BINDURA UNIVERSITY OF SCIENCE EDUCATION
FACULTY OF AGRICULTURE AND ENVIRONMENTAL SCIENCES

DEPARTMENT OF CROP SCIENCE

The effects of varying gibberelic acid (ga$_3$) levels on germination and seedling growth in different wheat (*triticum aestivum* l) varieties.

Muponda Blessing Barbra Mazvita

B190041B

A dissertation submitted to the Bindura University of Science Education in partial fulfilment of the requirement for the award of Bachelor of Agricultural Science Honours Degree in Crop Science

MAY 2023

ABSTRACT

Wheat (*Triticum aestivum* .L) is one of the most important crop in the world. Despite global advancement in farming technology, Zimbabwean farmers are still lagging in adopting new systems and the use of new products in wheat production. Gibberellic acid (GA_3), an eco- friendly bio regulator that is widely used to enhance the productivity and phenotypic characteristics of multiple crops. A 4x4 factorial RCBD study was conducted at DR&SS to showcase the benefits of using Gibberellic Acid on germination and seedling growth of wheat. The study involved 4 different wheat varieties which were Dande, Runde, Save and Ncema and 4 different GA_3 levels which were no $GA_{3,}$ 1ml, 2mls and 4mls, diluted with 2litres of water respectively. The parameters assessed were germination percentage, seedling vigour index, stem height, tiller number and leaf area index. Data collected during the experiment was subjected to statistical analysis of variance using GenStat package 18th Edition version and LSD at 5% level. The results indicated that varied levels of Gibberellic Acid affects different wheat varieties differently. The effective use of GA_3 at 4mls is effective to the Save, Dande and Ncema varieties only the Runde variety proved to do well when 2mls of GA_3 was applied. The application of Gibberellic Acid can, therefore, be used to enhance germination and seedling growth of wheat and hence combat food insecurity amongst communities of Zimbabwe.

RELEASE FORM

I, Blessing Barbra Mazvita Muponda, Student Number B190041B do hereby provide Bindura University of Science Education exclusive rights to replicate and dispense this research work in whole origin part in any suitable publication form that does not infringe or violet at any rights of others. I therefore give this consent the original owner of the rights to work and abstract. The author declares that the contents of this research have been created by the author herself and that no other resources mentioned in the literature used before. The copy right of this research is held by the author and the author is responsible for the contents of the work. The Bindura University of Science Education is exclusively and entirely responsible for the education guidance of this project and does not accept in any case, any responsibility for the contents. This dissertation in original work from scratch and that all the resources that involved from other sources are quoted and indicated by means of complete references.

Signature of student………………………………. **Date……/…. /……**

DECLARATION

I Blessing Barbra Mazvita Muponda, registration B190041B declare that this research project is my own work and has not been lifted or copied from any source without acknowledgement of source.

DEDICATION

I dedicate this work to my lovely family, especially my mom and my uncle, for making sacrifices during the period of my studies. Would also want to dedicate this work to my friends for the moral support they gave me during the research period.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank the Almighty God for his grace which guided me throughout the four years of study.

I wish to express my profound gratitude to my supervisors Ms Kamota and Dr.Goche for their diligent effort that made my research project to be a success. Many thanks Mr Mavindidze from DR&SS who also assisted to make the research project a success .I would also like to thank my friends Persistence Muchemwa, Nigel Salani, Artiwell Ndoorwi and Tafadzwa Mupfupi for their moral support. I would also like to thank my mother for supporting me financially and also praying for me during this research study. I appreciate the Department of Crop Science at the Bindura University of Science and Education and my fellow classmates for the assistance that they provided. I am also grateful for the support that my loving family extended to me who helped me in all the academic structuring of a dissertation project. The encouragement to forge forward when things got tough.

Table of Contents

LIST OF FIGURES

LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
DR&SS	Department of Research and Specialists Services
FAO	Food and Agriculture Organization
GA_3	Gibberellic Acid
/ha	per hectare
Ml	Millilitres
cm	Centimetres
g	Grams
%	Percent
CRD	Completely Randomized Design
GP	Germination percentage
LAI	Leaf Area Index
SVI	Seedling Vigor Index
CBI	Crop Breeding Institute

CHAPTER 1: INTRODUCTION

1.1 Background

Wheat (*Triticum aestivum* L.) is a winter annual grain grass, classified in the Poaceae family, (Kumar, 2017). Wheat is an essential crop in the world and about 35% of the world's population survive on it (Grote *et al*., 2021). It is considered an essential source of carbohydrates and numerous essential nutrition. Wheat is cultivated as a cash crop, as it produces a good yield per unit area. It is the second most produced cereal grain behind maize (*Zea mays L.)* and the global trade is greater than all other crops combined (Food and Agriculture, 2020). In 2020 the total global wheat production was around 760 million tonnes (World population review, 2020) .China, India and Russia are the three largest wheat producers in the world (World population review, 2020). In 2020 Zimbabwe managed to produce 180 000 tonnes of wheat (Knoema, 2020). In order to meet flour demands per year Zimbabwe needs 400 000 tonnes of wheat so is the need import more than 220 000 tonnes of wheat because wheat production in Zimbabwe is decreasing yearly (Knoema, 2020).

Wheat farmers and breeders are facing compromised yields in wheat production, its production is constantly threatened by various abiotic and biotic stresses. This stresses results in poor germination, and poor seedling growth which will eventually lead to compromised yields thus a decrease in production (Bleach, 2019). In order to curb this problem Zimbabwean farmers and breeders need to adopt new systems and use of new products in wheat production. Gibberellic acid (GA_3), an eco-friendly bio regulator is widely used to enhance the productivity and phenotypic characteristics of a number of crops.

Gibberellic acid is a hormone found in plants and fungi. The plant hormone Gibberellic acid has been used to improve seed germination and seedling growth of different crop species, such as rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.), (Chunthaburee *et al*., 2014). Gibberellic acid plays a very important role in several plant growth and development processes, including seed germination, stem elongation, and leaf expansion (Khan and Chaudhry, 2006). The use of the plant growth regulator Gibberellic acid (GA_3) in cereal production is now becoming common as it ensures efficient production. It is being used to manipulate growth thus resulting in an increased crop yield, (Sarkar *et al*, 2009).

GA_3 has been reported to increase germination percentage and seedling growth and overcome the preventive effects of the salt stress on germination (Nasril, 2012). Iftikhar, (2019) after doing a research on the effects of GA_3 noticed that Gibberellic Acid has an effect on wheat as it increases in plant height, increases yield, increases chlorophyll contents and it also increases antioxidant enzymes. Pavlista, (2014) also suggested that Gibberellic Acid stimulates the growth of stems in wheat production.

The study on varying levels of Gibberellic Acid on different wheat varieties aims to evaluate the effect of different doses of GA_3 on different wheat varieties. The study scrutinize various wheat varieties with different genetic makeups and growth habits. The study's overall goal is to determine whether the application of GA_3 can be used to optimize the growth and yield of wheat varieties. It involved the use of different levels of GA_3 to observe the physiological and biochemical changes in the different wheat varieties.

1.2 PROBLEM STATEMENT

Germination of seeds is one of the most important phase in the growth cycle of wheat plant, as it determines plant establishment and final yield .Due too poor germination and seedling growth challenges, they has been a global advancement to use gibberellic acid to enhance germination and phenotypic characteristics on wheat. For Gibberellic acid to be more effective it has to be applied at a certain dosage as different wheat cultivars react different to different dosages .If too much of it is applied it sometimes kill the seeds and if too little is applied it might fail to work as required of.

1.3 JUSTIFICATION OF THE STUDY

The use of Gibberellic Acid in wheat production will improve the germination rate and seedling growth in different wheat cultivars so as to recommend wheat farmers and minimise costs on seed expenses. Different wheat cultivars respond differently to varying GA_3 levels (Pavlista *et al.*, 2013). The differential response of wheat varieties to GA_3 holds promise for the identification and release of superior cultivars. . The findings from this study will be useful for wheat farmers and researchers, as they will provide insights into how to improve wheat yields and optimize the application of GA_3 by selecting the most appropriate varieties and GA_3 dosages.

1.4 MAIN OBJECTIVE

To determine the effects of varying Gibberellic Acid (GA_3) levels on germination and seedling growth in different wheat (*Triticum aestivum L*) varieties.

1.4.1 SPECIFIC OBJECTIVES

To assess the effects of GA_3 on germination percentage of wheat (*Triticum aestivum* L).

To assess the effects of GA_3 on the growth (seedling vigour index, leaf area index, steam height and tiller number.) of wheat (*Triticum aestivum* L).

1.5 HYPOTHESIS

H1= Varied varieties of wheat shows changes in germination when different quantities of GA_3 are administered.

H0= Varied varieties of wheat does not show changes in germination when different quantities of GA_3 are administered.

H1= There is a difference in seedling growth between various wheat varieties when varying quantities of GA_3 are administered.

H0= There is no difference in seedling growth between various wheat varieties when varying quantities of GA_3 are administered.

