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# Environment and Genotype Effect on Quality Baking Traits of Advanced Stem Rust Wheat (*Triticum aestivum* L.) Lines Grown in Kenya

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**Abstract:** Physicochemical and rheological properties of wheat flour defines its end use and are influenced by variety and environmental factors. New varieties need to be evaluated under different environments to determine the environment and variety best suited desired quality characteristics. This study was designed to evaluate the baking quality performance of 17 advanced stem rust wheat lines and 3 varieties under different environments. Completely Randomized Block Design experiments were set up in five zones in Kenya; Njoro, Narok, Naivasha, Eldoret and Timau where the 17 advanced lines and 3 varieties were grown and different baking quality parameters evaluated. The baking quality parameters were analysed following the approved and AACCI methods as described in the materials and methods section. Protein results ranged from 7.90 to 14.67%, gluten12.30 to 32.20%, and zeleny 10.07 to 56.33% respectively. Dough development time ranged from 1.50 to 7.33 minutes, dough stability0.92 to 15.67 minutes, water absorption60.67 to 70.07% and mixing toleranceindex8.33 to 96.67 B.U. Hectolitre weight ranged from 59.19 to 80.14 Kg/Hl, flour extraction 59.19 to 82.50%, starch47.17 to 75.27, ash0.50 to 1.26% and moisture11.67 to 16.10%. Timau a cooler environment in comparison to the other regions recorded lower protein levels compared to Narok a hotter environment which recorded high protein, gluten and zeleny levels regardless of line/genotype evaluated, confirming the influence of environment on baking quality parameters. K. Ibis and R1290 recorded high protein levels except in Timau which points to the stability of genotypic qualities across the environments. Timau proved to be the best site for soft wheat and Njoro for hard wheat due to the high quality characteristics observed in the lines/genotypes.

**Keywords:** Protein Content, Tolerance, Stability, Water Absorption

## 1. Introduction

Wheat is an important food crop and continues to play a crucial role in combating hunger and improving global food security [23]. In Kenya, wheat ranks as the second most important cereal crop after maize and contributes significantly in food security, poverty reduction and employment creation [12]. Demand for wheat and its products in Kenya continue to increase due to population growth and urbanization. To meet the raising demands and ensure grain production especially under challenges of climate change, new cultivars must be developed and evaluated for their high yield and quality. Thus, the main objective of many wheat breeding programmes has been to produce well-adapted and high-yielding varieties with finest end-use quality [8, 9].

In Kenya most wheat research has mainly focused on improving yields and resistance to diseases especially stem rust, while research into the end use characteristics has lagged behind. The most important factors considered when evaluating end-use quality are physiochemical and rheological properties of wheat flour: which have a greater bearing on the end use and quality of wheat products [22]. These properties of flour vary significantly among varieties and have far reaching effects on the end use [24]. The quality of the end product depends upon the quality of wheat grain and wheat suitable for one particular use may have certain properties that are totally unsatisfactory for other uses [2]. These variations, especially in functional properties are attributed largely to their gluten quality and quantity [19]. This study focused on the evaluation of proximate composition and rheological properties of 17 advanced Stem Rust Resistant lines and3Kenyan bread wheat cultivars grown in five study sites regarded as Kenyan wheat belts.

