization (Matsui and Kagata, 2003). Along with this, exposure to high temperature for a few hours can reduce pollen viability greatly and therefore cause yield loss (Wassman and Dobermann, 2007). The stigma is less sensitive to heat than the anther and pollination of the stigma with unstressed pollen generally restores the spikelet fertility (Yoshida *et al.*, 1981). The decrease in spikelet fertility can be termed a phenotypic character of rice plant under high temperature while the decrease in pollen germination and activity can be considered as the physiological factor responsible for this decrease (Tang *et al.*, 2008). Thus, all these traits, which somehow ensure normal pollination, are also vital for the thermo-tolerance capabilities of various genotypes.

2.6 Pollination in Relation to Spikelet Fertility at High Temperature

Pollination contributing factors (pollen production, viability and reception) play a dominant role in productivity of the crop. Generally, male reproductive development in rice is known to be more sensitive to heat stress (Wassmann *et al.,* 2009). Prasad *et al.* (2006) reported that high-temperature stress during rice flowering led to decreased pollen production and pollen shed. The probable reasons were the inhibition of swelling of pollen grains, indehiscence of anthers and poor release of pollen grains (Matsui *et al.*, 2000, 2005), and thus fewer numbers of pollen grains were available to be intercepted by the stigma. Mackill *et al.* (1982) stated that the proportional fertility was positively correlated with the number of pollen grains shed on the stigma under both high and ambient temperatures.

2.7 Effect of High Temperature on Yield and Yield Components

Temperatures beyond critical thresholds not only reduce the growth duration of the rice crop but also increase spikelet sterility, reduce grain-filling duration, and enhance respiratory losses, resulting in lower yield and lower quality rice grain (Fitzgerald and Resurreccion 2009, Kim *et al.*, 2011). Peng *et al.* (2004) analyzed weather data at the International Rice Research Institute farm from 1979 to 2003 to examine the temperature trends and the relationships between rice yields and temperature. Annual mean maximum and minimum temperatures increased by 0.35 and 1.13° C, respectively, for the above period and a close correlation between rice grain yield and mean minimum temperature was observed. Grain yield declined by 10% for each 1°C increase in minimum temperature in the dry season whereas the effect of maximum temperature was insignificant. The decrease in radiation and increase in minimum temperature were identified as the reasons for the yield decline. Although, high temperature at both day and night reduced the duration of grain growth, the rate of growth was lower in the early or middle stages of grain filling, and also reduced cell size midway between the central point and the surface of endosperm at high night temperature (22/34° C) than at high day temperature of 34/22° C (Morita *et al.*, 2005). Unlike other abiotic stresses, heat stress occurring during either the day or night has differential impacts on rice growth and production. Recently, high night temperatures having a greater negative effect on rice yield have been documented, with 1 °C above critical temperature (>24 °C) leading to a 10% reduction in both grain yield and biomass (Peng *et al.*, 2004; Welch *et al.*, 2010).

2.8 Mutation Induction to Induce Variation in Rice

Mutation means a sudden heritable change in the genetic material at the gene or chromosome level (Chahal and Gosal, 2002). They may be caused by error during cell division or by exposure to the DNA- damaging agents or mutagens in the environment. Ionizing radiations have been successful in inducing genetic variability in rice. Before the start of any sound breeding programme knowledge of the relative biological effectiveness and efficiency of various mutagens is useful in mutation breeding (Smith, 1972). Various attempts in this direction have been made by different scientists to determine the most effective mutagenic treatment for the induction of desirable traits in rice (Awan and Bari, 1979; Reddy and Rao, 1988; Bansal *et al.*, 1990; Katoch *et al.*, 1992; Pillai *et al.*, 1993; Sarawgi and Soni 1993; Kumar, 1998; Sanjeev *et al.*, 1998).

Radiation has been found to affect the size and weight of plants. In many radiobiological reactions, the effect of a given dose depends on the intensity of radiation or the manner in which the total dose is fractioned. Gamma rays are known to influence plant growth and development by inducing cytological, genetical, biochemical and physiological changes in cells and tissues (Gunckel and Sparrow., 1961). Gamma radiation can be useful for the alteration of physiological characters (Kiong *et al.*, 2008). The biological effect of gamma ray is based on the interaction with atoms or molecules in the cell, particularly water, to produce free radicals (Kumar *et al.*, 2013). These radicals can damage or modify important components of plant cells and have been reported to affect differentially the morphology, anatomy, biochemistry and physiology of plants depending on the radiation dose (Ashraff *et al.*, 2003). In view of the potential hazards of natural and artificial gamma radiations, it becomes essential to understand the extent of damage caused to the rice system. Since rice is the most important staple food crop, the ill effects of radiation at germination level need to be thoroughly investigated. The radiation induced growth abnormalities in seedlings were mainly due to cell death and suppression of mitosis at different exposures. Mutation induction continues to contribute to crop improvement, using physical mutagens such as gamma ray, X-ray, fast neutron, and chemical mutagens such as EMS (ethyl-methane-sulphonate) and sodium azides. Recently, new physical mutagens, such as, radiation hybrids (RH), have been proven to be effective for inducing mutations. This has been developed for genomic research. RHs are produced by exposing somatic cells to lethal doses of gamma radiation or X-ray, in order to fragment the chromosomes. They are then rescued by introduction into host cells, which are subsequently fused with suitable recipient cells for the assessment of their expressions providing unique materials for the establishment of physical maps, a process known as radiation hybrid mapping. RH maps have been developed in a number of crops, including rice, barley, maize and wheat for gene discovery and detailed linkage analysis. This may soon lead to the identification and transfer of genes affecting useful agronomic, quality and stress tolerance traits such as heat stress (Sato, 2006).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental Site

The study was conducted in the screen house at the Horticultural unit screen house and heat chamber located at the African Seed health Centre in the Department of Crop Science and Production at Sokoine University of Agriculture. Morogoro.

3.2 Experimental Materials

The materials used were M_3 generation mutant lines derived from four varieties of rice; Kihogo Red (local variety), CG 14 (*O. glaberrima*), WAB 56-50 and WAB 56-104 (*O. sativa*). These cultivars were earlier irradiated at the Seibersdorf Laboratory in Vienna with gamma rays at a dose of 150GY for the first three varieties and at 200GY for WAB 56-104.

3.3 Experimental Unit

Five liter plastic pots filled with soil were used as experimental units in these experiments, the pot dimensions were 20 and 19 cm for upper and lower circumference, respectively, with an average height of 20 cm. Soil was collected not more than 30 cm deep from crop Museum at Sokoine University of Agriculture. The soil was Natural clay loam soil.

3.4 Experimental Design

A completely randomized design (CRD) was used with three replications for evaluation of survived lines. This was done as pot experiments in the screen house.

3.5 Methods

3.5.1 Sowing

Seeds of mutant lines derived from Kihogo red (62 lines), CG14 (151 lines), WAB56-104 (172 lines), WAB 56-50 (281 lines) and their checks, were sown in separate plastic trays. 100 seeds of each line were sown into the tray, whereby in each tray, two lines from the required cultivar were sown to make 200 seeds in one tray (Fig.1), One week after sowing seedlings were scored for germination percentages.

Figure 1: Trays with germinating seeds in the screen house

3.5.2 Screening for heat tolerant

Fourteen days after germination, seedlings were transferred to the heat chamber where temperature was raised up to 45°C for six hours (Fig. 2 and 3), Then rice seedlings were removed from the heat chamber after heat exposure for four days, five days, and six days, this was done randomly by taking out twelve lines.

3.6 Heat Chamber Experiment

3.6.1 Kihogo red

A total of 62 mutant lines of Kihogo red were exposed to heat stress of 45°C for 6 hours per day at 4 days, 5 days and 6 days. In this study out of 62 lines, 20 lines were stressed for 4 days, 21 lines for 5 days and 21 lines for 6 days. The experiment included Kihogo red variety as a check after stress, the seedlings were then returned to the screen house for recovery at normal temperature.

3.6.2 CG 14

In this variety 151 mutant lines were stressed at 45°C, whereby out of those, 50 mutant lines were stressed for 4 days, another 50 lines for 5 days and the rest 51 mutant lines were stressed for 6 days. Also from CG control, 100 seedlings from untreated control were stressed at the same condition.

3.6.3 WAB 56-104

172 mutant lines derived from WAB 56-104 were exposed to heat stress of 45°C, among of those 57 lines, 57 lines and 58 lines were exposed for 4 days, 5 days and 6 days respectively, 100 seedlings untreated WAB 56-104 were also stressed under the same condition.

3.6.4 WAB 56-50

Out of 281 mutant lines of this genotype stressed to high temperature of 45°C, 94 lines were stressed for 4 days another 93 for 5 days and the remained 94 lines six days. Again 100 seedlings untreated WAB 56-50 were stressed under the same condition. A total of 18 trays of which 36 lines only were carried at one time due to capacity of heat chamber. Removal of lines was done randomly whereby 12 lines in the 6 trays were removed after 4 days of exposure to heat stress, again another 12 lines selected randomly were removed after 5 days and finally the rest, 12 lines were removed after six days of heat stress. Then all seedlings were returned to the screen house for recovery under normal condition. The data collected included number of rice seedlings survived, number of rice dead seedlings and percentage survived seedlings.

Figure 2: 14 days old seedling ready for heat stress

Figure 3: Seedlings in heat chamber

Survived seedlings of mutant lines from heat chamber expressing heat tolerance were transplanted in a potted container of 19 cm diameter and 20 cm height, with clay loam soil with three replications per lines. Regular irrigation was done just to keep soil moist and not too wet (Fig. 4).

3.7 Fertilizer Application

Fertilizer was applied in the form of Urea, TSP, Muriate of potash at respective rates of 125N/ha, 60 P_2O_5/ha, and 45 K_2O/ha. The whole P and K were applied as basal during transplanting. However; N (Urea) was split applied in three doses i.e. 40% at the time of seedling transplanting, 30% at the active tillering and 30% in the beginning of the reproductive stage. On the first day of appearance of anthers (Fig. 5), rice plants were again exposed to the temperature at 32°C to 35°C for three hours and maintained at 35°C for one hour for three days. Then after heat treatment, rice plants were taken back to the control condition at 29/21°C day and night where number of tillers per plant, days to first and 50% flowering data, were recorded.

Before rice plants were harvested for final yield determination, data for growth and yield components were recorded. These included days to maturity, plant height, panicle number and panicle length, number of spikelets, number of filled and unfilled grains, percentage sterility, weight of the 1000 grains and rice grain yield per plant.

Figure 4: Survived seedlings 2 days after transplanted in pots

Figure 5: Rice mutant plants exposed to temperature on the 1st days of appearance of anthers

3.8 Data Collection

3.8.1 Days to 50% flowering

The day at which the first flower appeared and the day when at least half of the rice plants exerted a fully opened panicle was recorded as first and 50% flowering, respectively.

3.8.2 Number of tillers per plant

Number of tillers per plant for each mutant line (plants survived) was counted at the maximum tillering stage, where by all tillers in the pots were counted and recorded. From the total tillers in each pot, the average number of tillers produced by single plant was calculated by dividing the total number of tillers by the number of plants that were present in each pot.

3.8.3 Panicle number

Number of panicles was taken by counting and recording number of panicles of each plant.

3.8.4 Plant height

Plant heights were measured at the time of rice maturity, the plants were measured by ruler from the surface of the soil to the longest leaf by lifting up leaves, and the measurement was recorded in centimeters.

3.8.5 Panicle length

These were taken by measuring three random panicles by using a ruler before harvesting, and then an average was recorded as panicle length of that plant in centimeter.

3.8.6 Days to maturity

This was counted from the day of sowing until when more than 90% of rice grain turned from green to brown. All rice heads from harvest pots were cut. The grains were sun dried before they were threshed, winnowed, weighed and then recorded for analysis.

3.8.7 Filled and unfilled grains

The total spikelets after threshing from panicles and air dried were weighed using a sensitive weighing balance, then were counted by using seed counter, then separation of filled and unfilled grains were done through seed separator and the data were recorded accordingly

3.8.8 Percentage sterility

The sterility in percentage was recorded by using the following formular:

$$\% \, sterility = \frac{\text{Number of Unfilled grain/plant}}{\text{Total number of spikelets/plant}} \text{X}100 \ldots\ldots (1)$$

3.8.9 1000 grain weight

A sample of 1000 seeds was taken from each plant within the line and weighed to give the 1000-grain weight. For the seeds that do not reach 1000, 100 seeds weight were taken and then converted to 1000 seeds weight.

3.8.10 Yield (g /plant)

Grain yield per plant was recorded by weighing the filled grain per plant, this was taken from the weight of filled grain harvested after removing the unfilled grain from each plants.

3.9 Data Analysis

All data that were recorded as direct measurements or as calculated data were subjected to the analysis of variance (ANOVA). The treatment means were compared through Duncan Multiple Range Test at 5% probability level using Genstat computer software (Gomez and Gomez, 1984).

CHAPTER FOUR

4.0 RESULTS

4.1 Heat Stress Experiment

Results from screening of rice mutant lines which were subjected to heat stress at 45°C at different days of exposure showed variation in survival among genotypes tested, but in the case of the Control varieties, all plants which were subjected to heat stress at 4,5 and 6 days were dead (Table 4).

Table 4: A summary of Rice mutant lines exposed to heat stress at 45°C for 6 hours/day and their percentage recovery

Genotype	Total number of line exposed			Number of Lines recovered			% recovery		
	At 4 days	At 5 days	At 6 days	At 4 days	At 5 days	At 6 days	At 4 days	At 5 days	At 6 days
KIHOGO RED	20	21	21	3	4	5	15	19.05	23.8
Control (plants)	100	100	100	0	0	0	0	0	0
CG 14	50	50	51	9	9	12	18	18	23.51
Control (Plants)	100	100	100	0	0	0	0	0	0
WAB 56-104	57	57	58	8	8	10	14.35	14.35	17.24
Control (Plants)	100	100	100	0	0	0	0	0	0
WAB 56-50	94	93	94	14	10	13	14.89	10.75	13.83
Control (Plants)	100	100	100	0	0	0	0	0	0

4.1.1 Kihogo red

For Kihogo red, 62 lines were exposed to heat stress at 45°C. Out of these 20 lines were exposed for 4 days where only three lines were recovered. These were lines 28, 29 and 30. Out of 21 lines which were exposed to heat stress for five days, four lines were recovered, these were lines No.9, 26, 39 and 40. For the heat treatment at 45°C, 21 lines were exposed for 6 days, out of which five lines survived. These were lines 3, 10, 27, 37 and 38. (Table 5).

Table 5: Rice mutant lines exposed to heat stress at 45°C for 6 hours/day (Kihogo red)

Stressed for 4 days		Stressed for 5 days		Stressed for 6 days	
Line No.	Survived (+) Dead (-)	Line No.	Survived (+) Dead (-)	Line No.	Survived (+) Dead (-)
KR 1	-	KR 6	-	KR 3	+
KR 2	-	KR 7	-	KR 10	+
KR 4	-	KR 8	-	KR 11	-
KR 5	-	KR 9	+	KR 12	-
KR 15	-	KR 17	-	KR 13	-
KR 16	-	KR 18	-	KR 14	-
KR 23	-	KR 21	-	KR 19	-
KR 24	-	KR 22	-	KR 20	-
KR 28	+	KR 25	-	KR 27	+
KR 29	+	KR 26	+	KR 32	-
KR 30	+	KR 34	-	KR 33	-
KR 31	-	KR 35	-	KR 36	-
KR 41	-	KR 39	+	KR 37	+
KR 42	-	KR 40	+	KR 38	+
K R43	-	KR 45	-	KR 48	-
KR 44	-	KR 46	-	KR 55	-
KR 49	-	KR 47	-	KR 56	-
KR 50	-	KR 51	-	KR 57	-
KR 53	-	KR 52	-	KR 58	-
KR 54	-	KR 59	-	KR 61	-
		KR 60	-	KR 62	-

4.1.2 CG 14

A total of 151 mutant lines of CG 14 were exposed to heat stress for four days, five days and six days, at 45°C. The results indicated that only nine lines out of 50 were recovered after four days, which was the same number survived when the same number of lines were exposed to five days at heat stress of 45°C. However, for the 51 mutant lines which were exposed to heat stress for six days, twelve lines were recovered (Table 6). The CG 14 non-irradiated plants failed to survive when exposed at the same temperature for 4, 5 and 6 days.