CHAPTER 2: LITERATURE REVIEW

2.1 ORIGINS AND TAXONOMY

Around 10,000 years ago, in the southeast of Turkey, wheat first appeared. National Wheat Growers Association, 2021.According to Damania (2013), wheat (Triticum durum Desf.) was one of the earliest plants to be domesticated and arrived to us from the Ethiopian Highlands and the Levant Region of the Near East about 10,000 years ago. There are various varieties of wheat that have 2n = 14, 28, or 42 and are diploid, tetraploid, or hexaploid, respectively. T aestivum (2n = 42), popularly known as bread wheat, T durum (2n = 28), also known as durum wheat, T dicoccum, and T sphaerococcum are the four species of common wheat aestivum and T durum, which are commonly referred to as spring wheat, may grow in temperate and subtropical climates, respectively. According to Boloch et al, (2022).

2.2 IMPORTANCE OF THE CROP

The majority of the calories, proteins, and micronutrients consumed worldwide that support growth and development come from foods made from wheat. According to Strugnell (2018), both whole and refined grain wheat products promote healthy nutrition on a worldwide scale. The majority of the world's temperate and subtropical regions rely on wheat as their main crop. The flour needed to make bread, biscuits, cookies, chapatti, etc. Is made from wheat. In the production of starch, gluten, malt, and distilled spirits, it is employed. Wheat bran is a good cattle feed because it is high in protein. Corrugated board is made from straw (Singh, 2022).

2.3 NUTRITIONAL VALUE OF THE CROP

The nutritional value of wheat is grouped into two components which are major nutrient and minor nutrient components. These components have carbohydrates, proteins and lipids, for major nutrients, and vitamins, minerals and phytochemicals for minor nutrients. Macronutrients, grains consist of approximately 75% carbohydrate have been proven that they are of importance of carbohydrate and fiber within wheat takes precedence over their concentrations of vitamins, minerals, and phytochemicals , (Brennan,2021) .

2.4 PRODUCTION TREND IN THE WORLD

According to Cossani and Reynolds (2012), wheat has been a staple food for major civilizations in Europe, North Africa, and West Asia for the past 8000 years. It is cultivated in approximately 220 million hectares of land, which accounts for 30% of the world's total cereal production area. Egypt being the largest wheat producer in Africa, produces approximately 9 million tons per annum, followed by Algeria with 4 million tons per annum, which is nearly half of Egypt's production (Tadesse et al., 2019). Sub-Saharan African countries import approximately 17 billion tons of wheat annually.

Erenstein et al. (2022) estimated that in 2018, 730 million metric tons of wheat were harvested from an estimated 217 million hectares of cultivation worldwide. The total global wheat production volume for the marketing year 2020/2023 was around 781 million metric tons. This represents an increase compared to the previous marketing year of 2021-2022, which had 779.33 million metric tons. This indicates a rising trend in wheat output internationally as the harvest continues to increase (Shahbandedh, 2023).

2.5 PRODUCTION TREND IN AFRICA

According to the Department of Agriculture, Land Reform and Rural Development (DALRRD, 2015) and the Food and Agriculture Organization (FAO, 2020), wheat is the second most significant grain grown in Southern Africa. However, there has been a decline in national wheat production in South Africa, with a decrease of approximately 740,000 tons between 2002 and 2012 (Dube et al., 2019). This decline in production has led to a deficit of about 1 million tonnes per year, which needs to be filled through imports. Over the past two decades, the wheat acreage in South Africa has decreased by around 500,000 hectares, totaling approximately a million hectares overall.

Wheat has been a staple food for major civilizations in Europe, North Africa, and West Asia for the past 8000 years, cultivated on approximately 220 million hectares of land, representing 30% of the world's total cereal production area (Cossani and Reynolds, 2012). In Africa, Egypt is the largest wheat producer, with an annual production of around 9 million tons, followed by Algeria with 4 million tons, which is almost half of Egypt's wheat production (Tadesse et al., 2019). Sub-Saharan African countries import approximately 17 billion tons of wheat annually.

2.6 WHEAT PRODUCTION IN ZIMBABWE

Wheat production in Zimbabwe started as early as 1925. It is one of the few crops that can be grown in winter. Wheat has become an important crop in Zimbabwe as urbanization, the general standard of living and family incomes increase. Many farmers have developed irrigation infrastructure and wheat provides a means of maximizing returns from their investments.
Initially, wheat production was very low, inn 1956, it was about 12 000 tonnes. By 1960, it dropped to 500 tonnes. In 1966, the government in response to the threat of sanctions after the Unilateral Declaration of Independence, initiated a farm Irrigation Fund to help farmers enter into irrigated wheat production. This paid off with output rising from 25 000 tonnes in 1968 to 85 000 tonnes by 1972, (DR&SS, 2015).

After independence, wheat production reached a record low of 99 000 tonnes in 1984. This was due to serious droughts in the preceding summers of 1982/83 and 1983/84 which reduced wheat hectares. The government responded by setting up a National Irrigation Fund to stimulate election of national water reservoirs as security against drought and to motivate farmers to enter irrigated wheat production. By 1986, production had reached 225 000 tonnes. Wheat farmers were also paid incentive producer prices. This led to more farmers entering into wheat production and also increasing the area under the crop. The production of wheat has increased by the years this has been a success due the introduction of improved varieties.

2.7 GIBBERELLIC ACID (GA)

Gibberellic acid is a hormone present in plants and fungi that plays a crucial role in stimulating their growth and development. It has various effects, including promoting seed germination, triggering transitions from meristem to shoot growth, influencing leaf stages from juvenile to adult, facilitating the transition from vegetative to flowering stage, and influencing sex expression and grain development. Chemically, it is a tetracyclic diterpenoid compound with a chemical formula of $C_{19}H_{22}O_6$ and a molar mass of 346.37 g/mol. When purified, it appears as a white to pale-yellow solid. While plants naturally produce significant amounts of GA3, it is also possible to produce this hormone industrially using microorganisms.

According to Garden Fundamentals (2023), gibberellic acid can be used to accelerate seed germination. However, excessive use of the hormone can lead to seed exposure and potential seed death. In some cases, seedlings may grow too quickly and become weak and elongated, while in others, no noticeable differences may be observed (Iftikhar et al., 2019). Research by Pavlista (2014) suggests that gibberellic acid stimulates stem growth in wheat production. It has also been observed by Smith (2001) that gibberellic acid persists in the soil for only about six weeks.

2.8 VARIETIES

Runde is a cultivar known for its short stature and erect flag leaf. It has large red seeds with medium anthocyanin coloration on the flag leaf auricle. This early maturing cultivar is tolerant to rust and has an average yield. Its unique feature is its high tolerance to rusts, thanks to the presence of resistance genes such as ‘Lr34, Sr2, and Lr68’. This resistance reduces the need for fungicide sprays, resulting in cost savings for farmers. Runde also has a high potential for flour extraction, good dough mixing characteristics, and a high flour protein content. It is well-adapted to various wheat-growing regions in Zimbabwe (DR&SS, 2015).

Ncema, on the other hand, is a white-seeded variety with moderate anthocyanin coloration on the flag leaf auricle. It is a semi-dwarf cultivar with a semi-erect growth habit and a floppy flag leaf. Ncema has a medium maturity period of 121 days, similar to Kana, Smart, and Sky varieties. It has high yields, particularly 9.2 tons per hectare in highveld areas, 5.5 tons per hectare in middleveld areas, and 5.2 tons per hectare in lowveld areas. It exhibits moderate resistance to rusts and powdery mildew. This cultivar is recommended for wheat production in all growing areas, especially under irrigation in high and middleveld regions. It possesses good milling and baking qualities (DR&SS, 2015).

Dande is characterized by its white oval-shaped grains and an erect growth habit with medium height. It has a semi-compact tillering capacity and is a high-yielding and medium-maturing cultivar. Dande also possesses good milling and baking qualities. It shows moderate resistance to rusts and powdery mildew biotypes. This cultivar is recommended for cultivation in all irrigated winter wheat-growing regions, particularly in high and mid-level areas (DR&SS, 2015).

2.9 PLANT POPULATIONS

The plant population density of wheat is influenced by the number of seeds sown and the success of seed establishment. Interestingly, there seems to be a decrease in the proportion of seeds that emerge as the number of seeds sown per square meter increases, although the reasons behind this phenomenon are not yet clear. It is crucial to provide sufficient fertilizer nitrogen (N) for poorly established crops. In fact, the use of fertilizer N may help compensate for poor establishment by promoting tillering and increasing the survival of tillers. It is notable that very few plants die after winter, and the structure of the crop is significantly influenced by the number of surviving plants per square meter (Agriculture and Horticulture Development Board, 2023).

2.10 PLANT MORPHOLOGY

Wheat plants have a length of 3 to 10 mm, with straight and cylindrical stems (Cossani and Reynolds, 2012). They consist of both root and shoot systems, characterized by long and slender leaves and hollow stems in most varieties (Setter and Carlton, 2000). The wheat grain is composed of a germ, embryo, and endosperm, with a typical size of 3 to 10 mm in length and 3 to 5 mm in diameter (Kumar et al., 2017).

The germination process in wheat occurs after a brief period of dormancy in the seeds (Kumar et al., 2017). Wheat seeds are known for having low dormancy levels that are easily broken down. The duration of dormancy can vary from 3 to 7 months after the seed coat is removed, depending on the cultivar (Dane, 2020).