## 2. Materials and Methods

### 2.1. Plant Materials Used in the Cropping Sites (Eldoret, Naivasha, Narok, Njoro and Timau)

17 advanced Stem Rust Resistant wheat lines and 3 varieties namely, Robin, K.Ibis, Njoro BWII and were all obtained from the Kenya Agricultural and Livestock Research Organization, Food Crops Research Centre located at Njoro. The 17 lines were selected based on their superior agronomical traits such as resistant to stem rust fungal infection, high yields, resistance to waterlogging and sprouting among other farmer desired traits. These lines were at an advanced release stage but their quality parameters needed to be evaluation before they could be released. The three wheat varieties were used as the quality control samples due to their superior baking properties especially the protein, gluten and zeleny qualities. The quality profiles for the three varieties used as controls in this study are: Njoro BWII (13-14.5% protein content, 19-22% gluten content and 35-45% zeleny content); Robin (13-14.5% protein content, 19-21% gluten content and 32-38% zeleny content) and K.Ibis (11.5-12.5% protein content, 25-30% gluten content and 40-50% zeleny content). The 17 wheat lines and the 3 control genotypes were grown in zones with differing agro-climatic conditions; Eldoret, Naivasha, Narok, Njoro and Timau as shown (Table 1) and analysed for physiochemical and rheological properties.

***Table 1.*** *Geographical location and edaphic features of Eldoret, Naivasha, Narok, Njoro and Timau experimental sites.*

| Site | Altitude (m) | Longitude | Latitude | Soil pH | Temperature (°C) | Precipitation (mm) |
|---|---|---|---|---|---|---|
| Eldoret | 2073 | 35°17'E | 0°31'N | 5.4-6.0 | 16.8 | 1103 |
| Naivasha | 1884 | 36°26'E | 0°43'S | 6.2-7.4 | 18.5 | 677 |
| Narok | 1898 | 35°51'E | 1°41'S | 5.4-8.2 | 18.1 | 771 |
| Njoro | 1800 | 35°35'E | 0°23'S | 5.8-6.8 | 17.5 | 1080 |
| Timau | 2410 | 37°14'E | 0°50'N | 4.0-6.5 | 15.2 | 1162 |

### 2.2. Experimental Design in Eldoret, Naivasha, Narok, Njoro and Timau

The wheat varieties and lines were planted in a Completely Randomized Block Design. The well prepared and levelled land was divided into three blocks, each consisting of 20 equal plots whose dimensions were 6 m in length and 1 m in width. The soil in each plot was treated with Di-Ammonium Phosphate (DAP) fertilizer at the rate of 50 Kg/ha before planting. After wheat seedlings had germinated the weeds in the experimental plots were controlled by spraying with 'Twigamethalin' herbicide for control of broadleaf weeds and grasses on wheat farms.

### 2.3. Harvesting and Sample Preparation

The wheat crop was grown for four months and harvested when the wheat head had completely filled and dried. The harvested lines/cultivars were then threshed and winnowed to remove physical debris and foreign matter. It was then dried in open air to reduce the moisture to 14.0% which is safe for storage. Moisture was determined using an Infratec grain analyzer following [1] method number 39.00.01.

### 2.4. Hectolitre Weight and Flour Extraction

The bushel weight/ hectoliter weight was determined using [1] method number 55-10.01. Flour extraction was determined using [1] method number 26-10.02. Then one kilogram of the harvested kernels were cleaned and milled using a Buhler miller (Number 220177, Uzwil, Switzerland) to yield white flour. The recovered flour in grams was calculated as a percentage weight of the starting wheat grain before milling.

### 2.5. Evaluation of Rheological Properties and Chemical Composition

The proximate flour composition was determined using the Foss Infratec Grain Analyzer (Model 1241 Denmark) following the outlined procedures in [1] method number 39-00.01. Approximately, 5g of flour was packed in a flour cuvette and placed in the Infratec Grain analyzer measuring cell for analysis of flour protein, gluten levels, moisture, starch, zeleny and ash content. The water absorption of flour was determined based on the procedure adapted from method [1].

### 2.6. Data Analysis

Data collected in triplicates per variety/line was subjected to Analysis of variance (ANOVA) for comparison and differences determination and correlation analysis to associations among the varieties at $p<0.05$ level of significance. Means differences were then separated by Fisher's least significant difference (LSD) test. ANOVA and

LSD were conducted using SAS software Version 9.1.3 (SAS Institute, Inc., 2004). Multivariate analysis was done using R software version 3.4.4. Biplot analysis was carried out using packages ‘factoextra’ and ‘FactoMineR’ packages while ‘gplots’ in R-software was used to generate a heatmap.