Table 6: Rice mutant Lines exposed to heat stress at 45°C for 6 hours/day (CG 14)

After 4 Days		After 5 Days		After 6 Days	
Line No.	Survived (+) Dead (-)	Line No.	Survived (+) Dead (-)	Line No.	Survived (+) Dead (-)
CG 14-1	-	CG14-3	-	CG14-5	+
CG 14-2	-	CG14-4	-	CG14-6	+
CG 14-11	-	CG14-9	-	CG14-7	+
CG 14-12	-	CG14-10	-	CG14-8	-
CG 14-19	-	CG14-17	-	CG14-13	+
CG14-20	+	CG14-18	-	CG14-14	-
CG14-23	-	CG14-25	-	CG14-15	-
CG14-24	-	CG14-26	-	CG14-16	+
CG14-29	-	CG14-27	-	CG14-21	+
CG14-30	-	CG14-28	-	CG14-22	+
CG14-35	-	CG14-31	-	CG14-33	-
CG14-36	-	CG14-32	-	CG14-34	-
CG14-37	-	CG14-49	+	CG14-45	-
CG14-38	-	CG14-50	+	CG14-46	-
CG14-39	-	CG14-54	+	CG14-59	+
CG14-43	-	CG14-51	+	CG14-73	-
CG14-44	-	CG14-42	-	CG14-61	+
CG14-41	-	CG14-60	+	CG14-62	+
CG14-52	+	CG14-74	-	CG14-63	+
CG14-53	+	CG14-57	-	CG14-64	+
CG14-65	+	CG14-66	+	CG14-69	-
CG14-58	-	CG14-67	-	CG14-70	-
CG14-71	-	CG14-68	-	CG14-55	-
CG14-72	-	CG14-40	-	CG14-56	-
CG14-77	+	CG14-82	+	CG14-87	-
CG14-78	+	CG14-83	-	CG14-88	-
CG14-80	+	CG14-84	-	CG14-91	-
CG14-79	+	CG14-109	-	CG14-92	-
CG14-81	+	CG14-110	-	CG14-85	-
CG14-103	-	CG14-93	-	CG14-86	-
CG14-104	-	CG14-94	-	CG14-99	-
CG14-105	-	CG14-89	-	CG14-100	-
CG14-106	-	CG14-90	-	CG14-107	-
CG14-95	-	CG14-102	-	CG14-108	-
CG14-96	-	CG14-75	+	CG14-97	-
CG14-101	-	CG14-76	+	CG14-98	-
CG14-147	-	CG14-115	-	CG14-119	-
CG14-148	-	CG14-116	-	CG14-120	-
CG14-113	-	CG14-117	-	CG14-125	-
CG14-114	-	CG14-118	-	CG14-126	-
CG14-127	-	CG14-123	-	CG14-129	-
CG14-128	-	CG14-124	-	CG14-130	-
CG14-133	-	CG14-131	-	CG14-121	-
CG14-134	-	CG14-132	-	CG14-122	-
CG14-137	-	CG14-139	-	CG14-111	-
CG14-138	-	CG14-140	-	CG14-112	-
CG14-143	-	CG14-141	-	CG14-135	-
CG14-144	-	CG14-142	-	CG14-136	-
CG14-151	-	CG14149	-	CG14-145	-
CG14-152	-	CG14-150	-	CG14-146	-

4.1.3 WAB 56-104

With regard to mutant lines of WAB 56-104, eight mutant lines out of 57 mutant lines exposed for four days at 45°C, were recovered, the same number of lines survived when the same number were exposed for five days at heat stress of 45°C. Moreover, when 58 lines were exposed to six days in heat stress at the same temperature level, ten lines survived (Table 7). The non-irradiated plants from WAB 56-104 control did not survive the heat stress.

Table 7: Rice mutant Lines exposed to heat stress at 45°C for 6 hours/day (WAB 56 – 104)

Stressed for 4 days		Stressed for 5 days		Stressed for 6 days	
Line No.	Survived (+) Dead (-)	Line No.	Survived (+) Dead (-)	Line No.	Survived (+) Dead (-)
				WAB56-104-9	+
WAB56-104-7	-	WAB56-104-11	-	WAB56-104-10	-
WAB 56-104-8	-	WAB56-104-12	+	WAB56-104-17	-
WAB56-104-19	-	WAB56-104-1	-	WAB56-104-18	+
WAB56-104-20	-	WAB56-104-2	-	WAB56-104-35	-
WAB56-104-23	-	WAB56-104-5	-	WAB56-104-36	+
WAB56-104-24	-	WAB56-104-6	-	WAB56-104-3	-
WAB56-104-25	-	WAB56-104-21	-	WAB56-104-4	-
WAB56-104-26	-	WAB56-104-22	-	WAB56-104-13	-
WAB56-104-29	-	WAB56-104-27	-	WAB56-104-14	-
WAB56-104-30	-	WAB56-104-28	-	WAB56-104-15	-
WAB56-104-31	-	WAB56-104-33	-	WAB56-104-16	-
WAB56-104-32	-	WAB56-104-34	-	WAB56-104-43	+
WAB56-104-39	+	WAB56-104-45	-	WAB56-104-44	-
WAB56-104-40	+	WAB56-104-46	+	WAB56-104-71	+
WAB56-104-49	-	WAB56-104-69	-	WAB56-104-72	-
WAB56-104-50	-	WAB56-104-70	+	WAB56-104-41	-
WAB56-104-77	-	WAB56-104-37	-	WAB56-104-42	-
WAB56-104-78	-	WAB56-104-38	-	WAB56-104-81	-
WAB56-104-73	+	WAB56-104-47	-	WAB56-104-82	-
WAB56-104-74	+	WAB56-104-48	-	WAB56-104-75	-
WAB56-104-63	-	WAB56-104-79	-	WAB56-104-76	+
WAB56-104-64	-	WAB56-104-80	-	WAB56-104-67	-
WAB56-104-65	-	WAB56-104-61	-	WAB56-104-68	-
WAB56-104-66	-	WAB56-104-62	+	WAB56-104-85	-
WAB56-104-83	-	WAB56-104-87	-	WAB56-104-86	-
WAB56-104-84	-	WAB56-104-88	-	WAB56-104-91	-
WAB56-104-89	-	WAB56-104-97	-	WAB56-104-92	-
WAB56-104-90	-	WAB56-104-98	-	WAB56-104-95	-
WAB56-104-93	-	WAB56-104-105	-	WAB56-104-96	-
WAB56-104-94	-	WAB56-104-106	-	WAB56-104-99	-
WAB56-104-101	-	WAB56-104-103	-	WAB56-104-100	-
WAB56-104-102	-	WAB56-104-104	-	WAB56-104-107	-
WAB56-104-109	-	WAB56-104-111	-	WAB56-104-108	-
WAB56-104-110	-	WAB56-104-112	-	WAB56-104-117	-
WAB56-104-115	-	WAB56-104-113	-	WAB56-104-118	+
WAB56-104-116	-	WAB56-104-114	-	WAB56-104-141	+
WAB56-104-131	-	WAB56-104-135	-	WAB56-104-142	-
WAB56-104-132	+	WAB56-104-136	+	WAB56-104-125	-
WAB56-104-133	+	WAB56-104-137	+	WAB56-104-126	-
WAB56-104-134	-	WAB56-104-138	-	WAB56-104-123	+
WAB56-103-121	-	WAB56-104-119	+	WAB56-104-124	-
WAB56-104-122	-	WAB56-104-120	-	WAB56-104-146	-
WAB56-104-129	-	WAB56-104-127	-	WAB56-104-139	-
WAB56-104-130	-	WAB56-104-128	-	WAB56-104-140	-
WAB56-104-143	-	WAB56-104-147	-	WAB56-104-149	-
WAB56-104-145	-	WAB56-104-148	-	WAB56-104-150	+
WAB56-104-151	-	WAB56-104-153	-	WAB56-104-158	-
WAB56-104-152	-	WAB56-104-154	-	WAB56-104-159	-
WAB56-104-169	-	WAB56-104-163	-	WAB56-104-160	-
WAB56-104-170	+	WAB56-104-164	-	WAB56-104-161	-
WAB56-104-171	+	WAB56-104-179	-	WAB56-104-162	-
WAB56-104-172	-	WAB56-104-180	-	WAB56-104-167	-
WAB56-104-165	-	WAB56-104-177	-	WAB56-104-168	-
WAB56-104-166	-	WAB56-104-178	-	WAB56-104-173	-
WAB56-104-175	-	WAB56-104-181	+	WAB56-104-174	-
WAB56-104-176	-	WAB56-104-182	-	WAB56-104-156	-
WAB56-104-183	-	WAB56-104-184	-	WAB56-104-155	-

4.1.4 WAB 56-50

A total of 281mutant lines of WAB 56-50 were exposed to heat stress, whereas at four days, fourteen lines out of 94 survived but when 93 lines after being exposed for five days at 45°C for six hours, only ten lines survived and after six days exposure, thirteen lines remained healthy out of 94 mutant lines stressed (Table 8). Plants from WAB 56-50 control did not survive the heat stress.

Table 8: Rice mutant Lines exposed to heat stress at 45°C for 6 hours/day (WAB 56- 50)

Stressed for 4 days		Stressed for 5 days		Stressed for 6 days	
Line No.	Survived (+) Dead (-)	Line No.	Survived (+) Dead (-)	Line No.	Survived (+) Dead (-)
WAB56-50-17	-	WAB56-50-11	-	WAB56-50-13	-
WAB56-50-18	-	WAB56-50-12	-	WAB56-50-14	-
WAB56-50-21	-	WAB56-50-19	-	WAB56-50-15	-
WAB56-50-22	-	WAB56-50-20	-	WAB56-50-16	-
WAB56-50-29	-	WAB56-50-31	-	WAB56-50-23	-
WAB56-50-30	-	WAB56-50-32	-	WAB56-50-24	-
WAB56-50-37	-	WAB56-50-33	-	WAB56-50-25	-
WAB56-50-38	-	WAB56-50-34	-	WAB56-50-26	-
WAB56-50-43	-	WAB56-50-39	-	WAB56-50-27	-
WAB56-50-44	-	WAB56-50-40	-	WAB56-50-28	-
WAB56-50-45	-	WAB56-50-35	-	WAB56-50-47	-
WAB56-50-46	-	WAB56-50-36	-	WAB56-50-48	+
WAB56-50-59	+	WAB56-50-70	+	WAB56-50-51	+
WAB56-50-60	+	WAB56-50-71	-	WAB56-50-52	-
WAB56-50-49	-	WAB56-50-57	-	WAB56-50-55	-
WAB56-50-50	-	WAB56-50-58	-	WAB56-50-56	+
WAB56-50-53	-	WAB56-50-78	-	WAB56-50-82	+
WAB56-50-54	-	WAB56-50-79	-	WAB56-50-83	-
WAB56-50-74	-	WAB56-50-80	-	WAB56-50-72	-
WAB56-50-75	-	WAB56-50-81	-	WAB56-50-73	-
WAB56-50-86	-	WAB56-50-90	+	WAB56-50-76	-
WAB56-50-87	+	WAB56-50-91	+	WAB56-50-77	-
WAB56-50-88	+	WAB56-50-92	-	WAB56-50-84	-
WAB56-50-89	-	WAB56-50-93	-	WAB56-50-85	+
WAB56-50-94	-	WAB56-50-100	+	WAB56-50-97	+
WAB56-50-95	+	WAB56-50-101	-	WAB56-50-98	+
WAB56-50-96	+	WAB56-50-107	+	WAB56-50-105	-
WAB56-50-99	+	WAB56-50-108	-	WAB56-50-106	-
WAB56-50-103	-	WAB56-50-117	-	WAB56-50-111	-
WAB56-50-104	-	WAB56-50-118	-	WAB56-50-112	-
WAB56-50-109	-	WAB56-50-119	+	WAB56-50-115	-
WAB56-50-110	-	WAB56-50-120	-	WAB56-50-116	-
WAB56-50-124	+	WAB56-50-113	-	WAB56-50-123	+
WAB56-50-125	+	WAB56-50-114	-	WAB56-50-102	-
WAB56-50-121	-	WAB56-50-139	+	WAB56-50-126	-
WAB56-50-122	-	WAB56-50-140	+	WAB56-50-127	+
WAB56-50-143	+	WAB56-50-131	-	WAB56-50-148	-
WAB56-50-144	-	WAB56-50-132	-	WAB56-50-129	-
WAB56-50-142	+	WAB56-50-146	+	WAB56-50-128	-
WAB56-50-150	-	WAB56-50-145	-	WAB56-50-137	-
WAB56-50-133	+	WAB56-50-130	-	WAB56-50-138	+
WAB56-50-134	+	WAB56-50-147	+	WAB56-50-141	+
WAB56-50-153	-	WAB56-50-159	-	WAB56-50-142	-
WAB56-50-154	-	WAB56-50-161	-	WAB56-50-151	-
WAB56-50-155	-	WAB56-50-162	-	WAB56-50-152	+
WAB56-50-156	+	WAB56-50-165	-	WAB56-50-135	+
WAB56-50-160	-	WAB56-50-166	-	WAB56-50-136	-
WAB56-50-163	-	WAB56-50-167	-	WAB56-50-157	-
WAB56-50-164	-	WAB56-50-168	-	WAB56-50-158	-
WAB56-50-173	-	WAB56-50-181	-	WAB56-50-169	-
WAB56-50-174	-	WAB56-50-182	-	WAB56-50-170	-

Table 8: Continue

Stressed for 4 days		Stressed for 5 days		Stressed for 6 days	
Line No.	Survived (+) Dead (-)	Line No.	Survived (+) Dead (-)	Line No.	Survived (+) Dead (-)
WAB56-50-179	-	WAB56-50-187	-	WAB56-50-171	-
WAB56-50-180	-	WAB56-50-188	-	WAB56-50-172	-
WAB56-50-185	-	WAB56-50-175	-	WAB56-50-177	-
WAB56-50-186	-	WAB56-50-176	-	WAB56-50-178	-
WAB56-50-189	-	WAB56-50-195	-	WAB56-50-183	-
WAB56-50-190	-	WAB56-50-196	-	WAB56-50-184	-
WAB56-50-193	-	WAB56-50-197	-	WAB56-50-191	-
WAB56-50-194	-	WAB56-50-198	-	WAB56-50-192	-
WAB56-50-199	-	WAB56-50-205	-	WAB56-50-203	-
WAB56-50-200	-	WAB56-50-206	-	WAB56-50-204	-
WAB56-50-201	-	WAB56-50-209	-	WAB56-50-213	-
WAB56-50-202	-	WAB56-50-210	-	WAB56-50-214	-
WAB56-50-207	-	WAB56-50-215	-	WAB56-50-217	-
WAB56-50-208	-	WAB56-50-216	-	WAB56-50-218	-
WAB56-50-211	-	WAB56-50-219	-	WAB56-50-225	-
WAB56-50-212	-	WAB56-50-220	-	WAB56-50-226	-
WAB56-50-223	-	WAB56-50-221	-	WAB56-50-229	-
WAB56-50-224	-	WAB56-50-233	-	WAB56-50-230	-
WAB56-50-227	-	WAB56-50-237	-	WAB56-50-231	-
WAB56-50-228	-	WAB56-50-238	-	WAB56-50-232	-
WAB56-50-234	-	WAB56-50-239	-	WAB56-50-235	-
WAB56-50-241	-	WAB56-50-240	-	WAB56-50-236	-
WAB56-50-242	-	WAB56-50-243	-	WAB56-50-245	-
WAB56-50-245	-	WAB56-50-244	-	WAB56-50-263	-
WAB56-50-251	-	WAB56-50-255	-	WAB56-50-264	-
WAB56-50-252	-	WAB56-50-256	-	WAB56-50-248	-
WAB56-50-257	-	WAB56-50-259	-	WAB56-50-253	-
WAB56-50-258	-	WAB56-50-260	-	WAB56-50-254	-
WAB56-50-265	-	WAB56-50-269	-	WAB56-50-249	-
WAB56-50-266	-	WAB56-50-270	-	WAB56-50-250	-
WAB56-50-267	-	WAB56-50-281	-	WAB56-50-268	-
WAB56-50-271	-	WAB56-50-282	-	WAB56-50-273	-
WAB56-50-272	-	WAB56-50-285	-	WAB56-50-274	-
WAB56-50-277	-	WAB56-50-286	-	WAB56-50-275	-
WAB56-50-278	-	WAB56-50-287	-	WAB56-50-276	-
WAB56-50-283	-	WAB56-50-288	-	WAB56-50-279	-
WAB56-50-284	-	WAB56-50-293	-	WAB56-50-280	-
WAB56-50-289	-	WAB56-50-294	-	WAB56-50-291	-
WAB56-50-290	-	WAB56-50-303	-	WAB56-50-292	-
WAB56-50-295	-	WAB56-50-304	-	WAB56-50-299	-
WAB56-50-296	-	WAB56-50-307	-	WAB56-50-300	-
WAB56-50-301	-	WAB56-50-308	-	WAB56-50-305	-
WAB56-50-302	-			WAB56-50-306	-

Table 9: Recovery percentage for mutant lines at 4, 5, and 6 days heat exposure

Genotype	Days for stress	Total line stressed	Line recovery	% survival
Kihogo Red	4 days	20	3	15
	5 days	21	4	19
	6 days	21	5	23.8
Total		62	12	19.3
CG 14	4 days	50	9	18
	5 days	50	9	18
	6 days	51	12	23.5
Total		151	30	19.9
WAB 56-104	4 days	57	8	14
	5 days	57	8	14
	6 days	58	10	17.2
Total		172	26	15.1
WAB56-50	4 days	94	14	14.9
	5 days	93	10	10.7
	6 days	94	13	13.8
Total		281	37	13.2

4.2 Yield and Yield Components

Results from the analysis of variance revealed significant difference among the rice genotypes for all the characters studied (Appendix 1, 2 and 3). However, the control plants which passed through heat stress did not survive, so the control data used to compare the performance of mutants was obtained from the plants grown in the screen house without heat treatment.