The initiation of germination happens when the seed absorbs moisture. It requires a relative humidity of approximately 97.7% and a moisture content of 35 to 45% of its dry weight (Jagdish, 2020).

2.11 CHALLENGES IN WHEAT PRODUCTION

In 2019, wheat production experienced a significant decline to 1.5 million tons due to severe drought events, resulting in a nearly 50% loss in production. The Western Cape Province in South Africa contributed 650,000 tons of wheat in 2020, accounting for 42.3% of the total crop, compared to the previous season's 47.7% (SAGL, 2020). The Free State province, with a wheat production of 326,000 tons, experienced a year-on-year decline of 15% but still maintained the second-highest provincial production figure (SAGL, 2020). According to the South African Grain Information Service (SAGL, 2020), the irrigation areas of the Northern Cape, which is the third-largest wheat-producing region, experienced a decrease of 11% in production compared to the 2018/2019 season. In Limpopo, the wheat residue produced decreased by 6% (SAGL, 2020). Similarly, the North West region experienced a 7% decrease in production (SAGL, 2020).On the other hand, the July 2020 harvest showed a production upturn due to favourable weather conditions and an above-average planted area, according to the Food and Agriculture Organization (FAO, 2020). Overall, the 2020 wheat cereal output was forecasted to be 18.6 million tons, which is nearly 30% higher than the five-year average and the second-largest output on record (FAO, 2020).

2.12 PLANT HORMONES ON SEED GERMINATION

Plant hormones are a class of natural or synthetic substances that regulate plant development. They act as chemical messengers, controlling various cellular activities and facilitating communication between different parts of the plant. These hormones play a crucial role in plant growth, reproduction, and survival mechanisms, as well as in seed germination and resistance against biotic and abiotic stress. Phytohormones such as cytokinins, abscisic acid, and gibberellins are particularly important in modulating physiological and molecular responses, thereby ensuring the plant's survival and promoting growth and yield under different environmental conditions (Sajjad et al., 2017; Vob et al., 2014; Verhage et al., 2010; De Vleesschauwer et al., 2013; Kazan, 2015; Colebrook et al., 2014; Xu et al., 2016; Bücker-Neto et al., 2017; Fahad et al., 2015).

2.13 FERTILIZER REQUIREMENTS

2.13.1 Nitrogen in wheat production

According to Schlatter et al. (2020), it is important to ensure an adequate supply of nitrogen (N) throughout the different stages of wheat plant development. Splitting N applications is recommended as it improves N use efficiency, reduces investment risk, and protects the environment. To maximize production efficiency, growers should apply top dress N early, before the joining phase. The timing, placement, and nitrogen source should be adjusted based on factors such as climatic conditions, soil type, and tillage system. Additionally, Wang (2020) suggested that even if the N supply is low, plant growth can be restored by administering gibberellic acid.

2.13.2 Phosphorus in wheat production

According to Schlatter et al. (2020), sufficient phosphorus (P) fertility in crops has several benefits, including increased tillering and grain head numbers, reduced winter-killing, improved water-use efficiency, accelerated maturity, and lower grain moisture at harvest. Winter wheat, for instance, requires approximately 0.6 to 0.7 pounds of phosphorus pentoxide (P_2O_5) per bushel of grain. To effectively address low to medium soil phosphorus levels, banded or starter applications are commonly recommended as they promote faster plant establishment and help mitigate the negative effects of soil acidity. Broadcast applications of phosphorus should be incorporated to enhance positional availability. Additionally, adequate phosphorus levels contribute to improved nitrogen (N) recovery and utilization efficiency, which is crucial in today's agricultural context.
In a related study by Wang (2020), it was suggested that GA3 (gibberellic acid) plays a role in regulating phosphate uptake. When plants experience phosphorus deficiency, GA3 assists in the accumulation of DELLAs (a class of growth-regulating proteins) in the roots. This DELLA-mediated signaling pathway contributes to anthocyanin accumulation, a process that influences plant pigmentation and other physiological responses

2.13.3 Potassium in wheat production

According to Schlatter et al. (2020), potassium (K) in wheat production is linked to improved moisture and nitrogen (N) use efficiency, as well as reduced disease incidence and lodging. The recommended amount of K is approximately equal to that of N. Unlike phosphorus (P), the placement of K is not as crucial since it is more mobile in soils. In high-rainfall areas with deep sandy soils, split applications of K should be made to enhance its utilization efficiency.

Furthermore, Wang (2020) suggests that low potassium levels, when gibberellic acid is applied, promote the accumulation of DELLA protein in the roots and the expression of high affinity potassium transporter.

2.14 SOIL AND CLIMATIC REQUIREMENTS

Wheat is a widely cultivated crop that can grow successfully in various types of soil and large land areas. When gibberellic acid is applied, it remains in the soil for about 6 weeks. The crop requires an average annual rainfall of 254 mm during the growing stage, but it can adapt to different climates. Wheat thrives in cool regions with temperatures ranging from 10 to 24 °C and prefers deep, fertile, well-drained soil with a pH level between 5.5 and 7.5. According to Moshe (1989), gibberellic acid is most effective at temperatures above 7 °C. Wheat is a vital staple cereal crop that provides a significant source of energy for approximately 4 billion people worldwide

CHAPTER3: MATERIALS AND METHODS

3.1 DESCRIPTION OF THE STUDY SITE

The pot experiment was carried out at the Department of Research and Specialist Services at the Crop Breeding Institute, corner Fifth Street Extension Street and Downe Avenue opposite the Harare Golf club. The station is in natural region IIa and receives about 800mm of rain per annum, Harare. The Global Positioning System coordinates of the site are: Latitude 17o48’ 31.9”S and Longitude 31o3’8.42”E.

3.2 EXPERIMENTAL DESIGN

The experiment was laid out as a 4*4 factorial experiment in a randomized complete block design (RCBD) with 3 replicates. Factor 1 was 4 wheat (genotypes (Save, Dande, Runde and Ncema. Factor 2 was the different GA_3 levels. No GA_3 which was the control was level 1, (1ml / 1litre) which was less than standard was level 2, (2ml/ litre) the standard was level 3 and more than standard (4ml/litre), was level 4.

3.3 EXPERIMENTAL PROCEDURE

The experiment was conducted over a period of seventy days. The wheat seeds were obtained from the Crop Breeding Institute (CBI), clay loamy soil was filled in forty-eight plastic pots. Solutions of 2 litres water (G1), 2litres of water and 1ml of GA_3 (G2), 2 litres water and 2ml of GA_3 (G3), 2 litres water and 4ml of GA3 (G4) was prepared. Ten seeds per variety were soaked in the 4 different solutions in 16 different plastic containers for 3 days. Compound D fertilizer was applied in pots at the rate of 5grams per pot. Ten soaked seeds were planted per pot. The pots were watered until the plants germinated. Five days after emergence seedlings were thinned to four seedling per pot. The germinating weeds were uprooted so that they did not compete with the wheat plants for water and nutrients .Ammonium nitrate fertilizer was applied 3 weeks after germination. All basic agronomic practices were done until the plants reached the tillering stage.

3.4 DATA COLLECTION

Data was collected in segments firstly germination characters then seedling characters. All 48 pots were used to collect data.

3.4.1 Germination percentage

Germination records were expressed as a percentage. Germination percentage (GP) was calculated by counting the number of emerged seeds 5 days after planting and then dividing the number by the number of seeds planted. The formula used to attain germination percentage was GP = $\underline{N^{i}\ {}^{*}100}$

3.4.2 Seedling vigour index

The seedling vigour index objective was achieved by thinning the wheat seedlings .Thinning was done because the germinated seeds varied within the pot, so in order to reduce bias within the results a uniform number of seedlings in the pot had to be worked with. The seedlings in the pots were thinned to 4 seedlings per pot. From the thinned seedlings shoot length and root length was measure using a sting and a ruler it was then multiplied by the germination percentage. The formula used was:

Seedling vigour index (SVI),

SVI= shoot length + root length x GP%

3.4.3 Leaf Area index

The leaf area index objective was achieved by measuring the leaf length and width and to get the area it was multiplied together, to then get then leaf area index the leaf area was divided by the ground area. The formula used was LAI=leaf area /ground area

3.4.4 Stem height

The stem height was measured 7 days after emergence, 14 days after emergence and 21days after emergence .The stem height was measured from the root crown to the apex of the last leaf using a string and a ruler. All the four seedlings per pot were measured and the average of the four was recorded.

3.4.5 Tiller number

To get the tiller number, the number of tillers were also counted from each pot. Tillers were counted from the four plants in the pots and averaged then they were averaged to get the average tiller number per pot and then recorded.

3.5 DATA ANALYSIS

Analysis of variance (ANOVA) was used for data analysis using GenStat version 18 and Least Square Difference (LSD) was used to separate the means at 0.05 level of significance where there was significant difference.

CHAPTER 4: RESULTS

4.1 Effects of GA_3 levels on germination percentage of wheat varieties

There was a significant difference on the germination percentage (GP) on wheat varieties $p<0.001$. Dande had the highest germination percentage at G4 (90%), followed by Ncema (83.3%), Save had (70%), and Runde had the lowest germination percentage of 36, 7%.The error bars indicated that Save at G1and Runde at G1 had a significant difference. Dande G1 and Runde G1 had a significant difference. Dande G1 and Ncema G1 also showed a significant difference. Looking at G2, Save and Dande showed a significant difference, also Dande and Runde showed a significant difference. At G3 Dande and Runde and Runde and Ncema showed a significant difference.