# 3. Results and Discussions

### *3.1. Protein, Gluten and Zeleny Content of Lines and Genotypes in the 5 Study Environments*

Protein and gluten composition for wheat flour was significantly ($p<0.05$) influenced by variety, site and interaction between variety × cropping site. Protein levels ranged from 7.90 to 14.67% across the five study sites. In Eldoret, highest levels were recorded in R1286 at 14.67% while the lowest was recorded in Njoro BWII at 11.47%, in Naivasha highest and lowest protein levels were recorded in R1301 and Njoro II at 13.70 and 11.60%. In both Narok and Njoro, highest protein levels were recorded in K.Ibis at 13.97% while lowest levels were recorded in R1306 and R1305 at 10.67 and 11.47%. In Timau, highest and lowest protein levels were recorded in R1308 and Robin at 11.33 and 7.90% respectively. Gluten levels were highest for R1298 and R1308 at 27.37% while lowest levels were recorded in R1287 at 19.20% for cultivars grown in Eldoret. For crop grown in Njoro and Narok, highest gluten levels were recorded in K. Ibis and R1301 at 32.13 and 32.20%. Timau recorded the lowest gluten levels regardless of the line/ cultivar with exceptionally low levels recorded in R1303 and R1304 at 17.47 and 17.20% (Table 2).

Agro climatic characteristics influence protein and gluten content in wheat; wheat grown in agro climatic regions with relatively warm temperatures contain high protein and gluten levels of up to 15% compared to varieties grown in cooler temperatures [21]. This pattern was observed in our study where irrespective of genotype, wheat grown in Narok and Naivasha sites, areas which experience relatively warmer temperatures had higher protein and gluten compared with those grown in Timau site. Timau is much cooler compared to the other 4 sites (Table 1). Gluten which is made up of glutenins and gliadins is a major storage protein found in wheat. Environmental conditions especially warmer temperatures and water stress shortens the grain filling period which increases the concentration of gluten and the ratio of gliadins/ glutenin in the kernel [7].

Zeleny/sedimentation value is related to the swelling of glutenins, which are intimately associated with the bread making quality of flours. Zeleny content ranged from 10.07 to 56.33% across the five study sites. Highest zeleny content were recorded for genotypes grown in Naivasha and Njoro while the lowest levels were recorded in Timau site. R1302 line and Robin recorded lowest levels at 12.43 and 10.07, when grown in Timau, while Njoro II and K.Ibis recorded the highest levels at 51.57 and 56.33%, when grown in Njoro site.

***Table 2.*** *Protein, gluten and zeleny content analysis for wheat varieties grown in Eldoret, Naivasha, Narok, Njoro and Timau cropping sites.*

| Size | Protein | | | | |
|---|---|---|---|---|---|
| Variety | Eldoret | Naivasha | Narok | Njoro | Timau |
| R1285 | 12.83efg | 12.43gh | 12.30bcdefg | 13.33b | 8.87d |
| R1286 | 14.67a | 12.63fg | 12.47bcde | 12.73fg | 9.57c |
| R1287 | 12.47h | 12.90de | 12.97b | 13.07cde | 9.90b |
| R1288 | 13.03de | 11.63k | 12.27bcdefg | 13.03de | 9.57c |
| R1290 | 13.27c | 13.47ab | 12.03defgh | 13.33b | 8.30ij |
| R1291 | 13.03de | 13.37b | 11.90efgh | 13.37b | 10.00b |
| R1294 | 11.50k | 12.93de | 12.23cdefg | 13.17bcd | 8.17jk |
| R1298 | 12.43h | 13.07cd | 12.60bcde | 13.27bc | 8.83de |
| R1301 | 12.37hi | 13.70a | 12.63bcd | 12.67hg | 8.93d |
| R1302 | 11.57k | 13.37b | 11.50h | 11.57j | 8.40hi |
| R1303 | 12.00j | 12.10ij | 11.63gh | 12.60hg | 8.67f |
| R1304 | 12.17ij | 12.70ef | 12.53bcde | 12.50h | 8.50gh |
| R1305 | 13.53b | 13.10cd | 12.30bcdefg | 11.47j | 8.13k |
| R1306 | 12.77fg | 13.27bc | 10.67i | 12.90ef | 9.43c |
| R1308 | 12.73g | 13.07cd | 11.33hi | 13.27bc | 11.33a |
| R1309 | 12.80fg | 11.93j | 12.37bcdef | 12.03i | 8.93d |
| R1312 | 12.97def | 12.33hi | 12.30bcdefg | 13.03de | 9.50c |
| KIBIS | 13.10cd | 13.23bc | 13.97a | 13.97a | 8.63fg |
| ROBIN | 11.60k | 12.30hi | 11.73fgh | 12.47h | 7.90l |
| NJOROII | 11.47k | 11.60k | 12.90bc | 13.33b | 8.70ef |