4.2.1 Days to 50 % flowering

There were significant ($P \leq 0.05$) differences on days to 50% flowering among the rice genotypes studied (Tables 10-21). The observation from Kihogo red (KR) genotype showed that the KR control plants were the latest to reach 50 % flowering as compared to all Kihogo red mutants stressed at four, five and six days to heat stress (Tables 10, 11 and 12). But in case of 50% flowering trait, KR30 mutant was the earliest to reach 50% flowering at four days heat stress (Table 10).

Table 10: Mean agronomic performance of KIHOGO RED mutants which survived heat stress at 45^{o}C for 4 days

Line	50%Flow	NT	NP	PH (cm)	PL(cm)	NS/Panicle	%Sterility	1000 Gwt(g)	GY/Plant(g)
KR28	99.7 ab	7.1 a	6.1 a	92.1 b	23.1 c	151.2 c	68.3 c	19.0ab	10.2 b
KR 29	99.0 a	11.3 b	9.7 b	72.7 a	20.0 a	99.6 a	90.3 d	16.0 a	2.7 a
KR 30	98.3 a	11.0 b	9.0 b	109.7 d	22.7 c	111.6 b	55.7 b	20.0 b	11.4 c
KRCntrl	101.0 b	22.0 c	19.7 c	100.0 c	22.0 b	104.3 a	42.0 a	32.0 c	16.3 d
mean	99.5	13	11	93.6	21.958	117	64.09	22	10.142
cv (%)	0.7	5	4.2	1.8	1.5	2.7	1.3	5.6	1.9

Means in the same column followed by the same letter are not significantly different at 5% level of probability
Note: PH=Plant height, NT=Number of tillers/plant, NP=Number of panicle/plant, NS=Number of spikelets/panicle,
GY=Grain yield, PL=Panicle length, and CV=Coefficient of variation,Cntrl=Control

Table 11: Mean agronomic performance of KIHOGO RED mutants which survived heat stress at 45^{o}C for 5 days

Line	50%Flow	TN/plant	PN/plant	PH(cm)	PL (cm)	NS/Panicle	%Sterility	1000 Gwt(g)	GY/Plant(g)
KR 9	99.7 bc	12.7 c	7.7 bc	115.7 c	26.4 c	144.7 d	46.1 b	18.0 a	12.4 a
KR26	97.7 a	9.7 b	8.7 c	110.7 b	24.4 b	153.0 e	58.2 e	19.0 ab	13.4 b
KR39	100.7 cd	7.7 a	5.7 a	109.3 b	25.3 b	119.0 b	47.1 c	19.0 ab	16.2 c
KR40	99.3 b	7.7 a	6.7 ab	115.3 c	22.9 a	124.1 c	49.0 d	21.0 b	13.8 b
KR-Cntl	101.0 d	22.0 d	19.7 d	100.0 a	22.0 a	104.3 a	42.0 a	32.0 c	16.3 c
mean	99.67	11.93	9.67	110.2	24.19	129.02	48.48	22.0	14.413
cv(%)	0.6	7.1	6.5	0.9	2	0.5	0.6	5.7	2.6

Means in the same column followed by the same letter are not significantly different at 5% level of probability
Note:PH=Plant height,NT=Number of tillers/plant,NP=Number of panicle/plant,NS=Number of spikelets/panicle,
GY=Grain yield,PL=Panicle length,and CV=Coefficient of variation,Cntrl=Control

Table 12: Mean agronomic performance of KIHOGO RED mutants which survived heat stress at 45°C for 6 days

Line	50%Flow	TN	PN	PH(cm)	PL(cm)	NS/Panicle	%Sterility	1000 Gwt(g)	GY/Plant(g)
KR3	99.3 b	31.3 e	24.7 d	111.7 d	26.3 c	158.3 d	64.5 d	19.0 ab	27.7 d
KR10	97.7 a	27.0 d	21.3 c	107.3 c	26.5 c	154.7 c	75.8 e	18.0 a	13.5 b
KR27	98.0 ab	19.7 bc	19.3 c	124.8 e	20.3 a	205.3 e	52.0 c	20.0 b	37.8 f
KR37	96.7 a	17.3 b	15.7 b	131.3 f	27.1 c	202.6 e	45.3 b	23.0 c	35.2 e
KR38	97.3 a	11.3 a	10.3 a	76.3 a	20.1 a	122.7 b	76.5f	17.0 a	5.9 a
KR-Cntl	101.0 c	22.0 c	19.7 c	100.0 b	22.0 b	104.3 a	42.0 a	32.0 d	16.3 c
mean	**98.33**	**21.44**	**18.5**	**108.58**	**23.7**	**157.98**	**59.356**	**21.72**	**22.639**
cv(%)	**0.9**	**6.1**	**5.8**	**0.7**	**3.4**	**1**	**0.5**	**5**	**1.2**

Means in the same column followed by the same letter are not significantly different at 5% level of probability

Note: PH=Plant height, NT=Number of tillers/plant, NP=Number of panicle/plant, NS=Number of spikelets/panicle,

GY=Grain yield, PL=Panicle length, and CV=Coefficient of variation,Cntrl=Control

Table 13: Mean agronomic performance of CG 14 mutants which survived heat stress at 45°C for 4 days.

Line	50%Flowering	TN	PN	PH(cm)	PL (cm)	NS/*Panicle*	%Sterility	1000Gwt(g)	GY/Plant(g)
CG14-20	71.7 bc	13.7 d	12.7 f	109.7cd	23.7 bc	97.7 e	35.7 a	19.0 a	13.8 f
CG14-52	71.3 abc	11.3 c	8.3 b	99.7 a	20.7 a	75.7 a	42.7 bc	20.0 ab	7.4 b
CG14-53	71.7 bc	10.7bc	10.3cde	104.3 b	25.7cd	87.0 c	80.4 g	23.0 bcd	3.5 a
CG14-65	70.3 a	11.3 c	11.3 ef	107.3 c	22.7 b	107.3 g	50.3 e	23.0 bcd	7.6 b
CG14-77	71.7 bc	11.3 c	10.7de	110.3 d	24.7bcd	98.7 e	44.3 c	21.0 abc	8.5 c
CG14-78	71.7 bc	9.7 bc	8.7 bc	110.3 d	26.0 d	103.3 f	43.7 c	24.0 cd	11.9 e
CG14-79	71.0 ab	6.7 a	6.0 a	110.0cd	26.0 d	190.3 h	42.7 bc	24.0 cd	12.0 e
CG14-80	72.3 c	9.0 b	8.7 bc	117.3 f	25.7 cd	93.3 d	47.6 d	24.0 d	10.9 d
CG14-81	70.3 a	9.7 bc	9.0bcd	109.7cd	24.7bcd	82.4 b	55.0 f	23.0 bcd	8.6 c
CG14Cntrl	82.0 d	16.7 e	16.7 g	114.3 e	23.3 b	86.6 c	41.2 b	33.0 e	15.0 g
Means	**72.4**	**11**	**10.23**	**109.3**	**24.28**	**102**	**48**	**23.4**	**9.92**
CV(%)		**9.6**	**10**	**1.3**	**4.8**	**1.6**	**2.3**	**6.5**	**2.9**

Means in the same column followed by the same letter are not significantly different at 5% level of probability

Note: PH=Plant height, NT=Number of tillers/plant, NP=Number of panicle/plant, NS=Number of spikelets/panicle,

GY=Grain yield, PL=Panicle length, and CV=Coefficient of variation,Cntrl=Control

At five days heat stress KR 26 mutant was the earliest (Table 11). When Kihogo red lines were stressed for six days, results showed that the earliest line was KR37 mutant (Table 12).

The CG 14-control plants showed the delay to reach 50% flowering as compared to the mutants treated with heat stress at 4, 5, and 6 days (Tables 13, 14 and 15). On the other hand, CG14-81 and CG14-65 mutants were the earliest to reach 50% flowering at four days heat stress (Table 13). CG14-54 mutant was the earliest to reach 50% flowering at five days heat stress (Table 14). Whereas, at six days CG14-59 mutant recorded the earliest to reach 50% flowering (Table 15).

The earliest WAB 56-104 genotype to reach 50% flowering at four days heat stress was WAB 56-104-40 mutant (Table 16). WAB 56-104-control plants recorded the latest days to reach 50% flowering compared to the mutants (Tables 16, 17 and 18). In case of earliest to 50% flowering at five days heat stress, WAB56-104-46 and WAB56-104-70 mutants were recorded as the earliest to flower (Table 17). When this genotype was stressed to six days, results revealed that WAB56-104-43 mutant was the earliest to reach 50% flowering (Table 18).

Table 14: Mean agronomic performance of CG 14 mutants which survived heat stress at 45°C for 5 days.

Line	50%Flowering	TN	PN	PH(cm)	PL(cm)	NS/*Panicle*	%Sterility	1000Gwt(g)	GY/Plant(g)
CG14-49	70.7 bcd	12.0 d	10.7 d	99.3 b	22.3 a	59.6 b	42.3 b	26.0 cd	5.7 b
CG14-50	71.3 cde	5.7 a	5.0 a	111.3 de	22.3 a	50.1 a	58.2 g	21.0 ab	4.7 a
CG14-51	70.0 ab	10.3 cd	9.7 cd	109.3 d	24.7 a	84.5 ef	51.8 e	25.0 cd	11.3 e
CG14-54	69.3 a	10.3bcd	10.3cd	105.3	24.3 a	74.5 d	57.2 g	24.0 bc	7.3 d
CG14-60	70.3 abc	11.0 cd	9.7 cd	86.3a	24.3 a	83.5 ef	54.3 f	23.0 abc	6.4 c
CG14-66	71.7 de	10.0bcd	9.0 bc	112.3 de	24.7 a	81.4 c	37.7 a	21.0 ab	7.3 d
CG14-75	72.3 c	12.3 d	10.0cd	109.7 d	21.7 a	95.2 g	49.1 d	19.0 a	7.6 d
CG14-76	70.3 abc	8.7 bc	7.7 b	104.0 c	22.0 a	74.8 d	38.0 a	28.0 d	7.2 d
CG14-82	69.7 ab	8.0 b	8.0 b	104.3 c	24.7 a	63.3 c	46.6 c	28.0 d	7.6 d
CG14Cntrl	82.0 f	16.7 e	16.7 c	114.3 e	23.1 a	86.6 f	41.2 b	33.0 e	15.0 f
Means	**71.77**	**10.5**	**9.67**	**105.63**	**23.41**	**75**	**47.65**	**24.8**	**8.007**
CV(%)	**0.8**	**11.8**	**8.6**	**1.8**	**7.2**	**2.3**	**2.2**	**8.4**	**5.2**

Means in the same column followed by the same letter are not significantly different at 5% level of probability
Note: PH=Plant height, NT=Number of tillers/plant, NP=Number of panicle/plant, NS=Number of spikelets/panicle,
GY=Grain yield, PL=Panicle length, and CV=Coefficient of variation,Cntrl=Control

Table 15: Mean agronomic performance of CG 14 mutants which survived heat stress at 45°C for 6 days.

Line	50%Flowering	TN	PN	PH(cm)	PL(cm)	NS/*Panicle*	%Sterility	1000Gwt(g)	GY/Plant(g)
CG14-5	71.7 bc	4.0 a	3.0 a	100.3 b	20.7 ab	118.3 de	58.0 ef	22.0 abcde	3.2a
CG14-6	72.7 cd	5.0 a	4.0 b	110.0 c	21.7 abc	143.4 f	56.6 de	26.0 def	5.0ab
CG14-7	71.3 b	15.0 d	14.0 f	123.3 f	23.0 cd	162.0 g	57.7 ef	19.7 a	20.5de
CG14-13	74.3 f	42.3i	33.6j	110.3 c	28.8 e	128.8 ef	44.9 bc	25.0 def	53.8 f
CG14-16	72.3 bcd	28.7 h	27.0 i	119.3 e	26.8 e	118.8 de	27.8 a	24.0 bcdef	55.8 f
CG14-21	73.3 de	18.0 f	16.3 g	102.3 b	21.7abc	133.6 ef	48.0 c	25.0 bdef	22.5 e
CG14-22	72.3 bcd	20.3 g	18.7 h	127.0 g	27.0 e	115.7 de	40.7 b	26.0 ef	18.9 d
CG14-59	69.7 a	8.7 b	7.0 c	113.3 d	24.3 d	59.0 a	68.6 h	21.0 abc	2.9 a
CG14-61	74.3 ef	10.0 b	8.7 d	102.0 b	21.0 abc	87.9 bc	52.8 d	22.0 abcd	7.7 b
CG14-62	74.3 f	15.7de	14.7 f	114.7 d	22.7 bcd	101.4 cd	56.3 de	21.0 ab	13. c
CG14-63	72.7 cd	9.3 b	9.0 d	100.7 b	27.7 e	68.9 ab	61.9 fg	23.0 abcdef	6.7b
CG14-64	71.7 bc	11.7 c	10.3 e	77.7 a	20.3 a	69.2 ab	63.7 g	27.0 f	5.3ab
CG14Cntrl	82.0 g	16.7 e	16.7 g	114.3 d	23.1 cd	86.6 bc	41.2 b	33.0 g	15.0 c
Means	**73.3**	**15.79**	**14.069**	**108.87**	**23.75**	**107**	**52.18**	**24.15**	**17.72**
CV(%)	**0.8**	**4.8**	**3.5**	**1.5**	**4.8**	**10**	**5**	**8.6**	**8.6**

Means in the same column followed by the same letter are not significantly different at 5% level of probability

Note: PH=Plant height, NT=Number of tillers/plant, NP=Number of panicle/plant, NS=Number of spikelets/panicle, GY=Grain yield, PL=Panicle length, and CV=Coefficient of variation,Cntrl=Control

Table 16: Mean agronomic performance of WAB 56-104 mutants line which survived heat stress at 45°C for 4 days

Line	50%Flowering	TN	PN	PH(cm)	PL(cm)	NS/Panicle	%Sterility	1000Gwt(g)	GY/Plant(g)
WAB56-104-39	71.7 a	6.7 c	6.7c	114.3 c	22.7cd	131.0 h	31.7 c	28.0abcd	19.1g
WAB56-104-40	71.0 a	9.3 d	8.0d	94.3 a	20.5b	89.7 d	18.3 a	29.67 cd	19.3g
WAB56-104-73	73.3 b	5.3b	5.3b	92.0 a	23.0d	81.8 b	30.7 e	27.0 ab	8.0b
WAB56-104-74	73.7 b	5.0b	4.7b	93.7 a	20.0b	15.3 f	31.7 c	27.0 abc	10.8d
WAB56-104-132	77.7 c	3.3a	3.3a	102.7 c	22.7cd	128.7 g	32.3 c	30.0 d	8.9 c
WAB56-104-133	78.3cd	3.3a	3.3a	108.7 d	21.3bcd	166.7 i	24.7 b	29.0bcd	11.9 e
WAB56-104-170	78.3cd	2.3 a	2.3a	98.3 b	20.7bc	99.6 e	51.0 e	26.0a	2.5a
WAB56-104-171	79.3d	2.3 a	2.3a	98.9 b	20.3b	88.1 c	72.0 f	27.0 abc	2.5a
WAB56-104-Cntrl	89.0 e	13.7e	12.0e	105.0 c	17.1a	79.6 a	36.9 d	28.0 abcd	13.2f
Means	76.9	**5.7**	**5.33**	**100.88**	**20.9**	**109**	**36.6**	**28.0**	**10.7**
CV%	0.9	**11.6**	**11.5**	**1.5**	5.6	**0.7**	**5.5**	**5.1**	**4**

Means in the same column followed by the same letter are not significantly different at 5% level of probability

Note:PH=Plant height,NT=Number of tillers/plant,NP=Number of panicle/plant,NS=Number of spikelets/panicle,