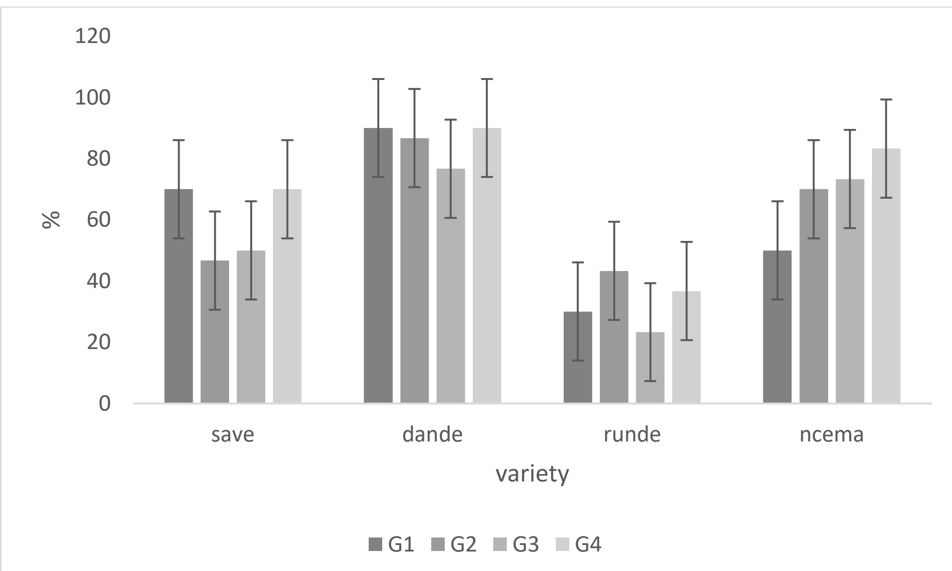

Figure 4.1: Effects of GA levels on germination percentage on wheat varieties

4.2 Effects of GA_3 levels on seedling vigour index on wheat varieties.

The seedling vigour index amongst the wheat varieties showed a significant difference at $p <0.001$. The Runde variety showed the least seedling vigour index and the Dande variety showed the least difference within the 4 different levels of GA_3. The error bars at G1 showed that Dande and Runde had a significant difference. Dande at G2 and Runde at G2 also had a significant difference. Save at G3 level and Dande at G3 showed a slight significant difference and Dande and Runde also showed a significant difference. At G4 Save and Runde, Dande and Runde and Runde and Ncema showed a significant difference.

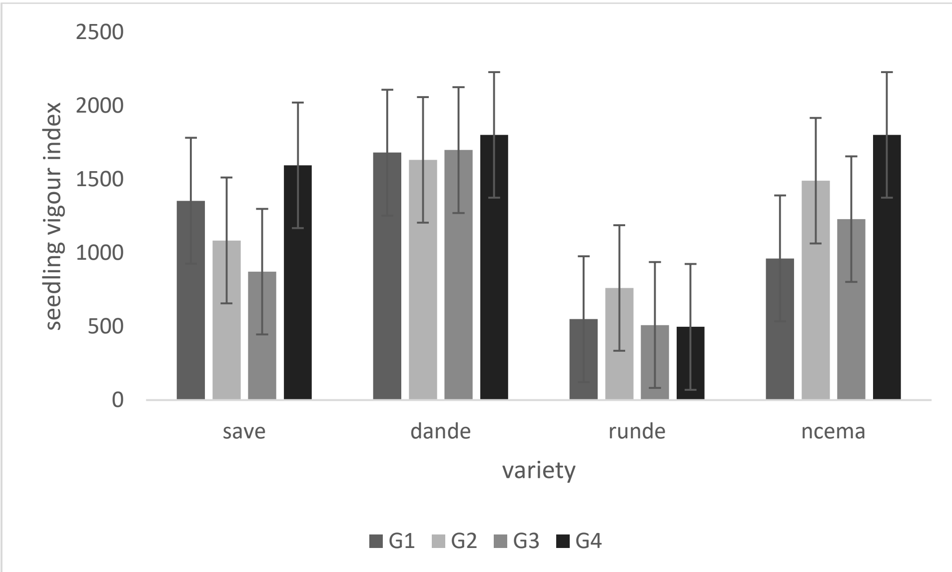

Figure4.2 Effects of GA_3 levels on seedling vigour index on wheat varieties

4.3 Effects of GA_3 levels on leaf area index on wheat varieties

The leaf area index did not have a significant difference at P value = 0.301.Only the Dande variety in GA_3 showed to have the highest leaf area index. Dande at G3 had the highest leaf area index.

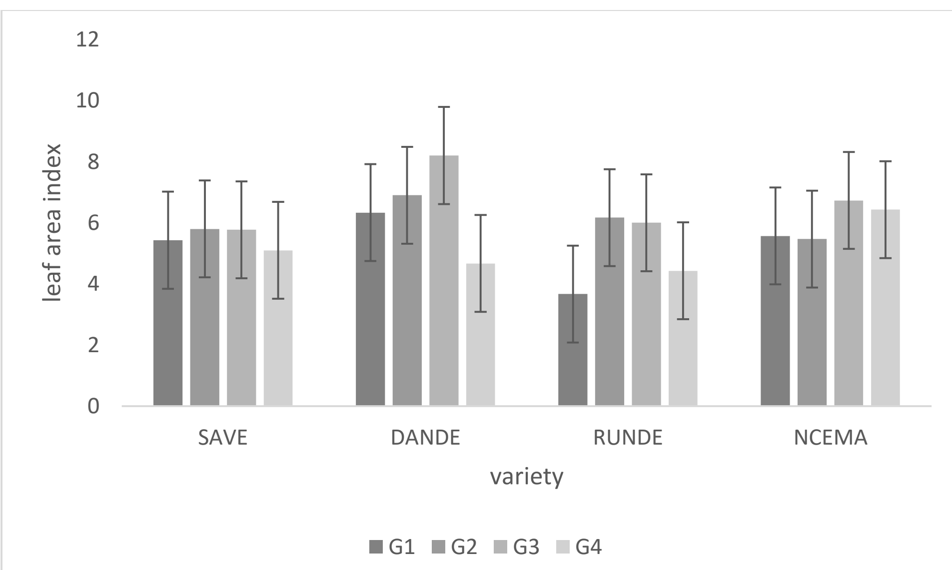

Figure4. 3 Effects of GA_3 levels on leaf area index on wheat varieties.

4.4 Effects of GA_3 levels the stem height on wheat varieties at 7days after emergence.

The stem height of wheat measured seven days after emergency had a significant difference, p= 0.029. The Save variety at level 4 had the highest stem height of 4.6cm compared to the Dande variety that had 4.32cm.Runde in level 4 of GA_3 had the least stem height of 1.67cm. Error bars at G4 Save and Runde had a significant difference. Dande and Runde had a significant difference. Runde and Ncema had a significant difference.

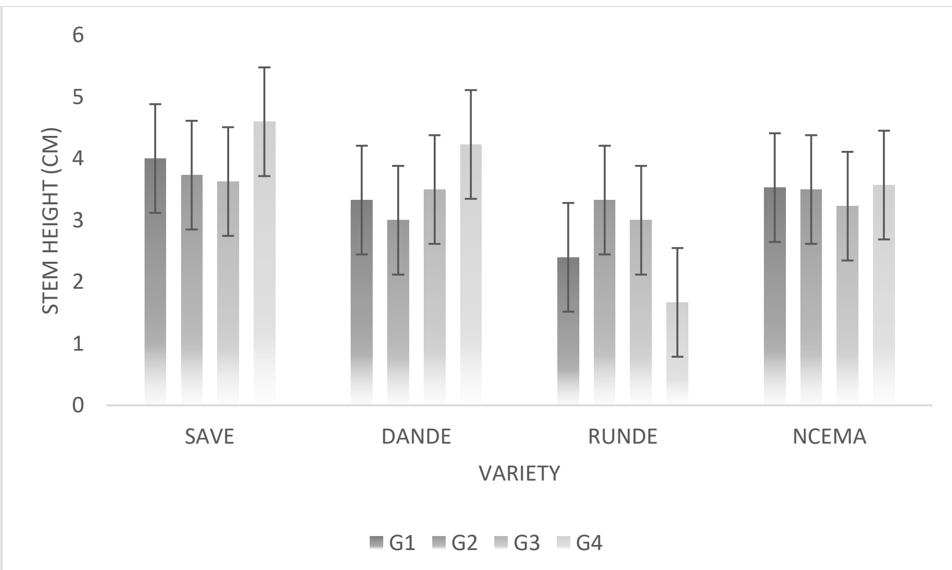

Figure 4.4 Effects of GA_3 levels the first stem height on wheat varieties.

4.5 Effects of GA_3 levels on the stem height on wheat varieties at 14 days after emergence

The stem height of wheat in different GA_3 levels at 14days after emergence had no a significant difference, P=0.501.The stem height of the wheat varieties showed little difference except for the runde variety at G3 that had a stem height.