| Size | Gluten | | | | |
|---|---|---|---|---|---|
| Variety | Eldoret | Naivasha | Narok | Njoro | Timau |
| R1285 | 23.60bcd | 25.47efghi | 26.67efgh | 28.60cdef | 18.53efgh |
| R1286 | 26.23abc | 26.77bcde | 27.80abcdef | 27.93defgh | 22.40bcd |
| R1287 | 19.20e | 12.30a | 29.23abcde | 28.37cdef | 21.77bcde |
| R1288 | 25.17abcd | 25.53efghi | 28.13abcdef | 28.93bcde | 23.00bc |
| R1290 | 24.23abcd | 28.20a | 26.77defgh | 29.67bc | 19.40defgh |
| R1291 | 26.57ab | 24.50i | 27.63bcdefg | 30.23b | 24.70ab |
| R1294 | 21.87de | 25.27fghi | 26.33efgh | 29.60bc | 18.97efgh |

| Size / Variety | Gluten | | | | |
|---|---|---|---|---|---|
| | Eldoret | Naivasha | Narok | Njoro | Timau |
| R1298 | 27.37a | 26.53bcdef | 31.23abcd | 28.30cdefg | 21.17cdef |
| R1301 | 23.07cd | 25.10ghi | 32.20a | 28.17cdefg | 18.23fgh |
| R1302 | 23.20bcd | 26.00defgh | 24.00fgh | 26.57hij | 19.07efgh |
| R1303 | 23.73bcd | 25.33fghi | 31.73ab | 27.57efghi | 17.47gh |
| R1304 | 23.77bcd | 26.40cdefg | 27.33bcdefgh | 27.40fghi | 17.20h |
| R1305 | 27.37a | 27.20abcd | 26.87cdefgh | 25.13j | 18.73efgh |
| R1306 | 23.70bcd | 27.83ab | 23.33gh | 28.77bcdef | 20.97cdef |
| R1308 | 23.97abcd | 27.50abc | 23.03h | 29.33bcd | 26.90a |
| R1309 | 23.87bcd | 25.20fghi | 28.17abcdef | 26.33ij | 20.37cdefgh |
| R1312 | 24.47abcd | 25.53efghi | 26.90cdefgh | 27.80efghi | 22.87bc |
| KIBIS | 22.87cd | 27.47abc | 31.30abc | 32.13a | 19.53defgh |
| ROBIN | 25.43abc | 24.83hi | 31.47ab | 26.80ghi | 18.17fgh |
| NJOROII | 25.83abc | 25.43efghi | 26.83cdefgh | 27.77efghi | 20.67cdefg |