GY=Grain yield,PL=Panicle length and CV=Coefficient of variation. Cntrl=Control

Table 17: Mean agronomic performance of WAB 56-104 mutants which survived heat stress at 45°C for 5 days

Line	50%Flow	TN	PN	PH(cm)	PL(cm)	NS/Panicle	%Sterility	1000Gwt(g)	GY/Plant(g)
WAB56-104-12	75.3 a	9.3d	8.7d	104.3c	23.4cd	144.9 e	32.5b	25.0c	25.0f
WAB56-104-46	74.7a	7.0 c	7.0c	102.0bc	21.1 bc	118.3 cd	24.9 a	31.0e	22.2e
WAB56-104-62	75.7a	4.0b	4.0b	103.3c	23.7d	123.6 d	39.9d	28.0cd	10.1c
WAB56-104-70	74.7a	2.3a	2.3a	95.0ab	21.1 bc	106.3 bcd	63.2f	30.0de	3.1a
WAB56104-5-119	80.7d	4.0b	4.0 b	104.0c	18.1 a	202.3 f	56.6e	22.0b	6.6b
WAB56-104-136	79.7 c	4.0b	4.0 b	95.3ab	20.7b	144.2 e	82.0h	26.0c	3.7a
WAB56-104-137	78.7b	2.3a	2.3 a	91.3a	23.5cd	100.6 bc	66.9g	30.0de	2.2a
WAB56-104-181	75.3a	8.3cd	6.7 c	93.7a	8.9ab	92.0 ab	87.9 i	16.0a	1.8a
WAB56-104Cntrl	89.0e	13.7e	12.0e	105.0 c	17.1a	79.6 a	36.9c	28.0cd	13.2d
Means	**78.2**	**6.1**	**5.7**	**99.3**	**20.8**	**123.5**	**54.5**	**26.0**	**9.8**
CV%	**0.7**	**13.4**	**13.3**	**4.2**	**6.5**	**8.6**	**1.8**	**6.4**	**13.7**

Means in the same column followed by the same letter are not significantly different at 5% level of probability

Note:PH=Plant height,NT=Number of tillers/plant,NP=Number of panicle/plant,NS=Number of spikelets/panicle,

GY=Grain yield,PL=Panicle length and CV=Coefficient of variation. Cntrl=Control

Table 18: Mean agronomic performance of WAB 56-104 mutants which survived heat stress at 45°C for 6 days

Line	50%Flow	TN	PN	PH(cm)	PL(cm)	NS/Panicle	%Sterility	1000 Gwt(g)	GY/Plant(g)
WAB56-104-9	72.67 bc	11.667e	11.333ef	112.0 e	23.00 e	105.1 d	24.10 a	29.00 ef	24.47 e
WAB56-104-18	72.33 abc	16.667g	14.333g	95.7 b	20.33 d	109.9 de	79.90 h	25.67 cd	7.67 b
WAB56-104-36	72.33 abc	10.667e	10.333 e	111.3 de	23.40 ef	230.9 g	32.80 b	24.33 bc	36.10 f
WAB56-104-43	71.33 a	6.667 c	6.333 c	121.3 f	27.07 h	173.1 f	23.67 a	30.67 f	24.27 e
WAB56-104-71	71.67 ab	10.667e	10.333 e	109.7 d	24.00 f	111.0 de	24.53 a	26.67 d	21.97 e
WAB56-104-76	76.67 d	8.000 d	8.000 d	110.0 d	20.10cd	106.5 d	39.73 d	24.00 bc	12.07 cd
WAB56-104-118	79.00 f	4.333 a	4.000 a	95.7 b	25.90 g	115.1 e	64.77 g	19.67 a	3.23 a
WAB56-104-123	78.67 ef	5.00ab	4.667 ab	95.0 b	20.67 d	91.5 b	96.53 i	18.33 a	1.20 a
WAB56-104-141	77.67 de	4.000 a	4.000 a	93.3 a	18.03 b	97.7 c	58.80 f	22.33 b	3.70 a
WAB56-104-150	73.33 c	5.667bc	5.667bc	103.7 c	19.33 c	77.5 f	40.73 e	23.00 b	9.87 bc
WAB56-104Cntrl	89.00 g	13.667f	12.000f	105.0 c	17.13 a	79.6 a	36.90 c	27.67 de	13.20 d
Means	**75.88**	**8.82**	**8.27**	**104.79**	**21.724**	**127.08**	**47.497**	**24.67**	**14.34**
CV%	**0.9**	**7.7**	**7.9**	**0.9**	**2.2**	**2.8**	**1.2**	**6.4**	**9.8**

Means in the same column followed by the same letter are not significantly different at 5% level of probability

Note:PH=Plant height,NT=Number of tillers/plant,NP=Number of panicle/plant,NS=Number of spikelets/panicle,

GY=Grain yield,PL=Panicle length and CV=Coefficient of variation. Cntrl=Control

Mean agronomic performance of WAB56-50-Control plants recorded the latest days to reach 50 % flowering compared to WAB 56-50 mutants which survived heat stress at 4 days, 5 days and 6 days (Tables 19, 20 and 21). But in case of the earliest to 50% flowering at four days heat stress, WAB56-50-142 mutant was the earliest (Table 19). The WAB56-50-91 mutant recorded as the earliest at 5 days heat stress (Table 20). The earliest to reach 50% flowering at six days heat stress was WAB56-50-127 mutant (Table 21).

Table 19: Mean agronomic performance of WAB 56-50 mutants which survived heat stress at 45°C for 4 days

Line	50%Flw	TN	PN	PH in cm	PL in cm	NS/Panice	%Steriliy	1000Gwt(g)	GY/Plant(g)
WAB56-50-59	73.67 ab	2.667 a	2.333 a	102.33fgh	22.33cdef	75.50 c	62.00 gh	33.33 g	2.000 a
WAB56-50-60	76.33 fg	4.333 c	4.333cd	94.67 c	23.00 def	91.08 d	40.33 b	27.00 ef	5.667 f
WAB56-50-87	79.33 j	3.000 a	3.000 ab	93.00 bc	19.67 b	92.00 de	38.33 ab	26.00 de	3.200 cd
WAB56-50-88	77.33 hi	4.333 c	4.333cde	83.00 a	19.67 b	93.58 e	55.00 ef	24.33 bcd	2.400 ab
WAB56-50-95	80.67 k	3.333 ab	3.000ab	95.67 cd	24.33 f	76.89 c	60.00 fgh	24.33 bcd	3.600 d
WAB56-50-96	80.33 k	6.000 de	6.000 f	102.67 gh	19.33 b	91.83 de	47.00 d	24.33 bcd	4.567 e
WAB56-50-99	79.33j	6.333 e	3.333 b	98.33 de	21.33 bcd	45.17 a	55.33 ef	20.33 a	1.833 a
WAB56-50-124	74.33 bc	6.000 de	6.000 f	102.00 fg	22.67 def	76.39 c	68.33ij	24.00 bcd	4.500 e
WAB56-50-125	77.67 i	4.000 bc	4.000 c	95.00 c	20.33 bc	111.67 h	59.33 fg	25.67 cde	6.300 g
WAB56-50-133	75.67 ef	3.000 a	3.000 b	99.67 ef	22.00 cde	73.11 b	46.33 cd	24.00 bcd	2.667 bc
WAB56-50-134	74.67 cd	3.000 a	3.000ab	105.00 h	22.33cdef	96.78 f	64.67 hi	22.67 b	4.300 c
WAB56-50-142	73.33 a	6.000 de	6.000 f	103.67 gh	20.33 bc	139.33 j	70.67j	23.67 bcd	6.433 g
WAB56-50-143	75.33 de	3.333 ab	3.000ab	98.33 e	23.67 ef	119.56 i	41.67 bc	27.33 ef	5.400 f
WAB56-50-156	76.67 gh	5.333 d	5.000 d	91.00 b	23.33 def	145.60k	50.67 de	23.33 bc	6.533 g
Cntrl WAB56-50	85.00l	7.667 f	7.000 g	95.00 c	17.10 a	109.00 g	33.97 a	29.33 f	9.000 h
Means	**77.311**	4.556	4.222	97.29	21.43	96	52.91	25.31	4.56
CV%	0.7	9.3	9.3	1.6	5.6	1.1	5.5	5.3	7.2

Means in the same column followed by the same letter are not significantly different at 5% level of probability
Note:PH=Plant height,NT=Number of tillers/plant,NP=Number of panicle/plant,NS=Number of spikelets/panicle,
GY=Grain yield,PL=Panicle length and CV=Coefficient of variation. Cntrl=Control

Table 20: Mean agronomic performance of WAB56-50 mutants which survived heat stress at 45^{0}C for 5 days

Line	50%Flw	TN	PN	PH in cm	PL in cm	NS/Panice	%Steriliy	1000Gwt(g)	GY/Plant(g)
WAB56-50-70	79.33 c	4.000 e	3.000 b	100.67 d	22.73 f	119.6 e	40.03 bc	25.67 bc	5.167 cd
WAB56-50-90	76.67 b	2.333 a	2.000 a	99.67 d	17.33 ab	107.7 cd	57.53 f	24.00 ab	1.767 a
WAB56-50-91	74.33 a	4.000 c	4.000 c	105.00 e	20.30 de	101.1 b	42.27 c	24.67 abc	6.200 ef
WAB56-50-100	79.67 c	5.000 d	3.000 b	83.00 a	18.43 abc	91.1 a	39.10 b	26.00 bc	4.067 b
WAB56-50-107	80.00 c	4.000 c	4.000 c	95.67 c	20.07 cde	120.8 ef	64.17 g	25.33 bc	4.567 bc
WAB56-50-119	76.67 b	3.000 b	2.000 a	90.00 b	19.00 bcd	92.8 a	66.13 g	27.33 cd	1.767 a
WAB56-50-139	77.67 b	5.000 d	3.000 b	95.00 c	21.00 e	105.7 c	48.33 d	23.33 ab	4.433 b
WAB56-50-140	76.67 b	4.000 c	4.000 c	105.67 e	23.10 f	122.4 f	46.73 d	23.67 ab	6.600 f
WAB56-50-146	77.00 b	5.000 d	5.000 d	94.33 c	18.63abcd	109.3 d	54.77 e	22.33 a	5.767 de
WAB56-50-147	77.67 b	7.000 c	7.000 e	122.67 f	23.83 f	100.0 b	55.07 ef	24.33 ab	9.167 g
Cntrl WAB56-50	85.00 d	7.667f	7.667f	95.00 c	17.10 a	109.0 d	33.97 a	29.33 d	9.000 g
Means	**78.24**	**4.636**	**4.061**	**98.79**	**20.14**	**107**	**49.83**	**25.09**	**5.318**
CV %	**0.9**	**5.2**	**4.3**	**1.4**	**4.7**	**1.1**	**3.1**	**5.9**	**6.9**

Means in the same column followed by the same letter are not significantly different at 5% level of probability
Note:PH=Plant height,NT=Number of tillers/plant,NP=Number of panicle/plant,NS=Number of spikelets/panicle,
GY=Grain yield,PL=Panicle length and CV=Coefficient of variation. Cntrl=Control

Table 21: Mean agronomic performance of WAB56-50 mutants which survived heat stress at 45°C for 6 days

Line	50%Flow	TN	PN	PH in cm	PL in cm	NS/Panicle	%Sterility	1000 Gwt(g)	GY/Plant(g)
WAB56-50-48	73.33 ab	3.000abc	3.000 b	100.0 d	20.27bcde	85.89 e	36.40 cd	26.33 e	4.200 d
WAB56-50-51	74.33 bc	2.333 a	2.000 a	109.7 f	21.33cdef	8.50 h	57.50 g	30.33 f	2.533 c
WAB56-50-56	75.33 cd	3.333bcd	3.000 b	101.3 d	18.33 ab	84.33 c	24.43 b	29.67 f	4.467 d
WAB56-50-82	77.67 f	8.333 h	7.000 e	112.7 g	22.57 fg	85.10 c	18.40 a	29.33 f	14.500 h
WAB56-50-85	76.67 ef	3.667 cd	2.000 a	98.7 d	19.93bcde	96.83 h	97.50 k	20.00 b	1.300 b
WAB56-50-97	79.33 g	5.000 fg	5.000 d	104.3 e	24.33 g	92.20 g	44.43 ef	20.00 b	5.533 e
WAB56-50-98	81.33h	4.000 de	4.000 c	89.7 b	19.43 bc	56.75 a	84.93 i	21.33 bc	0.533 a
WAB56-50-123	73.33 ab	4.000 de	2.000 a	112.7 fg	21.07cdef	62.83 b	43.90 ef	23.00 cd	1.667 b
WAB56-50-127	72.33 a	5.667 g	5.000 d	94.3 c	21.53 def	100.60i	53.70 g	21.67 bcd	4.400 d
WAB56-50-135	76.33 de	5.667 g	3.000 b	110.0 fg	27.50 h	164.89 k	47.00 f	29.67 f	4.333 d
WAB56-50-138	76.33 de	4.667 ef	4.000 c	106.0 e	19.67bcd	75.25 d	40.20 de	26.00 e	6.033 f
WAB56-50-141	74.67 c	4.000 de	4.000 c	94.7 c	21.90 ef	89.33 f	67.70 h	24.33 de	6.033 f
WAB56-50-152	73.33 ab	2.667 ab	2.000 a	72.3 a	17.27 a	69.50 c	91.33 j	15.33 a	1.333 b
Cntrl WAB56-50	85.00i	7.667 h	7.333 f	95.0 c	17.10 a	109.00j	33.97 c	29.33 f	9.000 g
Means	76.381	4.548	3.81	100.1	20.87	91	52.96	24.98	4.638
CV %	0.8	10.3	4.1	1.6	5.2	1.3	6.2	5.9	5.9

Means in the same column followed by the same letter are not significantly different at 5% level of probability
Note:PH=Plant height,NT=Number of tillers/plant,NP=Number of panicle/plant,NS=Number of spikelets/panicle,
GY=Grain yield,PL=Panicle length and CV=Coefficient of variation. Cntrl=Control

The combined results for days to 50% flowering verified that the earliest plant to reach 50% flowering at four days heat stress was recorded from CG14-65 and CG14-81 mutants (Table 22). At five days the earliest to flower was CG14-54 mutant and at six days heat stress the earliest to reach 50% flowering was CG14-59 mutant (Tables 22 and 23) respectively. On the other hand, KR control plants were the latest to reach days to 50% flowering compared for all mutants stressed to heat at 4,5,and 6 days although at four days the data was not statistically different to CG14-control plants and at five days were not statistically different to KR39 mutant (Tables 22, 23 and 24).