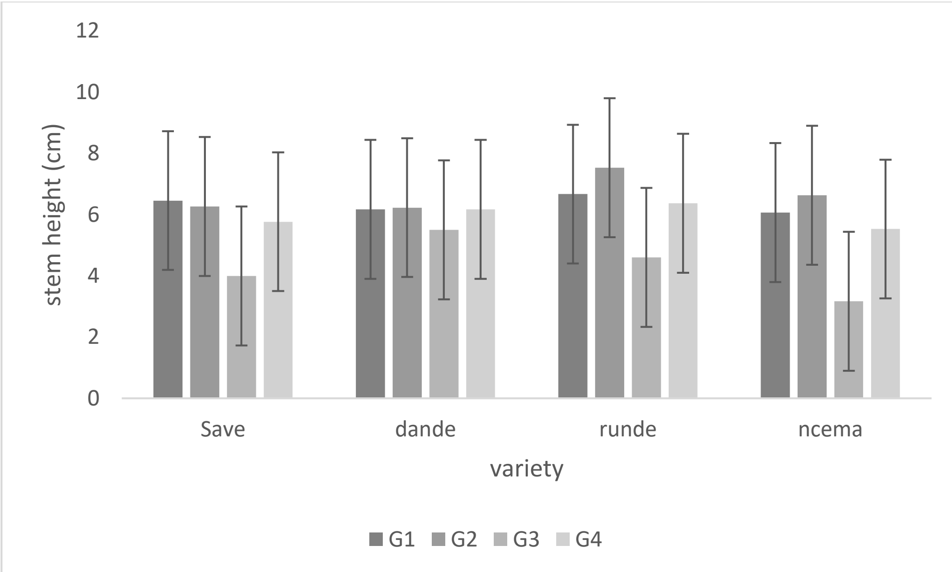

Figure 4.5: Effects of GA_3 levels on the second stem height on wheat varieties.

4.6Effects of GA_3 levels on the third stem height on wheat varieties at 21 days after emergence

The stem height of wheat in different GA_3 levels at 21days after emergence did show any significant differences p=<0.001.The Save variety in level 1 of GA_3 showed the height stem height of 18.07cm.The least stem height was the Runde variety with GA_3 level 1, showing 8.07cm. Error bars indicated that they were significant differences at Save and Runde at G1, Save and Ncema at G1.Dande G4 and Runde G4 also showed a significant difference.

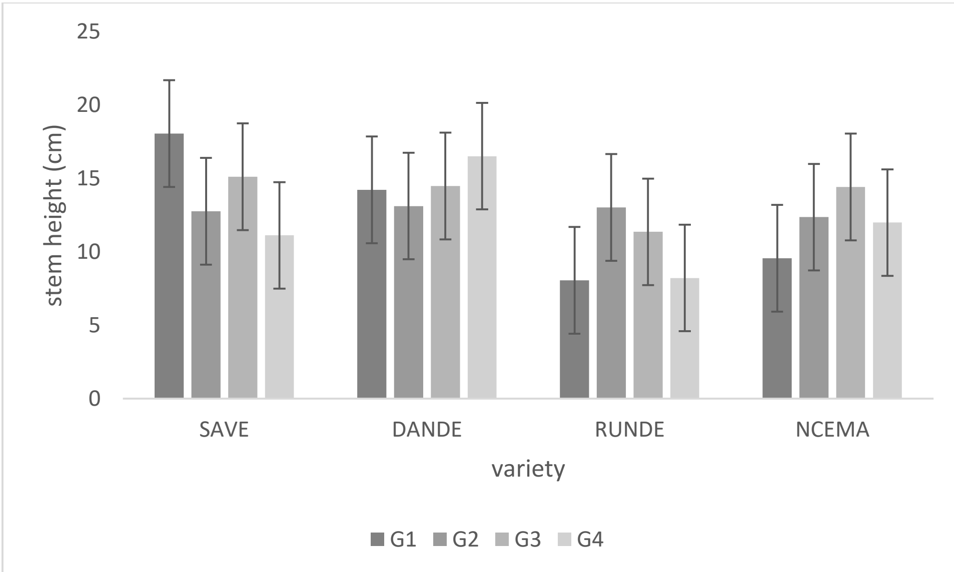

Figure 4.6 Effects of GA_3 levels on the third stem height on wheat varieties

4.7 Effects of GA_3 levels on tiller number on wheat varieties.

The tiller number of different varieties of wheat in different GA_3 levels showed that they was no significant difference, the P =0.097.

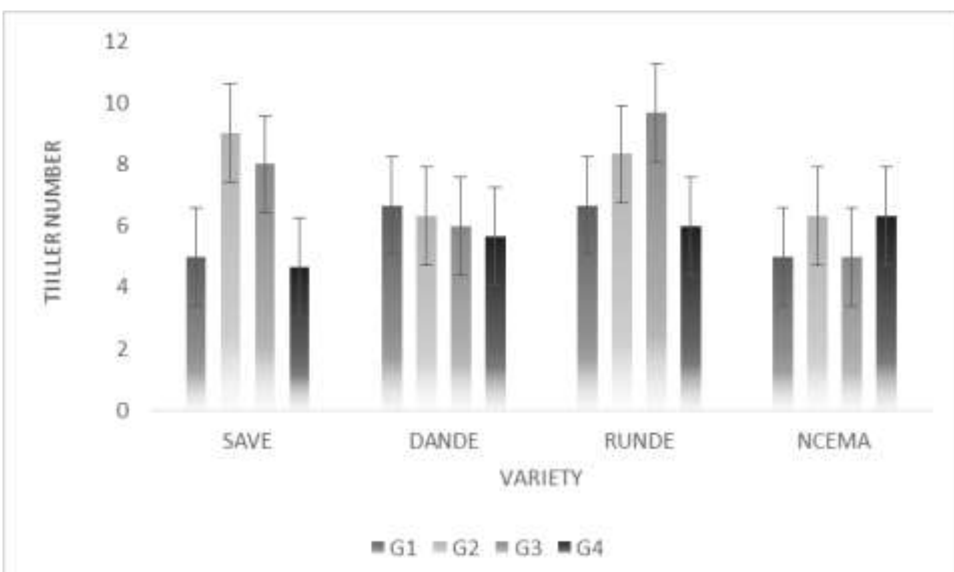

Figure 4.7 Effects of GA_3 levels on tiller number on wheat varieties.

CHAPTER 5: DISCUSSION

5.1 Effects of GA_3 levels on germination percentage on wheat varieties.

According to Figure 4.1, GA3 had a significant impact on germination. The study observed that different wheat varieties responded differently to varying levels of Gibberellic Acid (GA3) on germination, supporting the findings of Pavlista et al. (2013). This variation in response is due to genetic differences within the wheat varieties. The results indicate that the amount of GA3 applied affects the germination percentage until it reaches a saturation point. Maximum effectiveness was observed at 2 ml and 4 ml of GA3.

The study also demonstrated that GA3, as a natural or synthetic plant growth hormone, can regulate plant development by controlling various cellular activities in plants, as mentioned by Sajjad et al. (2017). Germination percentage was enhanced when certain wheat varieties were treated with GA3 using the soaking method. This method stimulates biochemical processes necessary for germination, such as hydrolysis, metabolism of growth inhibitors, and enzyme activation. Xu et al. (2016) also acknowledge the essential role of GA3 in seed germination and its contribution to resistance against biotic and abiotic stress in wheat plants.

However, it is important to note that GA3 can elicit different responses in different wheat varieties. For example, the runde variety showed a negative reaction compared to other varieties, while the Dande variety performed well in the absence of GA3. Furthermore, the study demonstrated that incorporating GA3 can reduce germination days, which was also supported by Ayaz et al. (2019).

5.2 Effects of GA_3 levels on seedling vigour index on wheat varieties

According to Iftikhar et al. (2016), the Save and Ncema varieties exhibited the highest seedling vigour index when treated with Gibberellic acid at level 4 (G4). The researchers suggest that the use of Gibberellic acid may have stimulated both root and shoot growth, resulting in enhanced seedling vigour index. Seedling vigour index is crucial for crop yield and resource utilization efficiency, as it determines the successful establishment of plants in the field and their ability to germinate and develop seedlings rapidly and uniformly across various environmental conditions.

Similar findings were reported by Nawel (2012), who also observed improved seedling vigour with the application of Gibberellic acid. Additionally, Ozturk and Unal (2023) and Archard (2013) acknowledge that GA3, a type of Gibberellic acid, regulates gene expression through DELLA proteins and promotes germination and shoot development by facilitating the degradation of the growth suppressor DELLA.

5.3 Effects of GA_3 levels the stem height on wheat varieties.

The stem height and development showed that it was sensitive to GA_3. The data in fig 4.4 showed that there is significant growth on the wheat varieties if a maximum of 4ml GA_3 was used. This agrees with the work of (Iftikhar *et al* ,2019) who also noticed that Gibberellic Acid has an effect on wheat as it increases in plant height However despite the results showing that they was no significant difference on the last stem height the varieties reacted differently to the GA_3 levels. On the stem height the runde and Ncema varieties are dwarf varieties so the study does prove that GA_3 can surpass genomic makeup.