| Size / Variety | Zeleny | | | | |
|---|---|---|---|---|---|
| | Eldoret | Naivasha | Narok | Njoro | Timau |
| R1285 | 35.03ef | 35.70jk | 33.80e | 48.87de | 21.93cde |
| R1286 | 43.03a | 36.67j | 45.00a | 43.33gh | 22.13cd |
| R1287 | 38.07d | 44.57ef | 31.63g | 43.57gh | 22.80c |
| R1288 | 35.17e | 31.63l | 45.17a | 48.27e | 21.40de |
| R1290 | 38.30c | 45.63de | 33.13e | 49.03cde | 14.07j |
| R1291 | 35.10e | 47.37bc | 35.20d | 50.73bcd | 25.10b |
| R1294 | 31.33i | 41.80h | 35.87d | 48.90de | 14.33ij |
| R1298 | 33.97g | 39.37i | 44.97a | 48.57e | 15.40h |
| R1301 | 34.00fg | 50.93a | 33.37e | 45.60f | 16.97g |
| R1302 | 30.17jk | 45.17def | 31.83fg | 38.03i | 12.43k |
| R1303 | 29.87k | 39.13i | 31.87fg | 41.73h | 14.70hij |
| R1304 | 31.07ij | 43.90fg | 39.93c | 39.70i | 14.53hij |
| R1305 | 39.37b | 43.77fg | 27.90h | 35.30j | 13.03k |
| R1306 | 33.90g | 46.40cd | 18.13i | 35.13j | 19.20f |
| R1308 | 33.90g | 42.37gh | 33.03ef | 50.87bc | 31.97a |
| R1309 | 38.70bc | 36.73j | 13.10j | 43.13h | 17.00g |
| R1312 | 33.93g | 39.70i | 42.63b | 50.50bcd | 21.17e |
| KIBIS | 36.77d | 48.13b | 31.03g | 56.33a | 15.37h |
| ROBIN | 30.37ijk | 34.47k | 39.23c | 45.03fg | 10.07l |
| NJOROII | 32.70h | 35.47jk | 44.50a | 51.57b | 15.07hi |

Means followed by the same letter in the same column are not significantly different at P<0.05 Level of significance. Means were separated using Fishers LSD

Wheat flour with a 30% and above are considered as having good quality for making pan breads. All the cultivars/lines grown in Eldoret had good baking quality except for R1303 which had 29.87% zeleny value while for cultivars grown in Naivasha they all surpassed the zeleny threshold for baking as they recorded values greater than 30.00%. In Narok cropping sites, all cultivars/lines recorded excellent zeleny values except for R1305, R1306 and R1309. All cultivars grown in Njoro recorded values greater than 30% which was excellent for baking while in Timau, no cultivar met the 30% zeleny threshold baking quality except for R1308 which recorded values of 31.97% (Table 2). The results obtained from this study show that zeleny levels in wheat flours is highly influenced by environment factors as was observed in studies done [18, 16]. In their studies, high temperatures increased the concentration of Zeleny while in cooler environments, low zeleny levels were reported.

### *3.2. Dough Stability, Dough Development Time and Mixing Tolerance Index*

Dough stability, dough development time and mixing tolerance index (MTI) were significantly (*p<0.05*) influenced by variety, site and interaction of variety × cropping site (ANOVA). In Eldoret dough stability ranged from 1.92 to 10.33 minutes. In Naivasha and Narok, highest levels were recorded in R1305 and K.Ibis at 15.67 minutes while lowest stability levels were recorded in Njoro BWII and R1303 at 2.75 and 2.08 minutes. In Njoro, highest dough stability levels were recorded in Robin at 9.17 minutes while the lowest levels were recorded at R1298 and R1305 at 3.33 minutes. Timau cropping site recorded overall lower stability times except for R1291 and R1308 which recorded dough stability of 10.33 and 10.00 minutes. Dough development time ranged from 1.50 to 7.33 minutes across the five study sites. In Eldoret and Naivasha highest dough development time levels were recorded in R1305 and R1290 at 5.33 and 5.67 minutes while lowest levels were recorded in R1294 at 2.17% and R1288 and R1312 at 2.33 minutes. Flour from K. Ibis, R1298 and R1290 grown in Narok recorded the highest dough development times at 7.33, 6.83 and 6.67 minutes, while flour prepared from K. Ibis and R1304 grown in Timau recorded the lowest levels at 1.50 and 1.75 minutes (Table 3). Long mixing times while an indicator of hard wheat could translate to higher running costs for the manufacturers and long production times which. in the end could lead to less products and low profits. A flour with moderate mixing times is preferred