Table 22: Combined Mean agronomic performance of mutants rice which survived heat stress at 45°C for 4 days and their control

Genotype	50% flowering	Tillers/plant	Panicles/ plant	Plant height (cm)	Panicle length (cm)	Spikelets/ panicle	%Sterility	1000 seeds weight (g)	Grain yield (g/plant)
KR 28	99.67 u	7.1 hi	6.1 fg	92.1 cd	23.10 fghi	151.2 u	68.33 s	18.7 b	10.17 l
KR 29	99.00 tu	11.3l	9.7 jk	72.7 a	20.03 bc	99.6 k	90.33 u	16.3 a	2.70 bc
KR30	98.33 t	11.0 l	9.0 ij	109.7 mn	22.70 efgh	111.6 o	55.67 o	20.3bcd	11.40 no
KR-Contl	101.00 v	22.0 o	19.7 p	100.0 fghi	22.00 cdefg	104.3 l	42.03 hi	32.0 rs	16.30 s
CG14-20	71.67 bc	13.7 m	2.7 n	109.7 mn	23.67 ghij	97.7 jk	35.67 def	33.3 s	13.83 q
CG14-52	71.33 abc	11.3 l	8.3 i	99.7 fg	20.67 bcde	87.0 f	42.67 ij	20.3 bcd	7.37 h
CG14-53	71.67 bc	10.7 kl	10.3 kl	104.3 jk	25.67 jl	87.0 f	80.43 t	22.7 def	3.50 d
CG14-65	70.33 a	11.3 l	11.3 lm	107.3 lm	22.67 efghi	107.3 m	50.33 mn	23.0 efg	7.63 hi
CG14-77	71.67 bc	11.3 l	10.7 kl	110.3 n	24.67 ijkl	98.7 jk	44.33 ijkl	21.3 cde	8.47 jk
CG14-78	71.67 bc	9.7 jk	8.7 ij	110.3 n	26.00 l	103.3 l	43.67 ijk	23.7 efgh	11.93 o
CG14-79	71.00 ab	6.7 ghi	6.0 fg	110.0 mn	26.00 l	190.3 w	42.67 ij	24.0 fghi	11.97 o
CG14-80	72.33 cd	9.0 j	8.7 ij	117.3 p	5.67 jkl	93.3 i	47.60 lmn	24.3 fghijk	10.93 mn
CG14-81	77.67 lm	9.7 jk	9.0 ij	109.7 mn	24.67 ijkl	82.4 e	54.97 o	22.7 def	8.57 jk
CG-Contrl	101.00 v	16.7 n	16.7 o	114.3 o	23.13 fghi	86.6 f	41.23 hi	33.0 s	15.00 r
WAB56-104-39	71.67 bc	6.7 ghi	6.7 g	114.3 o	22.73 efghi	131.0 r	31.67 c	28.3mnopq	19.10 t
WAB56-104-40	71.00 ab	9.3 j	8.0 hi	94.3 de	20.47 bcd	89.7 gh	18.33 a	29.7 pqr	19.27 t
WAB56-104-73	73.33 de	5.3 efg	5.3 ef	92.0 cd	23.00 fghi	81.8 de	30.67 c	26.7 iklmn	8.00 ij
WAB56-104-74	73.67 ef	5.0 def	4.7 de	93.7 cde	20.00 bc	115.3 p	31.67 c	27.3 lmnop	10.80 m
WAB56-104-132	77.67 lm	3.3 abc	3.3 abc	102.7 jk	22.67 efghi	128.7 r	32.33 cd	30.3 qr	8.87 k
WAB56-104-133	78.33 mn	3.3 abc	3.3 abc	108.7 mn	21.33 bcdef	166.7 v	24.67 b	28.7 nopq	11.90 o
WAB56-104-170	78.33 mn	2.3 a	2.3 a	98.3 f	20.67 bcde	99.6 jk	51.00 n	25.7 ghijkl	2.47 ab
WAB56-104-171	79.33 no	2.3 a	2.3 a	98.9 f	20.33 bcd	88.1 fg	72.00 s	27.3 lmnop	2.27 ab
WAB104-C	89.00 s	13.7 m	12.0 mn	105.0 kl	17.13 a	79.6 d	36.90 efg	27.7 lmnop	13.20 p
WAB56-50-59	73.67 ef	2.7 ab	2.3 a	102.3 gijk	22.33 defgh	75.5 bc	62.00 pq	33.3 s	2.00 a
WAB56-50-60	76.33 ijk	4.3 cde	4.3 cde	94.7 de	23.00 fghi	91.1 hi	40.33 ghi	27.0 lmno	5.67 f
WAB56-50-87	79.33 no	3.0 abc	3.0 ab	93.0 cde	19.67 b	92.0 hi	38.33 fgh	26.0hijklm	3.20 cd
WAB56-50-88	77.33 klm	4.3 cde	4.3 cde	83.0 b	19.67 b	93.6 i	55.00 o	24.3 fghijk	2.40 ab
WAB56-50-95	80.67 p	3.3 abc	3.0 ab	95.7 e	24.33 hijkl	76.9 c	60.00 p	24.3 fghijk	3.60 d
WAB56-50-96	80.33 op	6.0 fgh	6.0 fg	102.7 ijk	19.33 b	91.8 hi	47.00 klm	24.3 fghijk	4.57 e
WAB56-50-99	79.33 no	6.3 fgh	3.3 abc	98.3 f	21.33 bcdef	45.2 a	55.33 o	20.3 bcd	1.83 a
WAB56-50-124	74.33 efg	6.0 fgh	6.0 fg	102.0 ghij	22.67 efghi	76.4 c	68.33 rs	24.0 efghij	4.50 e
WAB56-50-125	77.67 lm	4.0 bcd	4.0 bcd	95.0 e	20.33 bcd	111.7 n	59.33 p	25.7 ghijkl	6.30 g
WAB56-50-133	75.67 hij	3.0 abc	3.0 ab	99.7 fgh	22.00 cdefg	73.1 b	6.33 jkl	24.0 fghij	2.67 bc
WAB56-50-134	74.67 fgh	3.0 abc	3.0 ab	105.0 kl	22.33 defgh	96.8 j	64.67 qr	22.7 def	4.30 e
WAB56-50-142	73.33 de	6.0 fgh	6.0 fg	103.7 jk	20.33 bcd	139.3 s	70.67 s	23.7 efgh	6.43 g
WAB56-50-143	75.33 ghi	3.3 abc	3.0 ab	98.3 f	23.67 ghijk	119.6 q	41.67 hi	27.3 lmnop	5.40 f
WAB56-50-156	76.67 jkl	5.3 defg	5.0 def	91.0 c	23.33 fghi	145.6 t	50.67 mn	23.3 efgh	6.53 g
Cntrl WAB50	85.00 r	7.7 i	7.0 gh	95.0 e	17.10 a	109.0 mn	33.97 cde	29.3 opq	9.00 k
Mean	78.263	7	7	100.91	22.12	103	49	25.07	8.01
C.V (%)	0.8	9.8	9.7	1.5	4.9	1.5	4.4	5.5	4.4

Means in the same column followed by the same letter are not significantly different at DMRT5 % level of probability

Table 23: Combined Mean agronomic performance of mutants rice which survived heat stress at 45°C for 5 days and their control

Genotype	50% flowering	Tillers/ plant	Panicles/ plant	Plant height (cm)	Panicle length (cm)	Spikelets/ panicle	% Sterility	1000 seeds weight (g)	Grain yield (g/plant)
KR-9	99.67 s	12.7 no		115.7 q	26.40 m	144.7 m	46.1 h	18 3 ab	12 40 mn
KR-26	97.67 r	9.7 ijkl	7.7 fgh	110.7 op	24.40 jklm	153.0 m	58 2 n	19.0 ab	13 40 no
KR-39	100.67 t	7.7 fg	8.7 hij	109.3 mno	25.30 lm	119 0 kl	47 1 hij	19.3 bcd	16 20 pq
KR-40	99.33 s	7.7 fg	5.7 de	115.3 q	22.87 fghijkl	124.1 l	49 0j	21.3 bcdef	13.77 o
KR-Contl	101.00 t	22.0 q	6.7 ef	100.0 ghij	22 00 efghij	104.3 ij	42.0 g	32 0 op	16.30 q
CG14-49	70.67 bcd	12.0 mn	19 7 o	99.3 efgh	22 33 efghijk	59 6 ab	42 3 g	25.7 hijkl	5 67 fgh
CG14-50	71.33 cde	5.7 de	10.7 l	111 3 opq	22 33 efghijk	50.3 a	58.2 n	21.0 bcde	4 73 def
CG14-51	70.00 ab	10.3 kl	5.0 cd	109.3 mno	24.67 klm	84.5 cdefg	51.8 k	25.3 ghijkl	6.20 ghi
CG14-54	69.33 a	10.3 kl	9.7 jkl	105.3 klmn	24.33 jklm	74.5 c	57.2 n	23.7 efghi	7.27 ij
CG14-60	70.33 abc	11.0 lm	10.3 l	86.3 ab	24.33 jklm	83.5 cdef	54 3 l	22.7 efgh	6.40 ghij
CG14-66	71.67 de	10.0 jkl	9.7 jkl	112.3 opq	24.67 klm	81.4 cde	66.1 p	21.3 bcdef	7.33 ij
CG14-75	72.33 e	12.3 mno	9.0 ijk	109.7 no	21.67 efghi	95.2 ghi	49.1 j	19.3 bc	7.63 j
CG14-76	70.33 abc	8.7 ghij	10.0 kl	104.0 ijkl	22.00 efghij	74 8 c	38.0 cde	28.3 lmn	7.17 ij
CG14-82	69.67 ab	8.0 fgh	7.7 fgh	104.3 jkl	24.67 klm	63.3 b	46.6 hi	27.7 klm	7.60 ij
Control-CG-14	82.00 o	16.7 p	8.0 ghi	114.3 pq	23.13 ghijkl	86.6 defg	41 2 fg	33.0 p	15.0 p
WAB50-104-12	75.33 fg	9.3 hijk	16.7 n	104.3 ijkl	23.43 ghijkl	144.9 m	32.5 b	25.3 ghijkl	24.97 s
WAB50-104-46	74.67 fg	7.0 ef	8.667 hij	102.0 hijkl	21.13 defgh	118.3 kl	24.9 a	31 0 nop	22.20 r
WAB50-104-62	75.67 gh	4.0 bc	7.0 fg	103.3 hijkl	23.67 ijkl	123.6 l	39.9 ef	27.7 klm	10.10 kl
WAB50-104-70	74.67 fg	2.3 a	4.0 bc	95.0 de	21.07 defgh	106.3 j	63.2 o	29.7 mno	3.13 bc
WAB50-104-119	80.67 n	4.0 bc	2.3 a	104.0 ijkl	18.07 ab	202.3 n	56.6 mn	22.3 cefg	6.60 hij
WAB50-104-136	79.67 lmn	4.0 bc	4.0 bc	95.3 def	20.67 cdef	144.2 m	82.0 q	26.0 ijkl	3.67 cd
WAB50-104-137	78.67 jl	2.3 a	4.0 bc	91.3 cd	23.47 hijkl	00 6 hij	66.9 p	3.03 mnop	2.23 ab
WAB50-104-181	75.33 fg	8.3 fghi	2.3 a	93.7 cd	18 87 abcd	92.0 efgh	87.9 r	16.3 a	1.83 a
WAB56-104-Cnt	89.00 q	13.7 o	6.7 ef	105.0 klm	17.13 a	79.6 cd	36 9 c	27.7 klm	13.20 no
WAB56-50-70	79.33 lm	4.0 bc	12.0 m	100.7 hijk	22 73 fghijk	119.6 kl	40.0 ef	25.7 hijkl	5 17 efg
WAB56-50-90	76.67 i	2.3 a	3.0 ab	99.7 fghi	17.33 a	107.7 j	57.5 n	24.0 efghi	1.77 a
WAB56-50-91	74.33 f	4.0 bc	2.0 a	105.0 klm	20.30 bcde	101.1 hij	42 1 g	24.7 ghijk	6 20 ghi
WAB56-50-100	79.67 lmn	5.0 cd	4.0 bc	83.0 a	18.43 abc	91 1 efgh	39 1 de	26 0 ijkl	4 07 cde
WAB56-50-107	80.00 mn	4.0 bc	3.0 ab	95.7 defg	20.07 bcde	120.8 l	64.2 o	25.3 ghijkl	4.57 def
WAB56-50-119	76.67 hi	3.0 ab	4.0 bc	90.0 bc	19.00 abcd	92.8 fgh	66.1 p	27.3 jklm	1.77 a
WAB56-50-139	77.67 ijk	5.0 cd	2.0 a	95.0 de	21.00 defg	105.7 ij	48 3 ij	23.3 efghi	4.43 cdef
WAB56-50-140	76.67 hi	4.0 bc	3.0 ab	105.7 lmn	23.10 ghijkl	122.4 l	46.7 hi	23.7 efghi	6 60 hij
WAB56-50-146	77.00 i	5.0 cd	4.0 bc	94.3 cd	18.63 abc	109.3 jk	54 8 lm	22.3 cdefg	5.77 fgh
WAB56-50-147	77.67 ij	7.0 ef	5.0 cd	122.7 r	23 83 ijkl	100.0 hij	55 1 lm	24 3 fghij	9.17 k
Cntrl WAB56-50	85.00 p	7.7 fg	7.0 fg	95.0 de	17 10 a	109.0 jk	34.0 b	29.3 mno	9.00 k
Mean	79.438	7.7	7.7 fgh	102.51	21.83	105	50.22	24.9	8.53
C.V (%)	0.8	10.9	6.9	2.4	5.7	5.6	2.3	6.7	8.8

Means in the same column followed by the same letter are not significantly different at DMRT5 % level of probability

Table 24: Mean agronomic performance of mutants' rice which survived heat stress at 45°C for 6 days and their control.

Genotype	50% flowering	Tillers/ plant	Panicles/ plant	Plant height (cm)	Panicle length (cm)	Spikelets/ panicle	% Sterility	1000 seeds weight (g)	Grain yield (g/plant)
KR-3	99.33 q	31.3 x	24.7 C	111.7 lmnopq	26.33 n	158.3 v	64.50 pqr	19.3 bcd	27.07 u
KR-10	97.67 op	27.0 v	21.3 B	107.3 jk	26.50 n	154.7 v	75.83 s	18.0 bc	13.53 mn
KR-27	98.00 p	19.7 t	19.3 zA	124.8 vw	20.33 defgh	205.3 y	52.00 k	20.3 cdef	37.83 w
KR-37	96.67 o	17.3 s	15.7 x	131.3 x	27.10 n	202.6 y	45.30 ij	23.3 ghijkl	35.23 v
KR-38	97.33 op	11.3 no	10.3 tu	76.3 b	20.10 cdefgh	122.7 rs	76.47 st	17.3 ab	5.87 hij
KR-Contl	101.00r	22.0 u	19.7 A	100.0 ef	22.00 hijk	104.3 lmnop	42.03 fghi	32.0 tu	16.30 o
CG14-5	71.67 bc	4.0 bcdef	3.0 ae	100.3 ef	20.67 defgh	118.3 qrs	58.00 mno	22.3 efghi	3.20 bcdef
CG14-6	72.67 cd	5.0 efg	4.0 ei	110.0 lm	21.67 ghijk	143.4 u	56.63 lmn	26.0 jlmno	5.00 efghi
CG14-7	71.33 b	15.0 q	14.0 w	123.3 uv	23.00 jkl	162.0 v	57.73 mn	19.7 bcde	20.50 pq
CG14-13	74.33 ef	42.3 y	33.6 E	110.3 lmnop	28.83 o	128.8 st	44.87 hij	24.7 ijklmn	53.83 x
CG14-16	72.33 bcd	28.7 w	27.0D	119.3 t	26.83 n	118.8 qrs	27.83 b	24.3 ijklmn	55.77 y
CG14-21	73.33 de	18.0 s	16.3 xy	102.3 fgh	21.67 ghijk	133.6 tu	48.00 j	24.7 ijklmn	22.47 rs
CG14-22	72.33 bcd	20.3 t	18.7 z	127.0 w	27.00 n	115.7 pqr	40.73 efgh	26.0 jklmno	18.93 p
CG14-59	69.67 a	8.7 jkl	7.0 op	113.3 qrs	24.33 lm	59.0 ab	68.57 r	20.7 cdefg	2.93 bcde
CG14-61	74.33 ef	10.0 lmn	8.7 rs	102.0 fgh	21.00 defghi	87.9 efghi	52.77 kl	22.0 defghi	7.67 jk
CG14-62	74.33 ef	15.7 qr	14.7 w	114.7 s	22.67 ijkl	101.4 klmno	56.33 lmn	20.7 cdefg	13.07 mn
CG14-63	72.67 cd	9.33 klm	9.0 s	100.7 ef	27.67 no	68.9 bc	61.93 op	23.3 ghijkl	6.73 ij
CG14-64	71.67 bc	11.7 o	10.3 t	77.7 b	20.33 defgh	69.2 bc	63.73 pq	26.7 nopq	5.30 fghi
CG-Contrl	82.00 l	16.7 rs	16.7 y	114.3 rs	23.13 jkl	86.6 defgh	41.23 fghi	33.0 u	15.00 no
WAB56-104-9	72.67 cd	11.7 o	11.3 tv	112.0 lmnopqr	23.00 jkl	105.1lmnop	24.10 b	29.0 pqrs	24.47 t
WAB56-104-18	72.33 bcd	16.7 rs	14.3 w	95.7 d	20.33 defgh	109.9 nopq	79.90 t	25.7 jklmno	7.67 jk
WAB56-104-36	72.33 bcd	10.7 mno	10.3 tu	111.3 lmnopq	23.40 kl	230.9 z	32.80 c	24.3 hijklmn	36.10 vw
WAB56-104-43	71.33 b	6.7 hi	6.3 no	121.3 tu	27.07 n	173.1 wx	23.67 b	30.7 stu	24.27 st
WAB56-104-71	71.67 bc	10.7 mno	10.3 tu	109.7 l	24.00 l	111.0 opq	24.53 b	26.7 nopq	21.97 qr
WAB56-104-76	76.67 hi	8.0 ijk	8.0 qr	110.0 lmn	20.10 cdefgh	106.5 lmnop	39.73 def	24.0 hijklmn	12.07 m
WAB56-104-118	79.00 k	4.3 cdefg	4.0 efi	95.7 d	25.90 mn	115.1 pqr	64.77 pqr	19.7 bcde	3.23 bcdef
WAB56-104-123	78.67 jk	5.0 efg	4.7 ijkl	95.0 d	20.67 defgh	91.5 fghijk	96.53 w	18.3 bc	1.20 ab