Also the stem height might have increased because, GA_3 induces internode lengthening, and a study conducted by Li et al. (2019) supports these findings, as he also investigated the role of Gibberellic Acid (GA_3) in regulating internode elongation and stem height showed that. GA_3 promote internode elongation by increasing cell division and elongation in the stem. Stem height might have also increased due to increased rate of photosynthesis, which ensures that the plant has enough nutrients to support growth of the plant. The study conducted by Wang et al. (2014) also supports these findings .In his investigations he discovered that GA_3 can increase the rate of photosynthesis by enhancing the efficiency of the photosynthetic electron transport chain. GA_3 was found to increase the activity of photosystem II (PSII), which is responsible for the initial light absorption and electron transfer in the photosynthetic process.

In addition to GA_3 effects on photosynthesis, GA_3 has also been found to play a role in nitrogen assimilation in plants. Nitrogen assimilation is the process by which plants take up and use nitrogen to synthesize amino acids and other essential compounds. GA_3 has been shown to increase the activity of nitrate reductase, an enzyme involved in the conversion of nitrate to ammonium, which is then used in the synthesis of amino acids. This was demonstrated in a study by Wang et al. (2015), which found that GA_3 treatment increased the activity of nitrate reductase in wheat plants.

5.5 Effects of GA_3 levels on tiller number and leaf area index on wheat varieties.

Due to the fact that GA_3 stays in the soils only for 6 weeks as sited by Smith, (2001), it does not cause any significant effect on the tiller number and leaf area index of wheat varieties. From these results highlights the importance of careful experimental design and statistical analysis to ensure that any observed differences are meaningful and not simply due to chance.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

Increasing GA_3 levels increased the germination and seedling growth on different wheat varieties to all varieties except for the Save variety. The germination percentage of plants treated with GA_3 was increased significantly as compared to the ones not treated ones in all the other varieties, only Save showed to be affected when gibberellic acid was applied. The first stem height (7 days) and the second stem height 14 days after emergency showed significant improvement when the plants were treated with GA_3. This may indicate that treating seed with GA_3 enhances growth and development in wheat varieties. However GA_3 did not cause any significant changes on the stem height 21days after emergency leaf area index, tiller number of the wheat varieties. This shows that GA_3 does have a period it persist in the soil as did not have significant differences.

6.2 RECOMMENDATIONS

The experimental data showed how GA_3 affects different wheat varieties differently, so I recommend farmers and breeders to use GA_3 during production of wheat .If a one is to grow the Save, Dande and Ncema variety, I recommend they soak the seeds in a GA_3 and water solution at a rate of 4ml of GA_3:2 litres of water and if one is to grow the Runde variety the seeds must be soaked in a solution of 2ml of GA_3:2 litres.

References

Agriculture and Horticulture Development Board (2023),| All Rights Reserved, Agriculture and Horticulture Development Board, Middlemarch Business Park, Siskin Parkway East, Coventry, CV3 4PE.

Alexandra D.Pavlista, Dipka K.Santra, David D. Baltensperger.2013 Bioassay of winter wheat for Gibberellic Acid sensitivity, *American Journal of Plant Sciences*, 2013, 4, 2015-**2022** Published Online October 2013 (http://www.scirp.org/journal/ajps).

Ardeshir B. Demamia,History of Introduction and Cultivation of Durum wheat in North America,4, 2013.

Dane, K. 2020. A Step-by-Step Guide to Wheat Seed Germination Procedure. [online]. Available from https://agriculturegoods.com/a-step-by-step-guide-to-wheatseed-germination-procedure/ *[accessed 02 December 2019]*.

Dube, E. Kilian, W. Mwadzingeni, L., Sosibo, N.Z. Barnard, A. and Tsilo, T.J. 2019. Genetic progress of spring wheat grain yield in various production regions of South Africa. *South African Journal of Plant and Soil*, *36*(1), 33-39.

Dr Rajeev Singh, Pharm Easy, and Wheat: Uses, Benefits, Side effects, November 2022.

Faheem Shehzad Baloch, Hüsnü Aktaş, Awais Rasheed, Muhammad Azhar Nadeem, Evren Cabi, Rüştü Hatipoğlu & Muhammad Sajjad , Origin, Taxonomy, and Distribution of Ancient Wheats in Turkey, Home Ancient Wheats Chapter, First Online: 30 August 2022.

Fatemeh Gholizadeh, Ghader Mirzaghaderi,Subhan Danish, Mohammad Farsi, Seyed Hasan Marashi, 2021 Evaluation of morphological traits of wheat varieties at germination stage under salinity stress, PLOS ONE,

Ferreira, N.C. Mazzuchelli, R.D.C.L. Pacheco, A.C. Araujo, F.F.D. Antunes, J.E.L. and Araujo, A.S.F.D. 2018. *Bacillus subtilis* improves maize tolerance to salinity. *Ciência Rural*, *48*.

Fetahu, S. Aliu, S., Rusinovci, I. Kelmendi, B. and Maliqi, N. 2013. Accumulation and distribution of dry matter in some common bean landrace seedlings at the phase of the cotyledons. *Agriculture & Forestry*, *59*(4).

Fetahu, S., Rusinovci, I., Aliu, S., Zeka, D. and Beluli, A. 2021. Genetic diversity of common bean landraces on seed imbibition and some quality traits. In *VIII South-Eastern Europe Symposium on Vegetables and Potatoes 1320*, 72-78.

Finkel, O.M. Castrillo, G. Paredes, S.H. González, I.S. and Dangl, J.L. 2017. Understanding and exploiting plant beneficial microbes. *Current Opinion In*

Food and Agriculture Organization (FAO) of the United Nations. 2020. Crop production statistics data.[online]. Available from: http://www.fao.org/faostat/en/#data/QC [Accessed on 13 June 2020].

Government of Zimbabwe |Department of Research and Specialist Services| All rights reserved. http://www.drss.gov.zw

Growth of Winter Wheat and Rye. Am. J. Plant Sci. **2014**, 05, 2984–2996.

Grote, U., Fasse, A., Nguyen, T., Erenstein O, 2021. Food security and the dynamics of wheat and maize value chain in Africa and Asia, 42p.

G. Dalessandro, F. Vita, R. Lavecchia, 1972 Inhibition of oxidative phosphorylation on mitochondria isolated from pea seedlings treated with CCC".

Iftikhar, Y. (2016).Gibberellic Acid: A key Phytohormone for seedling vigour. Journal of Plant Growth Regulation, 35(4), 855-870.doi:10.1007/s00344-016-9609-5.

International Food Policy Research Institute (IFPRI). 2002. Global food projections to 2020-emerging trends and alternative futures. [Online] Available from: http://www.ifpri.org. [Accessed 2 May 2020].

Laura Strugnell, 2018, the importance of wheat in the global food supply to a growing population. The importance of wheat in the global food supply and meeting future demand from a growing population.

Li, Q., Li, Y., Liu, J., Zhang, L., Wu, Y., Hou, Y., & Wang, Y. (2019). Gibberellins Modulate Internode Elongation by Regulating the Expression of Pin-formed Auxin Transporter in Rice. Scientific Reports, 9(1), 1-10.

Nawel Nasri, Hela Mahmoudi, Olfa Baatour, Sabah M'rah, Rym Kaddour and Mokhtar Lachâal.2012; Effect of exogenous Gibberellic acid on germination, seedling growth and phosphatase activities in Lettuce under salt stress ; African Journal of Biotechnology Vol. 11(56), pp. 11967-11971, 12 July, 2012 ,http://www.academicjournals.org/AJB
DOI: 10.5897/AJB12.339.

NAWG (National Association of Wheat Growers), The History of wheat and West bred wheat, Online June 2021.

Maluleke, Sandra, 2022. Stimulation of germination by gibberellic acid and bacillus subtilis on common bean, maize, wheat, and okra exposed to acid mine water at different temperature regimes. www.http://hdl.handle.net/10500/29193.

Mihaiela Cornea-Cipcigan, Doru Pamfil, Cristian Radu Sisea, and Rodica Margaoan, 2020: Gibberellic Acid Can Improve Seed Germination and Ornamental Quality of Selected Cyclamen Species Grown Under Short and Long Days.

Milan Skalicky , Jan Kubes, Pavla Vachova , Shokoofeh Hajihashemi ,Jaroslava Martinkova 1 and clav Hejnak ,2020 Effect of Gibberellic Acid on Growing-Point Development of Non-Vernalized Wheat Plants under Long-Day Conditions.

Munir Ozturk, Bengu Turkyilmaz Unal, 2023, Exogenous application of phytohormones and phytometobolites to plants alleviate the effects of drought stress.

Mosaic essential crop nutrients, crop nutrition, http://www.cropnutrition,com.
Knoema,2020,*wheatproductionquantity*.OnlineArticle:*Knoema*.com/atlas/Zimbabwe/topics/Agriculture/Crops-Production-Quantity-tonnes/Wheat-production?mode=amp,15-02-2023.