Dough stability is an indicator for flour strength and reflects the quantity and quality of dough protein [15], hence factors affecting protein levels strongly influences dough stability. The influence of environment and the genotype* environment interaction was observed in the high dough development time and dough stability for the different environments especially in Njoro BWII, R1285 and R1287 (Table 3). Flours with very low dough stability and dough development time values, change from a solid like to liquid like structure quickly indicating weak gluten, thus undesirable for baking pan bread [14].

Flours with mixing tolerance index (MTI) values of ≤30 BU are preferred as they indicate relative strong flours [11]. High level of MTI as obtained in flour from wheat grown in Timau site, indicates weak flours associated with low protein, gluten and zeleny levels in wheat grain. On the other hand, low levels as is the case for flour prepared from wheat crop grown in Narok site, is associated with strong flour [11]. Wheat grown in environments with high temperatures accumulate high levels and high quality proteins that impact strength to the dough thus reducing dough weakening while in cooler environments the quality of the protein might be low which may lead to high MTI values an indicator of relative weak flours.

***Table 3.*** *Stability, dough development time and mixing tolerance index analysis for wheat varieties grown in Eldoret, Naivasha, Narok, Njoro and Timau cropping sites.*

| Site / Variety | Stability | | | | |
|---|---|---|---|---|---|
| | **Eldoret** | **Naivasha** | **Narok** | **Njoro** | **Timau** |
| R1285 | 6.92ef | 6.67e | 8.83ef | 6.00e | 0.92l |
| R1286 | 6.33f | 6.00ef | 11.83c | 4.17gh | 3.33e |
| R1287 | 4.00gh | 11.00b | 7.67gh | 3.92hi | 6.42b |
| R1288 | 6.33f | 8.92c | 10.00d | 3.75hi | 2.00ghijk |
| R1290 | 6.83f | 8.25cd | 9.00e | 5.83e | 3.42e |
| R1291 | 4.25g | 8.83c | 9.83d | 5.17f | 10.33a |
| R1294 | 1.92k | 8.33cd | 6.75i | 3.50i | 2.50fg |
| R1298 | 2.00jk | 4.83g | 13.25b | 3.33i | 2.33fgh |
| R1301 | 4.08g | 5.17fg | 8.25fgh | 4.67fg | 1.50jkl |
| R1302 | 2.58j | 9.17c | 8.58ef | 4.17gh | 2.25fghi |
| R1303 | 2.33jk | 6.42e | 2.08k | 4.75fg | 4.50d |
| R1304 | 3.42hi | 11.58b | 7.67gh | 6.00e | 2.67f |
| R1305 | 8.92c | 15.67a | 7.58h | 3.33i | 1.75hijk |
| R1306 | 7.70de | 7.75d | 7.67gh | 7.00d | 3.76e |
| R1308 | 8.00d | 3.25h | 4.33j | 7.17cd | 10.00a |
| R1309 | 10.33a | 4.92g | 8.33efg | 4.67fg | 1.67ijk |
| R1312 | 7.75d | 7.67d | 8.33efg | 8.50b | 5.75c |
| KIBIS | 9.58b | 3.25h | 15.67a | 8.83ab | 2.42fg |
| ROBIN | 3.33i | 3.33h | 11.50c | 9.17a | 2.08fghij |
| NJOROBWII | 7.75d | 2.75h | 11.33c | 7.67c | 1.42kl |