Table 24 continue

Genotype	50% flowering	Tillers/ plant	Panicles/ plant	Plant height (cm)	Panicle length (cm)	Spikelets/ panicle	% Sterility	1000 seeds weight (g)	Grain yield (g/plant)
WAB56-104-141	77.67 ij	4.0 bcdef	4.0 efgi	93.3 d	18.03 ab	97.7 hijklm	58.80 no	22.3 efghi	3.70 cdefg
WAB56-104-150	73.33 de	5.7 gh	5.7 mn	103.7 ghi	19.33 bcd	177.5 x	40.73 efgh	23.0 fghijk	9.87 l
WAB56-104-Cont	89.00 n	13.7 p	12.0 v	105.0 ij	17.13 a	79.6 cde	36.90 cde	27.7 opqr	13.20 mn
WAB56-50-48	73.33 de	3.0 abc	3.0 abef	100.0 ef	20.27 defgh	85.9 defg	36.40 cd	26.3 lnop	4.20 defgh
WAB56-50-51	74.33 ef	2.3 a	2.0 ab	109.7 kl	21.33 efghij	98.5 ijklmn	57.50 mn	30.3 rstu	2.53 abcd
WAB56-50-96	75.33 fg	3.3 abcd	3.0 abcdefgh	101.3 fg	18.33 abc	84.3 def	24.43 b	29.7 rst	4.47 defgh
WAB56-50-82	77.67 ij	8.3 jk	7.0 op	112.7 mpqrs	22.57 ijkl	85.1 defg	18.40 a	29.3 qrst	14.50 no
WAB56-50-85	76.67 hi	3.7 abcde	2.0 abc	98.7 e	19.93 cdefg	96.8 ghijkl	97.50 w	20.0 bcde	1.30 ab
WAB56-50-97	79.33 k	5.0 efg	5.0 ilm	104.3 hi	24.33 lm	92.2 fghijk	44.43 ghij	21.3 defgh	'5.53 ghi
WAB56-50-98	81.33 l	4.0 bcdef	4.0 efghijk	89.7 c	19.43 bcde	56.8 a	84.93 u	23.0 fghij	0.53 a
WAB56-50-123	73.33 de	4.0 bcdef	2.0 abcd	112.7 mnpqrs	21.07 defghi	62.8 ab	43.90 fghij	23.3 fghijklm	1.67 abc
WAB56-50-127	72.33 bcd	5.7 gh	5.0 ijlm	94.3 d	21.53 fghijk	100.6 jklmno	53.70 klm	21.7 defghi	4.40 defgh
WAB56-50-135	76.33 gh	5.3 fgh	3.0 abcefg	110.0 lmno	27.50 no	164.9 vw	47.00 j	29.7 rst	4.33 defgh
WAB56-50-138	76.33 gh	4.7 defg	4.0 efghi	106.0 ij	19.67 bcdef	75.2 cd	40.20 defg	26.0 jklmno	5.10 fghi
WAB56-50-141	74.67 f	4.0 bcdef	4.0 efghij	94.7 d	21.90 hijk	89.3 efghij	67.70 qr	24.3 hijklmn	6.03 hij
WAB56-50-152	73.33 de	2.7 ab	2.0 a	72.3 a	17.27 a	69.5 bc	91.33 v	15.3 a	1.33 ab
Cntrl WAB56-50	85.00 m	7.7 ij	7.3 pq	95.0 d	17.10 a	109.0 mnopq	33.97 c	29.3 qrst	9.00 kl
Mean	78.333	11.242	10	105.02	22.327	114	52.24	24.2	13.384
C.V (%)	0.8	7	5.7	1.4	4.4	5.5	4.5	6.4	8.4

Means in the same column followed by the same letter are not significantly different at DMRT 5% level of probability

4.2.2 Number of tillers per plant

The analysis of variance revealed significant difference among the rice genotypes for this trait (Tables 10-21). KR-control plant had the highest number of tillers as compared to KR mutants stressed at 4 and 5 days heat stress (Tables 10 & 11). KR-28 mutant had the lowest number of tillers per plant at 4 days (Table 10). Table 11, shows the lowest number was from KR-39 and KR 40 mutants at five days of exposure. After six days of heat stress, the highest number of tillers per plant was observed for KR-3 mutant and the lowest number was from KR38 mutant (Table 12). Results from mutants of CG 14 genotype, recorded CG14 control plant to have the highest number of tillers per plant, as compared to stressed mutants at four and five days heat stress. CG14- 79 mutant had the lowest number of tillers per plant at four days of stress (Tables 13 and 14). The lowest number after 5 days of heat stress was recorded from CG14-82 mutant with 8 tillers per plant (Table 14). At six days of heat stress the highest number of tillers per plant was obtained from CG14-13 mutant, while the lowest number was recorded for CG14-5 mutant (Table 15).

WAB 56-104 control plants, recorded the highest number of tillers per plant compared to the mutants stressed at 4 and 5 days recorded (Tables 16 and 17). The lowest tiller number per plant after four days, were obtained from line WAB56-104-171 mutant (Table 16). At five days heat stress, 2.3 tillers was the smallest number which was recorded from WAB56-104-70 and WAB56-104-137 mutants (Table 17). After six days of heat stress, the highest tiller number per plant was noted from WAB56-104-18 mutant, WAB56-104-141 mutant recorded the lowest tiller numbers per plant (Table 18).

For WAB 56-50 control, the average number of tillers recorded. (7.7) was the highest tiller number compared to WAB 56-50 mutants stressed at 4 and 5 days heat stress. while from WAB56-50-59 mutant 2.7 tillers were observed as smallest number at 4 days (Table 19). At 5 days heat stress, the smallest number of tillers was 2.3 which was recorded from WAB56-50-90 mutant (Table 20). WAB56-50-82 mutant recorded the highest tiller numbers at six days heat stress and WAB56-50-51 mutant had the lowest number of tillers (Table 21). The combined results also showed the significant ($P \leq 0.05$) differences among genotypes where KR-Control plant and WAB 56-104-control plant recorded the highest number of tillers per plant, compared to mutants stressed at 4 and 5 days heat stress, whereas WAB 56-104-170 and WAB56-104-171 mutants produced the lowest number of tiller per plant at 4 days heat stress (Tables 22 & 23). At 5 days heat stress, WAB56-50-100, WAB56-104-139 and WAB56-50-90 mutants observed the lowest tillers number where both recorded 2.3 tillers per plant (Table 23). From six days heat stress, the combined analysis revealed that the highest number of tiller per plant was obtained from CG14-13 mutant, whereas WAB56-50-51 mutant recorded the lowest tillers per plant (Table 24).

4.2.3 Number of panicles per plant

The mutant lines significantly ($P \leq 0.05$) differed in their number of panicles per plant at 4, 5 and 6 days heat stress (Tables 10, 11 and 12). Results from Kihogo red revealed, KR control recorded 19.7 panicles per plant as the highest number compared to Kihogo red mutants which survived at four and five days heat stress (Tables 10, and 11). On the other hand, the lowest number of panicles was noted from KR28 mutant at 4 days of heat stress (Table10). KR39 and KR38 mutants recorded the lowest number of panicles at 5 and 6 days respectively (Tables 11 and 12) while at six days of hear stress, KR3 mutant had the highest number of panicles per plant.

CG14-Control plant recorded the highest number of panicles per plant as compared to all CG14 mutants which were heat stressed at 4 and 5 days (Tables 13 and 14). At six days heat treatment, CG14-13 mutant was the highest by having 33.6 panicles per plant (Table 15). Six panicles per plant from CG14-79 mutant was the lowest value recorded at 4 days of heat stress (Table 13).

At five days of heat stress CG14-50 mutant produced the lowest number of panicles per plant with five panicles (Table14). However, CG14-5 mutant recorded the lowest number of panicles per plant at six days of heat stress (Table 15).

WAB56-104-control plant when compared with Mutants stressed at four, and five days of heat stress recorded the highest number of panicles plant (Tables 16, and 17). On the other hand, the lowest number of panicles at four days of stress were observed from WAB 56-104-17 and WAB56-104-171 mutants (Table 16). At five days of heat stress the minimum number of panicles per plant were recorded from WAB56-104-70 and WAB56-104-137 mutants (Table 17). WAB56-104-118 and WAB56-104-141 mutants produced the lowest number of panicles at six days of heat stress exposure, with 4 panicles per plant as compared to WAB 56-104-18 mutant which produced the highest number of panicles (Table 18). In case of performance for WAB 56-50 mutants, the highest number of panicles per plant were recorded from WAB56-50-control plant compared to all WAB 56-50 mutants which were exposed at 4, 5 and 6 of days heat stress (Tables 19, 20, and 21). The lowest number of panicles (2.3) were recorded at four days of heat stress from WAB56-50-59 mutant (Table 19). At five days of stress, WAB56-50-90 and WAB 56-50-119 mutants produced the lowest number of panicles (Table 20). When the genotypes were stressed for six days, results showed that WAB56-50-51, WAB56-50-85, WAB 56-50-123 and WAB56-50- 152 mutants produced the lowest number of panicles, the highest number of panicles among the mutants recorded was WAB56-50-82 mutant (Table 21).

Combined results revealed that KR control plants produced the highest number of panicles per plant (19.7) as compared to all mutants stressed at four and five days heat stress (Tables 22 and 23). At the same time, WAB56-104-170, WAB56-104-171 and WAB 56-50-59 mutants recorded the lowest number of panicles per plant at 4 days of stress (Table 22). At five days of heat stress, results showed that WAB56-50-90 and WAB 56-50-119 mutants produced the lowest number of panicles per plant (Table 23). Combined results of all tested genotypes revealed that mutant CG 14-13 had the highest number of panicles per plant at six day heat stress, while WAB 56-50-152 mutant had the lowest (Table 24).

4.2.4 Plant height

The significant ($P \leq 0.05$) variations in plant height were observed among mutant lines of Kihogo red studied (Tables 10, 11 and 12). At four day heat stress, line KR 30 mutant with 109.67 cm had the tallest while KR-28 mutant was the shortest

(Table 10). At five days heat stress, the tallest plant was KR 9 mutant with 115.7 cm long, whereas the shortest plant was KR- Control plant with 100 cm (Table 11). When the Kihogo red mutants were stressed for six days, results showed KR 37 mutant was the tallest plant at 131.3 cm but the shortest plant was KR 38 mutant with 76.3 cm (Table 12).

Similarly for the CG 14 mutants, there were also highly significant($P \leq 0.005$) variations among lines in plant height whereas the tallest plants at four days of heat stress were observed for line CG14-80 mutant and the shortest plants was from line CG14-52 mutant (Table 13). CG14 control plant recorded the tallest plants compared to mutants. At five days heat stress the shortest plants were in CG14-60 mutant with 86.3 cm (Table 14). The tallest plants at six days of heat stress were from CG14-22 mutant while the shortest plants were from CG14-64 mutant with 77.7 cm (Table 15).

With regard to WAB56- 104 mutants, WAB 56-104-39 mutant was the tallest genotype with 114.3 cm, at four days heat stress, while WAB56-104-73 genotype was recorded as the shortest (Table 16). WAB56-104 control plant with 105 cm was the tallest plant compared to WAB 56-104 mutants. Results of six days heat treatment for this genotype indicated the longest plant recorded was for WAB56-104-43 mutant with 121.3 cm and the shortest plant was WAB 56-104-141 mutant (Table 18). When WAB 56-50 genotype was exposed to heat stress for four days, results showed that 105 cm was the tallest plant height which was recorded for WAB56-50-134 mutant. The shortest plant height was 83 cm recorded for WAB56-

50-88 mutant line (Table 19). However, at five days of heat stress exposure, the tallest plant observed was WAB56-50-147 mutant while WAB 56-50- 70 mutant was recorded as the shortest plant (Table 20). In case of heat stress for six days genotype, WAB56-50-82 mutant was the tallest plant with 112.7 cm long while WAB56-50-152 mutant was the shortest plant (Table 21).

Combined results for plant height showed significant ($P \leq 0.05$) difference among the genotypes from where CG14-80 mutant had the tallest plants with 117.3 cm and KR 29 mutant recorded as the shortest plant at 4 days of heat stress with 72.7 cm (Table 22). At 5 days exposure, WAB56-50-147 mutant was the tallest while 83 cm was the shortest plant height recorded for WAB56-50-100 (Table 23). The tallest plant after six days of heat stress was KR37 mutant (131.3 cm), and the shortest plants were observed from WAB56-50-152 mutant (Table 24).

4.2.5 Panicle length

There were significant ($P \leq 0.05$) differences in panicle length among the genotypes tested in all conditions except for CG 14 at five days heat stress (Table 14). At four days heat stress agronomic performance of Kihogo red mutant showed that the longest panicle was from KR28 mutant although it was not statistically different from KR30 mutant, and the shortest panicle length was recorded from KR29 mutant (Table 10). For five days of stress, KR9 mutant produced the longest panicle with 26.4 cm, compared to 22 cm long which was the shortest one from KR-control plants (Table 11). When the mutants were stressed at six days, results indicated that KR37 mutant produced the longest panicle whereas, KR 38 mutant produced the shortest panicle (Table 12).

At four days heat stress, 26 cm was the longest panicle length recorded from CG14-78 and CG14-79 mutant lines, but the shortest panicle was recorded from CG14-52 (Table 13). At five days of stress there were no significant differences among CG14 mutant lines (Table 14). However, at six days heat stress, CG14-13 mutant produced the longest panicle while CG14-64 mutant produced the shortest panicles (Table 15). Based on WAB 56-104 mutants, WAB 56-104-73 mutant produced the longest panicle of which 23 cm were recorded at four days heat stress, while WAB 56-104-control plants produced the shortest panicle compared to mutants lines stressed at four, five and six day heat stress (Tables 16, 17 & 18). At five days of heat stress, WAB56-104-62 recorded the longest panicle (Table 17). Panicle length recorded from WAB56-104-43 was the longest among all WAB 56-104 lines stressed at six days of heat (Table 18).

Results from WAB56-50 mutants at 4 days of heat stress revealed that the longest panicle was recorded from WAB56-50-95 mutant at which 24.33 cm were recorded, WAB 56-50-control plant produced the shortest panicles compared to mutants stressed at four, five, and six days heat stress (Tables 19, 20 & 21). After five days of heat stress, 23.83 cm was the longest panicle length recorded from WAB56-50-147 mutant (Table 20). For the WAB 56-50 mutants which survived at six days of heat stress, WAB56-50-135 mutant produced the longest panicle with 27.5 cm long, while WAB56-50-152 mutant attained the shortest panicle length (Table 21).

The combined data showed that, the longest panicles were recorded from CG14-78 and CG14- 79 mutants (4 days), KR 9 mutant (5 days) and CG 14-13 mutant (6 days) of heat stress (Tables 22, 23 and 24). WAB 56-104-control and WAB 56-50-control recorded the shortest panicles as compared to the mutants stressed at 4, 5 and 6 days of heat stress (Tables 22, 23 and 24). At five days heat stress the combined record showed the longest panicles were from KR9 mutant with 26.4 cm (Table 23). Panicle length data from six days heat stress for combined means, recorded that CG14-13 mutant produced the longest panicle (Table 24).

4.2.6 Number of spikelets per panicle

Number of spikelets per panicle exhibited significant ($P \leq 0.05$) difference among genotypes (Tables10-21). At four days heat stress, KR28 mutant had the highest number of spikelets per panicle while KR29 mutant gave the lowest number of spikelets per panicle (Table 10). At five days heat stress KR26 mutant produced the highest number of spikelets per panicle while KR control plant recorded the lowest number of spikelets per panicle compared to KR mutants stressed at five and six days heat stress (Tables 11 and 12). At 6 days heat stress, KR27 and KR37 mutants produced the largest number spikelets per panicle (Table 12).

Results from CG 14 mutants' revealed that CG14-79 mutant produced the highest number of spikelets with 190.3 at four days of heat stress and CG14-52 mutant as the producer of lowest number of spikelets per panicle (Table 13). The highest record for number of spikelets per panicle at five days of heat stress (95.2) was recorded from CG14-75 mutant, and 50.3 number of panicles were the lowest observed from CG14-

50 mutant (Table 14). The mutant CG 14-7 recorded the maximum number of spikelets per panicle whereas CG14-59 mutant recorded the minimum number of spikelets per panicle (Table 15).

On the other hand, results for WAB56-104 mutants, recorded at 4 days heat stress revealed that WAB56-104-133 mutant gave the highest number of spikelets per panicle and the lowest number was from WAB56-104-control plant when compared to all WAB 56-50 mutants exposed to 4, 5, and 6 days heat stress (Table 16, 17 and 18). With a total of 202.3 spikelets per panicle, WAB56-104-119 mutant had the highest number of spikelets per panicle at five days heat stress (Table 17). When plants were stressed for six days, WAB56-104-36 mutant recorded the highest number of spikelets per panicle (Table 18).