Moshe J.Pinthus ,Michael D.Gale,Nigel E.J.Appleford and John R.Lenton.1989, Effects of Temperature on Gibberellin Responsiveness and on Endogenous GA1 Content of tall and dwarft wheat genotypes, Plant Physiology.1989.jul;90(3):854-895.dio:10.1104/pp.90.3.854

Kumar, A. Prasad, B. Bharati, A. and Kumar, A. 2017. Botanical description of Wheat. *Wheat a Premier Food Crop*, 23.

Pavlista, A.D.; Baltensperger, D.D.; Santra, D.K.; Hergert, G.W.; Knox, S. Gibberellic Acid Promotes Early.

Sana Salih and Ruveyde Tuncturk, 2020: Advances in Crop Science and Technology. Low Doses of Gibberellic Acid can Enhance Germination of Wheat Seed under, Drought Stress.

Sandeep Rout, Sashikala Beura, Neelam Khare and Ajay Kumar Prusty,(2021) Role of Different Concentrations Gibberellic Acid (GA3) on Seed Germination and Seedling Quality of *Saraca asoca* (Roxb.) De Wilde.

Sandra Maluleke, 2022, Stimulation of germination by Gibberellic acid and Bacillus subtilis on common beans, maize, wheat and okra exposed to acid mine water at different temperature regimes.

Smith,J.(2001).The persistence of Gibberellic Acid in soil. Journal of Agriculture Science, 137(3), 289-295.

Waleed A.E. Abido, A. Allem, L. Zsombik and N. Attila, 2019. Effect of Gibberellic acid on germination of six wheat cultivars under salinity stress levels. Asian J. Biol. Sci., 12: 51-60.

Wheat Research, http://www.cimmyt.org

Xu, S.; Chong, K. Remembering winter through vernalisation. Nat. Plants **2018**, 4, 997–1009.

Yubin Wang ,Qingqing Yao,Yushi Zhang,Yuexia Zhang,Jiapeng Xing,Benzhou Yang,Guohua Mi,Zhaohu Li and Mingcai Zhang,2020,The Role of Gibberellins in regulation of Nitrogen uptake and physiological traits in maize responding to nitrogen availability,int J Mol Sci.2020 Mar ;21(5):1824.publishedonlineon2020mar6,dio:10.3390/ijms21051824.
http//:www.ncbi.nlm.nih.gov/pmc/articles/PMC7084584/

APPENDICES

1.1 APPENDIX 1:

Genstat Release 18.1 (PC/Windows 8) 15 May 2023 09:22:26

Registered to: ICARDA

```
  3  "Data taken from unsaved spreadsheet: New Data;1"
  4  DELETE [REDEFINE=yes] _stitle_: TEXT _stitle_
  5  READ [PRINT=*; SETNVALUES=yes] _stitle_
  8  PRINT [IPRINT=*] _stitle_; JUST=left
```

Data imported from Clipboard
on: 15-May-2023 9:23:15

```
  9  DELETE [REDEFINE=yes] block,wheat,GA,GP,SVI,SH1,SH2,SH3,LAI,CB,TLN
 10  UNITS [NVALUES=*]
 11  FACTOR [MODIFY=no; NVALUES=48; LEVELS=3; LABELS=*; REFERENCE=1] block
 12  READ block; FREPRESENTATION=ordinal
```

Identifier	Values	Missing	Levels
block	48	0	3

```
 15  FACTOR [MODIFY=no; NVALUES=48; LEVELS=4; LABELS=*; REFERENCE=1] wheat
 16  READ wheat; FREPRESENTATION=ordinal
```

Identifier	Values	Missing	Levels
wheat	48	0	4

```
 19  FACTOR [MODIFY=no; NVALUES=48; LEVELS=4; LABELS=*; REFERENCE=1] GA
 20  READ GA; FREPRESENTATION=ordinal
```

Identifier	Values	Missing	Levels
GA	48	0	4

```
 23  VARIATE [NVALUES=48] GP
 24  READ GP
```

Identifier	Minimum	Mean	Maximum	Values	Missing
GP	0.0000	61.88	100.0	48	0

```
 27  VARIATE [NVALUES=48] SVI
 28  READ SVI
```

Identifier	Minimum	Mean	Maximum	Values	Missing
SVI	0.0000	1221	2450	48	0

```
 32  VARIATE [NVALUES=48] SH1
 33  READ SH1
```

Identifier	Minimum	Mean	Maximum	Values	Missing
SH1	0.0000	3.392	5.800	48	0

```
VARIATE [NVALUES=48] SH2
READ SH2
```

Identifier	Minimum	Mean	Maximum	Values	Missing	
SH2	0.0000	7.487	84.90	48	0	Skew

```
VARIATE [NVALUES=48] SH3
READ SH3
```

Identifier	Minimum	Mean	Maximum	Values	Missing
SH3	0.0000	12.79	22.10	48	0

```
VARIATE [NVALUES=48] LAI
READ LAI
```

Identifier	Minimum	Mean	Maximum	Values	Missing
LAI	0.0000	5.792	11.10	48	0

```
VARIATE [NVALUES=48] CB
READ CB
```

Identifier	Minimum	Mean	Maximum	Values	Missing
CB	0.0000	40.14	81.30	48	0

```
VARIATE [NVALUES=48] TLN
READ TLN
```

Identifier	Minimum	Mean	Maximum	Values	Missing
TLN	0.0000	6.542	10.00	48	0

```

"Two-way design in randomized blocks"
DELETE [REDEFINE=yes] _ibalance
A2WAY [PRINT=aovtable,information,means,%cv; TREATMENTS=GA,wheat;
BLOCKS=block; FACTORIAL=2;\
 FPROB=yes; PSE=diff,lsd,means,alllsd; LSDLEVEL=5; PLOT=*;
COMBINATIONS=present; EXIT=_ibalance]\
 GP; SAVE=_a2save
```

Analysis of variance

Variate: GP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	1950.0	975.0	2.53	
block.*Units* stratum					
GA	3	1272.9	424.3	1.10	0.365
wheat	3	17389.6	5796.5	15.01	<.001
GA.wheat	9	2935.4	326.2	0.84	0.582
Residual	30	11583.3	386.1		
Total	47	35131.2			

Information summary

All terms orthogonal, none aliased.

Message: the following units have large residuals.

block 1 *units* 2	42.1	s.e.	15.5
block 3 *units* 2	-42.9	s.e.	15.5

Tables of means

Variate: GP

Grand mean 61.9

GA	1	2	3	4
	60.0	61.7	55.8	70.0

wheat	1	2	3	4
	59.2	85.8	33.3	69.2

GA	wheat	1	2	3	4
1		70.0	90.0	30.0	50.0
2		46.7	86.7	43.3	70.0
3		50.0	76.7	23.3	73.3
4		70.0	90.0	36.7	83.3

Standard errors of means

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30

e.s.e.	5.67	5.67	11.34

Standard errors of differences of means

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
s.e.d.	8.02	8.02	16.04

Least significant differences of means (5% level)

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
l.s.d.	16.38	16.38	32.77

Stratum standard errors and coefficients of variation

Variate: GP

Stratum	d.f.	s.e.	cv%
block	2	7.81	12.6
block.*Units*	30	19.65	31.8

```
  66  SET [IN=*]
  72  "Two-way design in randomized blocks"
  73  DELETE [REDEFINE=yes] _ibalance
  74  A2WAY [PRINT=aovtable,information,means,%cv; TREATMENTS=GA,wheat;
BLOCKS=block; FACTORIAL=2;\
  75   FPROB=yes; PSE=diff,lsd,means,alllsd; LSDLEVEL=5; PLOT=*;
COMBINATIONS=present; EXIT=_ibalance]\
  76   SVI; SAVE=_a2save
```

Analysis of variance

Variate: SVI

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	10998.	5499.	0.02	
block.*Units* stratum					
GA	3	833789.	277930.	1.01	0.401
wheat	3	8015750.	2671917.	9.74	<.001
GA.wheat	9	1406413.	156268.	0.57	0.811
Residual	30	8233431.	274448.		
Total	47	18500380.			

Information summary

All terms orthogonal, none aliased.

Message: the following units have large residuals.

block 1 *units* 7	-979.	s.e.	414.
block 2 *units* 8	-1102.	s.e.	414.

Tables of means

Variate: SVI

Grand mean 1221.

GA	1	2	3	4
	1138.	1243.	1078.	1425.

wheat	1	2	3	4
	1227.	1705.	580.	1372.

GA	wheat	1	2	3	4
1		1355.	1683.	550.	963.
2		1085.	1633.	762.	1492.
3		873.	1700.	510.	1230.
4		1596.	1803.	498.	1803.

Standard errors of means

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30

e.s.e.	151.2	151.2	302.5

Standard errors of differences of means

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
s.e.d.	213.9	213.9	427.7

Least significant differences of means (5% level)

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
l.s.d.	436.8	436.8	873.6

Stratum standard errors and coefficients of variation

Variate: SVI

Stratum	d.f.	s.e.	cv%
block	2	18.5	1.5
block.*Units*	30	523.9	42.9

```
  77  SET [IN=*]
  83  "Two-way design in randomized blocks"
  84  DELETE [REDEFINE=yes] _ibalance
  85  A2WAY [PRINT=aovtable,information,means,%cv; TREATMENTS=GA,wheat;
BLOCKS=block; FACTORIAL=2;\
  86   FPROB=yes; PSE=diff,lsd,means,alllsd; LSDLEVEL=5; PLOT=*;
COMBINATIONS=present; EXIT=_ibalance]\
  87   LAI; SAVE=_a2save
```

Analysis of variance

Variate: LAI

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	45.882	22.941	6.09	
block.*Units* stratum					
GA	3	18.718	6.239	1.66	0.198
wheat	3	14.415	4.805	1.27	0.301
GA.wheat	9	18.450	2.050	0.54	0.831
Residual	30	113.092	3.770		
Total	47	210.557			

Information summary

All terms orthogonal, none aliased.