| Site / Variety | Dough development time | | | | |
|---|---|---|---|---|---|
| | **Eldoret** | **Naivasha** | **Narok** | **Njoro** | **Timau** |
| R1285 | 3.42cde | 3.33efgh | 3.33fg | 2.67efg | 2.17cdef |
| R1286 | 3.83bc | 2.83ghi | 4.33de | 2.00g | 2.08cdef |
| R1287 | 3.00efg | 3.67defg | 3.67ef | 2.17g | 3.92a |
| R1288 | 2.33hi | 2.33i | 5.33c | 2.67efg | 2.33bcde |
| R1290 | 3.17def | 5.67a | 6.67ab | 3.00def | 1.92def |
| R1291 | 3.58cd | 5.17ab | 3.83ef | 4.17b | 2.42bcde |
| R1294 | 2.17i | 4.00def | 3.67ef | 3.00def | 2.50bcd |
| R1298 | 2.33hi | 3.17fghi | 6.83a | 3.00def | 2.00cdef |
| R1301 | 3.50cde | 4.50bcd | 5.08cd | 3.33cde | 3.00b |
| R1302 | 2.50ghi | 4.17cde | 3.67ef | 2.67efg | 1.83def |
| R1303 | 2.67fghi | 3.50efgh | 2.00i | 2.17g | 2.67bc |
| R1304 | 2.25i | 3.67defg | 3.00fgh | 3.67bcd | 1.75ef |
| R1305 | 5.33a | 2.83ghi | 3.50ef | 2.33fg | 2.00cdef |
| R1306 | 2.67fghi | 3.67defg | 2.17hi | 3.83bc | 2.25cde |
| R1308 | 2.83fgh | 5.00abc | 2.50ghi | 4.17b | 3.83a |
| R1309 | 2.50ghi | 2.67hi | 5.08cd | 2.33fg | 2.17cdef |
| R1312 | 4.33b | 2.33i | 4.33de | 3.00def | 2.25cde |
| KIBIS | 3.17def | 2.67hi | 7.33a | 3.33cde | 1.50f |
| ROBIN | 2.33hi | 3.17fghi | 5.83bc | 5.00a | 2.25cde |
| NJOROBWII | 3.67cd | 4.50bcd | 4.25de | 3.67bcd | 2.00cdef |

| Site / Variety | Mixing tolerance index | | | | |
|---|---|---|---|---|---|
| | Eldoret | Naivasha | Narok | Njoro | Timau |
| R1285 | 21.67j | 36.67ghi | 23.33fg | 46.67fg | 66.67d |
| R1286 | 36.67gh | 63.33cd | 36.67e | 76.67bc | 56.67ef |
| R1287 | 53.33f | 23.33jkl | 45.00bcd | 73.33bcd | 48.33fg |
| R1288 | 31.67hi | 43.33fgh | 40.00ed | 70.00cd | 66.67d |
| R1290 | 41.67g | 46.67efg | 36.67e | 76.67bc | 85.00b |
| R1291 | 58.33def | 50.00ef | 26.67f | 73.33bcd | 45.00g |
| R1294 | 75.00ab | 26.67ijk | 41.67cde | 76.67bc | 55.00f |
| R1298 | 83.33a | 56.67de | 26.67f | 83.33b | 85.00b |
| R1301 | 75.00ab | 83.33a | 41.67cde | 96.67a | 65.67de |
| R1302 | 56.67ef | 23.33jkl | 43.33cde | 43.33gh | 65.00de |
| R1303 | 63.33cde | 16.67klm | 51.67b | 63.33de | 45.00g |
| R1304 | 70.00bc | 13.33lm | 26.67f | 56.67ef | 65.00de |
| R1305 | 33.33gh | 8.33m | 48.33bc | 63.33de | 70.00d |
| R1306 | 15.00j | 23.33jkl | 38.33de | 43.33gh | 50.00fg |
| R1308 | 33.33gh | 76.67ab | 76.67a | 56.67ef | 45.00g |
| R1309 | 33.33gh | 63.33cd | 43.33cde | 36.67gh | 96.67a |
| R1312 | 36.67gh | 33.33hij | 41.67cde | 13.33j | 35.00h |
| KIBIS | 36.67gh | 70.00bc | 23.33fg | 23.33ij | 71.67cd |
| ROBIN | 66.67bcd | 56.67de | 16.67g | 66.67j | 80.00bc |
| NJOROBWII | 23.33ij | 43.33fgh | 8.33h | 33.33hi | 55.00f |