For WAB56-50 mutants which survived heat stress for 4 days, WAB56-50-156 had the highest number of spikelets per panicle and the lowest were recorded from WAB 56-50-99 mutant (Table 19). However, at 5 days heat stress WAB56-50-140 mutant recorded the highest number of spikelets per panicle, while the lowest number was from WAB56-50-100 mutant (Table 20). After six days of heat stress the results showed that the highest number of spikelets were obtained from WAB56-50-135 mutant and the lowest number were recorded from WAB56-50-98 mutant (Table 21).

From the combined mean at 4 days of heat stress, the highest spikelets number per panicle were recorded from CG14-79 and the lowest were from WAB56-50-99 mutant (Table 22). At 5 days of heat stress, the combined data showed that WAB56-

104-119 mutant produced the highest number of spikelets per panicle while CG14-50 observed the lowest value of spikelets number per panicle (Table 23). After six days heat stress the highest number of spikelets came from WAB56-104-36 mutant, and the lowest number was recorded from WAB56-50-98 mutant (Table 24).

4.2.7 Percent sterility

Significant ($P \leq 0.05$) variations in percent sterility were observed among rice genotypes when heat stressed for 4, 5 and 6 days (Tables 10-21). For Kihogo red genotype evaluated, KR Control plants showed the lowest percentage sterility as Compared to the mutants (Tables 10, 11 and 12). However, at four days heat stress, the highest percentage sterility was observed from KR 29 mutant (Table 10). KR 26 mutant produced the highest number of percentage with 58.5% at five days of heat stress (Table 11). At six days heat stress KR 38 mutant recorded the highest percentage sterility (Table12).

The highest percentage sterility of 80.43% were noted from CG14-53 mutant line at four days heat stress and CG 14-20 mutant recorded the lowest percentage from the same duration (Table 13). Results observed when genotypes were heat stressed for five days indicated significant ($P \leq 0.05$) difference on percent sterility from which CG14-50 mutant was the highest while CG14-76 mutant had the lowest percent sterility (Table 14). CG14-59 mutant recorded 68.57% as the highest percentage sterility, and 27.83% from CG 14-16 as the lowest percentage sterility at six days heat stress (Table 15). Significant differences ($P \leq 0.05$) were observed among WAB56-104 mutants for percentage sterility at four days heat stress, whereas the highest percentage was recorded from WAB56-104-171 mutant and the lowest percentage was from WAB 56-104-40 mutant (Table 16). At five days heat stress WAB56-104-181 mutant recorded the highest percentage sterility (80%) while WAB56-104-46 mutant, recorded the lowest percentage (Table 17). WAB56-104-123 mutant observed the highest percentage sterility at six days heat stress, with the same stress, the lowest percentage came from WAB 56-104-43 mutant (Table 18). The highest percentage sterility at four days heat stress for the genotype WAB56-50 was obtained from WAB56-50-142 mutant (70.67%), WAB56-50-Control plant had the lowest mean percentage sterility(33.97%) as compared to all mutants stressed at four and five days heat stress (Tables 19 and 20). Results observed when genotypes were heat stressed for five days indicated significance ($P \leq 0.05$) on percentage sterility from which WAB 56-104-119 mutant was the highest although was not statistically different from WAB56-50-107 mutant (Table 20). The highest overall mean of percentage sterility for genotype WAB56-50 at six days heat stress was recorded from WAB56-50-85 mutant, the lowest was noted in WAB56-50-82 mutant (Table 21).

Results from combined analysis showed that there were significant differences ($P \leq 0.05$) in percentage sterility among the evaluated tested genotype for both conditions whereby at four days heat stress, KR2 mutant recorded the highest percentage sterility and the lowest record was from WAB 56-104-4 mutant (Table 22). At five days heat stress, the combined results showed that WAB56-104-181 mutant produced the highest percentage sterility whereas the lowest percentage was recorded from WAB56-104-46 mutant (Table 23). The highest means of percentage sterility at six days heat stress from combined means data were observed from WAB56-50-85 mutant, while the lowest was from WAB56-50-82 mutant (Table 24).

4.2.8 1000 grain weight

The tested genotypes exhibited significant ($P \leq 0.05$) differences in 1000 grain weight (Tables 10-21). KR-control gave the largest grain weight as compared to mutants (Tables 10, 11 and 12). However, KR 29 mutants were observed to have the lowest grain weight at four days (Table 10). At five days heat stress, KR 9 mutants recorded the lowest number (Table 11). When stressed for six days, the lowest 1000 grain weight was observed from KR10 mutant (Table 12).

CG14-control recorded the largest grain weight compared to the mutants that were exposed to heat stress at 4, 5, and 6 days (Tables 13, 14 and 15). In case of 1000 grain weight, CG14-20 mutant gave the lowest at four days heat stress, CG 14-75 mutant, at five days and CG14-7 mutant at six days heat stress (Tables 13, 14 and 15) respectively.

From WAB 56-104 mutants, the largest 1000 grain weight at four days heat stress was observed in WAB56-104-132 mutant (30.3g) while the lowest was from WAB56-104-170 mutant (Table 16). WAB56-104-46 mutant displayed the highest grain weight and WAB 56-104-181 mutant recorded the lowest 1000 grain weight at five days heat stress (Table 17). At six days heat stress, mean agronomic performance revealed that the largest 1000 grain weight was recorded from WAB56-104-43 mutant, whereas the lowest comes from WAB 56-104-123 mutant which was not statistically different from WAB56-104-118 (Table 18). 1000 grain weight varied significantly ($P \leq 0.05$) among WAB 56-50 mutants (Tables 19, 20 and 21). The largest overall mean of 1000 grain weight, at 4 days heat stress was obtained from WAB56-50-59 mutant, while the lowest was achieved from WAB56-50-99 mutants (Table 19). WAB56-50 control plants recorded the highest 1000 grain weight as compared to the mutants, (22.0 g) was the lowest data recorded from WAB56-50-146 mutant (Table 20). The highest data recorded for 1000 grain weight at six days heat stress was from WAB56-50-51 mutant. On the other hand the lowest value was obtained from WAB56-50-152 mutant (Table 21).

Results from combined analysis (Tables 22, 23 and 24) indicated that CG14-20 and WAB56-50-59 mutants recorded the highest 1000 grain weight at four days heat stress similarly to CG14-control plant, while the lowest data were obtained from KR 29 mutant (Table 22). The highest 1000 grain weight was observed from CG 14-Control plant but the lowest value at five days comes from WAB56-104-181 mutant (Tables 22 and 23). WAB 56-50-152 mutant displayed the lowest 1000 grain weight at six days heat stress (Table 24).

4.2.9 Grain yield per plant

There were significant ($P \leq 0.05$) differences in grain yield performance among the evaluated genotypes both at four, five and six days heat stress (Tables 10-21). The performance recorded from Kihogo red showed that KR control plants recorded the highest grain yield per plant compared to mutants (Tables 10 and 11). However, at six days heat stress the highest grain yield was observed from KR27 mutant (Table

12). KR 29 mutant recorded the lowest grain yield per plant at four days heat stress (Table 10). At five days heat stress the lowest grain yield was noted from KR 9 mutant (Table 11). The lowest grain yield per plant (5.87g) was recorded from KR38 mutant at six days heat stress (Table 12).

Results for the CG14 mutants indicated CG14-control plants produced the highest grain yield compared to the treated mutants (Tables 13 and 14). The lowest value of grain yield at four days heat stress was observed from CG14-53 mutant (Table 13). The mutant line CG14-50 produced the lowest grain yield per plant at five days heat stress (Table 14). At six days heat stress results illustrated that highest grain yield per plant was from CG14-16, and the lowest value was recorded from CG14-59 mutant (Table 15).

The highest mean of grain yield per plant for the WAB 56-104 variety at four days heat stress was recorded from WAB 56-104-40 mutant although it was not statistically different from WAB56-104-39 mutant, while the lowest record was from WAB56-104-171 mutant (Table 16). At five days heat stress WAB56-104-12 mutant produced the highest grain yield similarly to WAB56-104-181 mutant which obtained the lowest value (Table 17). WAB56-104-36 mutant at six days heat stress displayed the highest grain yield per plant. On the other hand WAB56-104-123 mutant recorded the lowest grain yield (Table 18).

Mean agronomic performance of WAB56-50 mutants revealed that WAB 56-50-control had the highest grain yield per plant as compared to the mutants.

The lowest grain yield at 4 days heat stress was noted from WAB 56-50-99 mutant even though it was not statistically different from WAB56-104-59 mutants (Table 19). At five days heat stress, results showed that WAB 56-50-147 mutant recorded the highest grain yield per plant but this was not statistically different from WAB 56-50-Control plant and the lowest yield was recorded from WAB56-50-90 and WAB56-50-119 mutants (Table 20). WAB 56-50-82 mutant produced the highest grain yield per plant at six days heat stress whereas WAB 56-50-98 mutant recorded the lowest grain yield (Table 21).

Results from combined analysis revealed that there were significant differences ($P \leq 0.05$) in grain yield per plant among the evaluated tested genotypes (Tables 22, 23 and 24). At four days heat stress the highest grain yield was recorded from WAB56-104-40 mutant while the lowest value was observed from WAB56-50-99 mutant (Table 22). At five days heat stress, the combined results indicated that WAB 56-104-12 mutant produced the highest grain yield per plant while the lowest grain yield was obtained from WAB56-50-90 and WAB56-50-119 mutants (Table 23). CG14-16 mutant produced 55.77g depicting the highest grain yield per plant at six days heat stress from combined analysis while WAB56-50-98 mutant produced the lowest yield per plant (Table 24).

CHAPTER FIVE

5.0 DISCUSSION

Since the genetic diversity for heat tolerance is important for breeding new varieties for areas affected by high temperatures during the rice-growing season, the results derived from this study could be used for designing effective breeding programs aiming to broadening the heat tolerant upland rice in face of climatic change in Tanzania.

5.1 Heat Chamber Experiment

The results from the Heat Chamber experiments where the rice plants were subjected to high temperature at 45°C indicated that variations existed among the genotypes evaluated. The results also revealed that mutant plants tolerated to some extent the heat stress as compared to controls. All the control plants did not survive at that temperature. This indicated that mutant plants have the genes which can withstand heat stress and these mutants could be utilized by plant breeders. Based on survival percentage of the mutant from the four genotypes there were a limited variation among them, this variation could be attributed to the difference in genetic materials and environmental conditions of the experiment.

5.2 Screen House Experiment

Results from this study based on days to 50% flowering showed that all mutants flowered earlier after 4, 5, and 6 days heat stress as compared to controls. This is similar to what Jeng *et al.* (2003) reported, that the shortening of ripening period in rice due to a high temperature was caused by the higher activity of enzyme involved in starch synthesis during the early grain growth stage. Similarly, Satake & Yoshida, (1978) reported that high temperature promote the ripening and shorten the duration of grain filling.

Results from this study showed that there were variations in tillers and panicle numbers per plant among the genotypes evaluated whereas, the controls produced many tillers and panicle number per plant than the mutants at 4 and 5 days heat stress. This result is similar to what Poli *et al.* (2013) reported that heat stress resulted in reduction of number of tillers, number of panicles and panicle length. Islam, (2011) also reported the reduction of panicle number per plant by 10% when rice was exposed to temperature of 34°C for seven days during grain filling stage. At six days heat stress, results showed that mutants produced high number of tillers per plant than the controls, the same findings were reported by Yoshida, (1973) who found that high temperature increased tiller numbers. This variation could be due to the compensation effect for the mutants.

Plant heights of mutant plants from all genotypes were higher as compared to control. This is contrasting to Cheng *et al.* (2009) and Yoshida *et al.* (1981) who reported reduction in plant height for rice IR 72 (Indica cultivars) as a result of high temperatures, but agreed with results from CG 14 and WAB 56-104 mutants at five days heat stress, where the plant height was reduced compared to Controls. The variations here could be due to the effects of treatment that mutation did not occur successfully. In a way radiation may have increased plant height of some mutants.

Also genotypes may interact with temperature on effect on plant height such that genotypes may respond differently.

Results in this study showed that the mutants from all rice genotypes evaluated produced longer panicles per plant than the controls after being subjected to 4, 5 and 6 days heat stress, the results contrasted to that of Poli *et al.* (2013) who reported that heat stress resulted in reduction of panicle length. The reason for the mutants to produce longer panicles per plant could be irradiation produced mutants which are resistant to heat stress as far as panicle length is concerned, another possible reasons for mutants to have longer panicle could be the range of heat stress level might have been different therefore brought contrasting findings.

From this study, the number of spikelets per panicle recorded from most of mutants was higher than that recorded for the controls. This result differed from the results of Matsui *et al.* (2001) reported decreases in number of pollen grains on the stigma and poor germination of pollen on stigma due to heat stress, also Mohammed and Tapley (2010) reported the high temperature resulting in spikelets sterility. The variation here could be due to expression of genes for mutants which withstand heat stress that makes no reduction of number of spikelets due to high temperature.

Results obtained indicated that all mutants from the four rice genotypes had higher percent sterility at 4, 5, and 6 days heat stress, as compared to the controls except for WAB 56-50-82 mutant line which recorded 18.4% lower than the control. The results are similar to that reported by Mohammed and Tapley (2010) who found that high temperature induced abnormal anther dehiscence leading to reduction in number of germinated pollen on stigma and resulting in spikelets sterility. Also panicle fertility may be influenced by environmental factors, such as temperature. Spikelet fertility of rice is sensitive to night temperature, where the degree of sensitivity depends upon the developmental stage of the spikelet as reported by Zakaria *et al*, (2002).

Higher 1000 grain weight was recorded for the controls than for mutants of KR and CG14 stressed at 4, 5, and 6 days heat stress. Whereas for WAB 56-104 some of mutants recorded higher grain weight after being stressed at 4, 5, and 6 days heat stress compared to the control. The results were in good agreement with the findings of Jeng *et al.* (2003) who reported that, the reduction in 1000-grain weight under high temperature condition was caused by the reduced activity of sink for starch synthesis. Lin *et al.* (2010) also reported the reduction in panicle weight for 7% and spikelets weight for 16% when rice was exposed to 35/30°C day/night temperatures. Recently, Johkan *et al.* (2011) reported that plants grown under high night temperature showed 20% decrease in grain weight compared to plants grown under normal temperatures.

In earlier studies, Tanaka *et al.* (1995) also reported that reduction in grain weight due to high temperature was attributed to excessive energy consumption to meet the respiratory demand of seed. Kobata and Uemuki, (2004) reported that the reduction in grain weight due to high temperature is attributed to higher grain dry matter accumulation rate together with a shortened grain-filling period. During seed development, many features of rice grains are changed by a high-temperature environment, sometimes grains may display lower grain weight (Yamakawa *et al.*, 2007). This phenomenon is considered to be caused by the formation of large air spaces in the endosperm because of the insufficient growth of starch granules (Zakaria *et al.*, 2002).

In high temperatures ripening, expression of multiple genes, such as those for starch biosynthesis in the endosperm, is resulting in reduction of amylose content and aberration of amylopectin structure (Yamakawa *et al.*, 2007). All this makes rice grain weight to be lower. Although, WAB 56-50 and WAB 56-104 mutants produced higher 1000 grain weight than control this variation could be due to genetic factors conferring tolerance of genotypes, hence can be utilized by breeders.

Results revealed higher grain yields for the Kihogo Red and CG 14 Controls, compared to their mutants which stressed at 4 and 5 days heat stress also WAB 56-50 Control recorded the higher grain yield as compared to mutants stressed at 4 days heat stress. The reduction of yield for the mutants could be due to the facts that heat stress lowers the total spikelets numbers, high percent sterility, and reduced grain weight as reported by Yang and Heilman (1993). The high temperature can decrease crop yields by decreasing crop growth duration, suppressing floral bud development and decreasing pollen production and viability (Ahmed and Hall, 1993; Mohammed and Tarpley, 2009; Prasad *et al.*, 2006). Although WAB 56-104 mutants which were treated at 4, 5, and 6 days heat stress, recorded higher grain yield than the control, the number of tillers with grain produced were greater at the higher temperature regimes.

However, the decrease in yield was due to a higher number of unfilled spikelets per panicle. This was also observed by Samson and Zandstra (1980). WAB 56-50 genotype control produced higher grain yield than the mutants stressed at 4 and 5 days heat stress, but at 6 days heat stress, WAB56-50-82 mutant produced higher grain yield than the control. The variation of grain yield could be due to the differences in genetic materials and heat treatment (days exposure to heat stress). Mohamed and Tarpley (2009) also reported that rice plants grown under high temperature showed 90% decrease in yield compared to plants grown under ambient temperatures.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

From this study, we can draw the following conclusions:

The results showed that the genotypes tested differed significantly in some agronomic traits stressed in different treatments, this indicated the differences of the mutant materials used. Most of the mutant lines performed better in some of agronomic traits when stressed at 6 days heat stress than at 4 and 5 days heat stress. This indicated that there were more genetic variations in those mutant lines as far as the heat tolerance is concerned which make mutation not effective in yield increment under heat stress.