Message: the following units have large residuals.

block 1 *units* 12	-3.59	s.e.	1.53

Tables of means

Variate: LAI

Grand mean 5.79

GA	1	2	3	4
	5.25	6.08	6.68	5.16

wheat	1	2	3	4
	5.53	6.53	5.07	6.05

GA	wheat	1	2	3	4
1		5.43	6.33	3.67	5.57
2		5.80	6.90	6.17	5.47
3		5.77	8.20	6.00	6.73
4		5.10	4.67	4.43	6.43

Standard errors of means

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
e.s.e.	0.560	0.560	1.121

Standard errors of differences of means

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
s.e.d.	0.793	0.793	1.585

Least significant differences of means (5% level)

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
l.s.d.	1.619	1.619	3.238

Stratum standard errors and coefficients of variation

Variate: LAI

Stratum	d.f.	s.e.	cv%
block	2	1.197	20.7
block.*Units*	30	1.942	33.5

```
  88  SET [IN=*]
  94  "Two-way design in randomized blocks"
  95  DELETE [REDEFINE=yes] _ibalance
  96  A2WAY [PRINT=aovtable,information,means,%cv; TREATMENTS=GA,wheat;
BLOCKS=block; FACTORIAL=2;\
  97   FPROB=yes; PSE=diff,lsd,means,alllsd; LSDLEVEL=5; PLOT=*;
COMBINATIONS=present; EXIT=_ibalance]\
  98   TLN; SAVE=_a2save
```

Analysis of variance

Variate: TLN

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	20.292	10.146	2.68	
block.*Units* stratum					
GA	3	30.917	10.306	2.72	0.062
wheat	3	26.250	8.750	2.31	0.097
GA.wheat	9	42.750	4.750	1.25	0.302
Residual	30	113.708	3.790		
Total	47	233.917			

Information summary

All terms orthogonal, none aliased.

Message: the following units have large residuals.

block 1 *units* 9	-5.75	s.e.	1.54
block 1 *units* 12	-5.08	s.e.	1.54

Tables of means

Variate: TLN

Grand mean 6.54

GA	1	2	3	4
	5.83	7.50	7.17	5.67

wheat	1	2	3	4
	6.67	6.17	7.67	5.67

GA	wheat	1	2	3	4
1		5.00	6.67	6.67	5.00
2		9.00	6.33	8.33	6.33
3		8.00	6.00	9.67	5.00
4		4.67	5.67	6.00	6.33

Standard errors of means

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30

e.s.e.	0.562	0.562	1.124

Standard errors of differences of means

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
s.e.d.	0.795	0.795	1.590

Least significant differences of means (5% level)

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
l.s.d.	1.623	1.623	3.246

Stratum standard errors and coefficients of variation

Variate: TLN

Stratum	d.f.	s.e.	cv%
block	2	0.796	12.2
block.*Units*	30	1.947	29.8

```
SET [IN=*]
"Two-way design in randomized blocks"
DELETE [REDEFINE=yes] _ibalance
A2WAY [PRINT=aovtable,information,means,%cv; TREATMENTS=GA,wheat;
BLOCKS=block; FACTORIAL=2;\
  FPROB=yes; PSE=diff,lsd,means,alllsd; LSDLEVEL=5; PLOT=*;
COMBINATIONS=present; EXIT=_ibalance]\
  SH1; SAVE=_a2save
```

Analysis of variance

Variate: SH1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	3.292	1.646	1.41	
block.*Units* stratum					
GA	3	0.285	0.095	0.08	0.970
wheat	3	12.082	4.027	3.46	0.029
GA.wheat	9	8.890	0.988	0.85	0.579
Residual	30	34.948	1.165		
Total	47	59.497			

Information summary

All terms orthogonal, none aliased.

Message: the following units have large residuals.

block 1 *units* 9	-2.48	s.e.	0.85
block 3 *units* 9	1.95	s.e.	0.85

Tables of means

Variate: SH1

Grand mean 3.39

GA	1	2	3	4
	3.32	3.39	3.34	3.52

wheat	1	2	3	4
	3.99	3.52	2.60	3.46

GA	wheat	1	2	3	4
1		4.00	3.33	2.40	3.53
2		3.73	3.00	3.33	3.50
3		3.63	3.50	3.00	3.23
4		4.60	4.23	1.67	3.57

Standard errors of means

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30

e.s.e.	0.312	0.312	0.623

Standard errors of differences of means

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
s.e.d.	0.441	0.441	0.881

Least significant differences of means (5% level)

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
l.s.d.	0.900	0.900	1.800

Stratum standard errors and coefficients of variation

Variate: SH1

Stratum	d.f.	s.e.	cv%
block	2	0.321	9.5
block.*Units*	30	1.079	31.8

```
 110  SET [IN=*]
 116  "Two-way design in randomized blocks"
 117  DELETE [REDEFINE=yes] _ibalance
 118  A2WAY [PRINT=aovtable,information,means,%cv; TREATMENTS=GA,wheat;
BLOCKS=block; FACTORIAL=2;\
 119   FPROB=yes; PSE=diff,lsd,means,alllsd; LSDLEVEL=5; PLOT=*;
COMBINATIONS=present; EXIT=_ibalance]\
 120   SH2; SAVE=_a2save
```

Analysis of variance

Variate: SH2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	14.292	7.146	3.86	
block.*Units* stratum					
GA	3	6.253	2.084	1.13	0.354
wheat	3	39.186	13.062	7.06	0.887
wheat.GA	9	7.715	0.857	0.46	<.001
Residual	30	55.503	1.850		
Total	47	122.949			

Information summary

All terms orthogonal, none aliased.

Message: the following units have large residuals.

block 1 *units* 11	51.0	s.e. 9.4
block 2 *units* 11	-26.3	s.e. 9.4
block 3 *units* 11	-24.7	s.e. 9.4

Tables of means

Variate: SH2

Grand mean 5.82

wheat	1	2	3	4
	6.34	6.67	4.32	5.96

GA	1	2	3	4
	5.62	6.02	6.29	5.35

wheat	GA 1	2	3	4
1	6.46	6.17	6.67	6.07
2	6.27	6.23	7.53	6.63
3	4.00	5.50	4.60	3.17
4	5.77	6.17	6.37	5.53

Standard errors of means

Table	wheat	GA	wheat GA
rep.	12	12	3
d.f.	30	30	30
e.s.e.	0.393	0.393	0.785

Standard errors of differences of mean

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
s.e.d.	0.555	0.555	1.111

Least significant differences of means (5% level)

Table	wheat	GA	wheat GA
rep.	12	12	3
d.f.	30	30	30
l.s.d.	1.134	1.134	2.268

Stratum standard errors and coefficients of variation

Variate: SH2

Stratum	d.f.	s.e.	cv%
block	2	0.668	11.5
block.*Units*	30	1.360	23.4

```
 121  SET [IN=*]
 127  "Two-way design in randomized blocks"
 128  DELETE [REDEFINE=yes] _ibalance
 129  A2WAY [PRINT=aovtable,information,means,%cv; TREATMENTS=GA,wheat;
BLOCKS=block; FACTORIAL=2;\
 130   FPROB=yes; PSE=diff,lsd,means,alllsd; LSDLEVEL=5; PLOT=*;
COMBINATIONS=present; EXIT=_ibalance]\
 131   SH3; SAVE=_a2save
```

Analysis of variance

Variate: SH3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	33.14	16.57	0.84	
block.*Units* stratum					
GA	3	22.81	7.60	0.38	0.765
wheat	3	153.69	51.23	2.59	0.072
GA.wheat	9	166.31	18.48	0.93	0.512
Residual	30	594.23	19.81		
Total	47	970.18			

Information summary

All terms orthogonal, none aliased.

Tables of means

Variate: SH3

Grand mean 12.79

GA	1	2	3	4
	12.48	12.83	13.86	11.98

wheat	1	2	3	4
	14.28	14.60	10.18	12.09

GA	wheat	1	2	3	4
1		18.07	14.23	8.07	9.57
2		12.77	13.13	13.03	12.37
3		15.13	14.50	11.37	14.43
4		11.13	16.53	8.23	12.00

Standard errors of means

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
e.s.e.	1.285	1.285	2.570

Standard errors of differences of means

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
s.e.d.	1.817	1.817	3.634

Least significant differences of means (5% level)

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
l.s.d.	3.711	3.711	7.421

Stratum standard errors and coefficients of variation

Variate: SH3

Stratum	d.f.	s.e.	cv%
block	2	1.018	8.0
block.*Units*	30	4.451	34.8

```
 132  SET [IN=*]
```

Reference