Environmental conditions namely high temperature during production stages play an important role in phenotypic expression of grain yield and yield components.

The percentage sterility was one of the agronomic traits which was affected by heat stress in rice also it has an impact on grain yield; some of mutant lines WAB 56-104-40, WAB 56-104-123 and WAB 56-50-82 were identified to be tolerant to heat stress as far as yield is concerned. The phenotypic screening revealed the following lines to be heat tolerant; KR 37, CG-14-7, CG 14-13, CG 14-16, WAB 56-104-36, WAB 56-104-43, WAB 56-104-82, WAB 56-104-40, WAB 56-104-12, WAB 56-104-123, WAB 56-104-181, WAB 56-50-82 and WAB 56-50-132.

Plant height, days to 50% flowering, panicle length, number of spikelets per panicle and 1000-grain weight for KR and CG 14 were found to be not affected by heat stress. So these traits could be used by plant breeders for further heat tolerant researches to get rice variety that can tolerate in high temperatures.

6.2 Recommendations

Based on the performance of the four mutant rice evaluated in different days of heat stress in this study, with regard to variation due to genotypes and number of days in response to heat stress, the following recommendations could be made:-

1. Mutant lines; KR 37, CG-14-7, CG 14-13, CG 14-16, WAB 56-104-36, WAB 56-104-43, WAB 56-104-82, WAB 56-104-40, WAB 56-104-12, WAB 56-104-123, WAB 56-104-181, WAB 56-50-82 and WAB 56-50-132 can be recommended to be grown in the areas of high temperature.

2. Since this study was conducted only during one season, it is suggested that this study be carried out further for at least two seasons with additional number of replications to further verify the results obtained.

3. Heat stress trials should be set in field plots in such a way that the flowering period will coincide with high day temperature under field conditions especially in January to February for Morogoro region.

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APPENDICES

Appendix 1: Analysis of Variance (ANOVA) for agronomic performance of rice mutants which survived heat stress at 45°C for 4 days

Source of variation	Degree of freedom	50% flowering	No. of tillers/ plant	No. of panicles/ plant	Plant height (cm)	Panicle length (cm)	No. of spikelets/ panicle	%Sterility	1000 grains weight	Grain yield (g/plant)
Rep	2	0.1053	0.1527	0.0593	2.862	0.277	9.345	9.924	0.04351	0.1527
Genotypes	37	216.5254***	59.2335***	48.8207***	241.678***	14.688***	2381.274***	733.133***	0.46165***	69.4487***
Error	74	0.3845	0.5302	0.4323	2.264	1.194	2.469	4.652	0.01927	0.1227
Total	113									

* indicate significant difference at $P \leq 0.05$

** indicate significant difference at $P \leq 0.01$

*** indicate significant difference at $P \leq 0.001$

ns indicate no significant difference at $P \leq 0.05$

Appendix 2: Analysis of Variance (ANOVA) for agronomic performance of rice mutants which survived heat stress at 45°C for 5 days

Source of variation	Degree of freedom	50% flowering	No. of tillers/ plant	No. of panicles/ plant	Plant height (cm)	Panicle length (cm)	No. of spikelets/ panicle	%Sterility	1000 grains weight	Grain yield (g/plant)
Rep	2	0.0667	0.2952	0.2952	17.171	5.209	58.03	1.132	0.01724	0.1192
Genotypes	34	268.6818***	57.7412***	47.9625***	236.066***	19.461***	2655.27***	531.753***	0.48416***	93.8207***
Error	68	0.3608	0.7168	0.4129	6.054	1.553	35.10	1.319	0.02743	0.5586
Total	104									

* indicate significant difference at $P \leq 0.05$

** indicate significant difference at $P \leq 0.01$

*** indicate significant difference at $P \leq 0.001$

ns indicate no significant difference at $P \leq 0.05$

Appendix 3: Analysis of Variance (ANOVA) for agronomic performance of rice mutants which survived heat stress at 45°C for 6 days

Source of variation	Degree of freedom	50% flowering	No. of tillers/ plant	No. of panicles/ plant	Plant height (cm)	Panicle length (cm)	No. of spikelets/ panicle	%Sterility	1000 grains weight	Grain yield (g/plant)
Rep	2	0.3712	1.2803	0.2355	1.672	0.2187	31.37	2.046	0.01371	2.673
Genotypes	43	237.4419***	233.4630***	169.7818***	474.288***	29.7987***	5027.44***	1178.066***	0.52110***	545.419***
Error	86	0.4255	0.6136	0.3185	2.017	0.9469	38.85	5.489	0.02379	1.252
Total	131									

* indicate significant difference at $P \leq 0.05$

** indicate significant difference at $P \leq 0.01$

*** indicate significant difference at $P \leq 0.001$

ns indicate no significant difference at $P \leq 0.05$

Appendix 4: Analysis of Variance (ANOVA) for agronomic performance of KIHOGO RED mutants which survived heat stress at 45°C for 4 days

Source of variation	Degree of freedom	50% flowering	No. of tillers/ plant	No. of panicles/ plant	Plant height (cm)	Panicle length (cm)	No. of spikelets/ panicle	%Sterility	1000 grains weight	Grain yield (g/plant)
Rep	2	0.2500	0.1758	0.0633	0.557	0.0358	10.00	0.1058	0.01583	0.35583
Genotypes	3	3.8889ns	122.1244***	104.5189***	739.653***	5.56088***	1664.48***	1264.1675***	1.45889***	94.88750***
Error	6	0.4722	0.4203	0.2189	2.758	0.1025	10.26	0.6725	0.01472	0.03583
Total	11									

* indicate significant difference at $P \leq 0.05$

** indicate significant difference at $P \leq 0.01$

*** indicate significant difference at $P \leq 0.001$

ns indicate no significant difference at $P \leq 0.05$

Appendix 5: Analysis of Variance (ANOVA) for agronomic performance of Kihogo red mutants which survived heat stress at 45°C for 5 days

Source of variation	Degree of freedom	50% flowering	No. of tillers/ plant	No. of panicles/ plant	Plant height (cm)	Panicle length (cm)	No. of spikelets/ panicle	%Sterility	1000 grains weight	Grain yield (g/plant)
Rep	2	0.0667	0.4667	0.0667	0.6000	0.1607	0.8540	0.03800	0.01800	0.0087
Genotypes	4	5.1667***	107.5667***	97.5000***	120.9333***	9.5307***	1165.4227***	107.97767***	0.97500***	9.1877***
Error	8	0.3167	0.7167	0.4000	0.9333	0.2432	0.4707	0.07467	0.01550	0.1362
Total	14									

* indicate significant difference at $P \leq 0.05$ ** indicate significant difference at $P \leq 0.01$

*** indicate significant difference at $P \leq 0.001$ ns indicate no significant difference at $P \leq 0.05$

Appendix 6: Analysis of Variance (ANOVA) for agronomic performance of Kihogo red mutants which survived heat stress at 45°C for 6 days

Source of variation	Degree of freedom	50% flowering	No. of tillers/ plant	No. of panicles/ plant	Plant height (cm)	Panicle length (cm)	No. of spikelets/ panicle	%Sterility	1000 grains weight	Grain yield (g/plant)
Rep	2	0.6667	3.722	0.167	1.6250	0.6489	1.902	0.24389	0.00389	0.13556
Genotypes	5	7.4667***	150.756***	73.700***	1143.8583***	32.1086***	5019.736***	685.49689***	0.89389***	488.09789***
Error	10	0.7333	1.722	1.167	0.5583	0.6436	2.284	0.07322	0.01189	0.07022
Total	17									

* indicate significant difference at $P \leq 0.05$ ** indicate significant difference at $P \leq 0.01$

*** indicate significant difference at $P \leq 0.001$ ns indicate no significant difference at $P \leq 0.05$

Appendix 7: Analysis of Variance (ANOVA) for agronomic performance of CG 14 mutants which survived heat stress at 45°C for 4 days

Source of variation	Degree of freedom	50% flowering	No. of tillers/ plant	No. of panicles/ plant	Plant height (cm)	Panicle length (cm)	No. of spikelets/ panicle	%Sterility	1000 grains weight	Grain yield (g/plant)
Rep	2	0.7000	1.900	0.233	1.200	0.259	13.316	4.360	0.01900	0.25900
Genotypes	9	35.3185***	22.000***	25.559***	71.367***	9.137***	3158.609***	463.933***	0.42578***	35.76607***
Error	18	0.3296	1.122	1.048	2.089	1.344	2.590	1.227	0.02344	0.08419
Total	29									

* indicate significant difference at $P \leq 0.05$

*** indicate significant difference at $P \leq 0.001$

** indicate significant difference at $P \leq 0.01$

ns indicate no significant difference at $P \leq 0.05$

Appendix 8: Analysis of Variance (ANOVA) for agronomic performance of CG 14 mutants which survived heat stress at 45°C for 5 days

Source of variation	Degree of freedom	50% flowering	No. of tillers/ plant	No. of panicles/ plant	Plant height (cm)	Panicle length (cm)	No. of spikelets/ panicle	%Sterility	1000 grains weight	Grain yield (g/plant)
Rep	2	0.6333	1.200	0.8333	2.633	2.232	1.606	1.384	0.00700	0.2563
Genotypes	9	41.3370***	25.722***	26.5185***	199.885***	4.622ns	576.341***	175.626***	0.50385***	26.7724***
Error	18	0.3370	1.533	0.6852	3.596	2.829	2.972	1.136	0.04330	0.1752
Total	29									

* indicate significant difference at $P \leq 0.05$

*** indicate significant difference at $P \leq 0.001$

** indicate significant difference at $P \leq 0.01$

ns indicate no significant difference at $P \leq 0.05$

Appendix 9: Analysis of Variance (ANOVA) for agronomic performance of CG 14 mutants which survived heat stress at 45°C for 6 days

Source of variation	Degree of freedom	50% flowering	No. of tillers/ plant	No. of panicles/ plant	Plant height (cm)	Panicle length (cm)	No. of spikelets/ panicle	%Sterility	1000 grains weight	Grain yield (g/plant)
Rep	2	.3333	0.7179	0.3562	3.410	1.653	158.2	3.342	0.00077	7.055
Genotypes	12	25.9915***	323.9188***	230.8647***	484.474***	25.283***	2968.4***	378.460***	0.36256***	944.953***
Error	24	0.3056	0.5791	0.2423	2.660	1.323	114.1	6.849	0.04327	2.328
Total	38									

* indicate significant difference at P ≤ 0.05	** indicate significant difference at P ≤ 0.01
*** indicate significant difference at P ≤ 0.001	ns indicate no significant difference at P ≤ 0.05

Appendix 10: Analysis of Variance (ANOVA) results of mean squares for agronomic performance of WAB56-104 mutant surviving heat stress at 45°C for 4 days

Source of variation	Degree of freedom	50% flowering	No. of tillers/ plant	No. of panicles/ plant	Plant height (cm)	Panicle length (cm)	No. of spikelets/ panicle	%Sterility	1000 grains weight	Grain yield (g/plant)
Rep	2	0.2593	0.1481	0.3333	3.970	0.889	1.2737	0.907	0.00481	0.2359
Genotypes	8	90.8981***	42.0370***	29.9167***	167.228***	9.988***	2527.2029***	764.538***	0.06370***	112.9451***
Error	16	0.5093	0.4398	0.3750	2.395	1.354	0.5708	4.028	0.02065	0.1822
Total	26									

* indicate significant difference at P ≤ 0.05	** indicate significant difference at P ≤ 0.01
*** indicate significant difference at P ≤ 0.001	ns indicate no significant difference at P ≤ 0.05

Appendix 11: Analysis of Variance (ANOVA) for agronomic performance of WAB 56-104 mutants which survived heat stress at 45°C for 5 days

Source of variation	Degree of freedom	50% flowering	No. of tillers/ plant	No. of panicles/ plant	Plant height (cm)	Panicle length (cm)	No. of spikelets/ panicle	%Sterility	1000 grains weight	Grain yield (g/plant)
Rep	2	0.0370	0.3333	0.7778	23.44	2.934	291.6	1.1848	0.00481	0.979
Genotypes	8	64.8426***	43.1667***	30.9167***	87.33ns	17.665***	4077.1***	1496.3831***	0.63565***	228.170***
Error	16	0.3287	0.6667	0.5694	17.15	1.812	113.5	0.9306	0.02856	1.788
Total	26									

* indicate significant difference at $P \leq 0.05$

** indicate significant difference at $P \leq 0.01$

*** indicate significant difference at $P \leq 0.001$

ns indicate no significant difference at $P \leq 0.05$

Appendix 12: Analysis of Variance (ANOVA) for agronomic performance of WAB 56-104 mutants survived heat stress at 45°C for 6 days

Source of variation	Degree of freedom	50% flowering	No. of tillers/ plant	No. of panicles/ plant	Plant height (cm)	Panicle length (cm)	No. of spikelets/ panicle	%Sterility	1000 grains weight	Grain yield (g/plant)
Rep	2	0.1212	0.0909	0.0909	0.3939	0.1676	15.42	0.1221	0.01939	0.309
Genotypes	10	82.1515***	51.9576***	38.5879***	244.2848***	30.5101***	6430.40***	1787.2410***	0.42800***	363.897***
Error	20	0.4879	0.4576	0.4242	0.8939	0.2182	12.79	0.3218	0.01273	1.973
Total	32									

* indicate significant difference at $P \leq 0.05$

** indicate significant difference at $P \leq 0.01$

*** indicate significant difference at $P \leq 0.001$

ns indicate no significant difference at $P \leq 0.05$

Appendix 13: Analysis of Variance (ANOVA) for agronomic performance of WAB-56-50 mutants which survived heat stress at 45^{o}C for 4 days

Source of variation	Degree of freedom	50% flowering	No. of tillers/ plant	No. of panicles/ plant	Plant height (cm)	Panicle length (cm)	No. of spikelets/ panicle	%Sterility	1000 grains weight	Grain yield (g/plant)
Rep	2	0.3556	0.1556	0.1556	0.089	0.131	0.469	11.724	0.04689	0.0167
Genotypes	14	30.1651***	7.2698***	6.3651***	99.994***	11.73 9***	2067.603***	388.912***	0.28451***	12.2477***
Error	28	0.3079	0.1794	0.1556	2.470	1.421	1.214	8.548	0.01784	0.1074
Total	44									

* indicate significant difference at P ≤ 0.05 ** indicate significant difference at P ≤ 0.01

*** indicate significant difference at P ≤ 0.001 ns indicate no significant difference at P ≤ 0.05

Appendix 14: Analysis of Variance (ANOVA) for agronomic performance of WAB 56-50 mutants which survived heat stress at 45^{o}C for 5 days

Source of variation	Degree of freedom	50% flowering	No. of tillers/ plant	No. of panicles/ plant	Plant height (cm)	Panicle length (cm)	No. of spikelets/ panicle	%Sterility	1000 grains weight	Grain yield (g/plant)
Rep	2	0.1212	0.09091	0.03030	4.212	2.8594	7.414	2.171	0.01727	0.0764
Genotypes	10	23.0727***	7.43030***	10.32121***	313.552***	16.0499***	339.925***	334.278***	0.11673***	17.7456***
Error	20	0.4545	0.05758	0.03030	1.879	0.8911	1.381	2.324	0.02227	0.1360
Total	32									

* indicate significant difference at P ≤ 0.05 ** indicate significant difference at P ≤ 0.01

*** indicate significant difference at P ≤ 0.001 ns indicate no significant difference at P ≤ 0.05

Appendix 15: Analysis of Variance (ANOVA) for agronomic performance of WAB-56-50 mutants which survived heat stress at 45°C for 6 days

Source of variation	Degree of freedom	50% flowering	No. of tillers/ plant	No. of panicles/ plant	Plant height (cm)	Panicle length (cm)	No. of spikelets/ panicle	%Sterility	1000 grains weight	Grain yield (g/plant)
Rep	2	0.6667	0.1667	0.02381	3.881	2.172	0.594	10.56	0.02595	0.02310
Genotypes	13	37.3260***	9.2619***	9.36996***	353.150***	22.839***	2019.635***	1780.00***	0.60588***	39.64352***
Error	26	0.3590	0.2179	0.02381	2.727	1.156	1.299	10.62	0.02159	0.07566
Total	41									

* indicate significant difference at $P \leq 0.05$

** indicate significant difference at $P \leq 0.01$

*** indicate significant difference at $P \leq 0.001$

ns indicate no significant difference at $P \leq 0.05$