Means followed by the same letter in the same column are not significantly different at $P<0.05$ Level of significance. Means were separated using Fishers LSD.

### 3.3. Analysis of Hectolitre Weight, Flour Extraction and Starch Content

Hectolitre weight ranged from 59.19 to 80.14 Kg/hl, flour extraction 59.19 to 82.50% and starch 60.67 to 70.07% across the five study sites (Table 4). Highest hectolitre weight was recorded in R1302 grown in Naivasha while the lowest was recorded in R1286 grown in Eldoret. Eldoret site recorded averagely lower levels compared to the other four sites. The highest flour extraction levels were recorded in R1286 grown in Naivasha at 82.50% while the lowest was recorded in R1286 line grown in Eldoret at 59.19%. Overall Timau site recorded the highest starch content values while Njoro recorded the lowest (Table 4).

Hectolitre weight remains among the most essential and widely used grading system for cereals [5]. High hectolitre weight is preferred by both farmers and traders and is highly influenced by environment, variety, their interaction and management practices [6]. In our study the effect of variety and environment were evident, while G*E interaction was highly manifested especially in Eldoret where low levels were recorded for most of the varieties while the same varieties recorded higher levels when grown in Timau. These observations are in line with a study conducted [13], who concluded that hectolitre weight is determined mainly by genotype, environment and their interaction though the influence of genotype is of less importance. Varieties with high flour extraction are more desirable as this translates to higher incomes for millers. The effects of environment and G*E effect on flour extraction was clearly evident for wheat grown in Timau and Narok sites, which recorded slightly higher and lower levels compared to the other sites. This is in agreement with observation [17] who showed that varieties with high hectolitre weight also record high flour extraction rates but in most cases have low protein content. Wheat growing regions that experience high temperatures especially during grain filling, record low levels of starch content while areas with low temperatures record high starch levels. High temperatures decrease the activities of starch biosynthetic enzymes leading to accumulation of low starch content [25]. This was evident in Timau site which is much cooler at 15.2°C compared to the other sites which recorded the highest starch levels compared to those grown in Naivasha and Narok.

***Table 4.** Hectolitre and flour extraction analysis for wheat varieties grown in Eldoret, Naivasha, Narok, Njoro and Timau cropping sites.*

| Site / Variety | Hectolitre | | | | |
|---|---|---|---|---|---|
| | Eldoret | Naivasha | Narok | Njoro | Timau |
| R1285 | 69.83efg | 72.21o | 77.42ab | 71.00h | 76.72bc |
| R1286 | 59.19j | 77.87de | 74.60fgh | 73.17c | 75.77gh |
| R1287 | 72.30a | 76.61ij | 74.77efg | 73.27c | 75.53hi |
| R1288 | 69.60fg | 74.23n | 73.55i | 72.30fg | 76.63bcd |
| R1290 | 69.30g | 75.49m | 77.77a | 71.35h | 75.48hi |
| R1291 | 69.88defg | 77.89de | 74.33h | 72.05g | 74.00k |
| R1294 | 71.50b | 76.90hi | 77.02b | 71.17h | 75.29i |
| R1298 | 62.64i | 77.09gh | 75.31c | 70.47i | 75.12ij |
| R1301 | 67.50h | 77.87de | 75.38c | 74.33b | 76.00efg |
| R1302 | 67.17h | 80.14a | 74.60fgh | 72.78de | 74.85j |
| R1303 | 67.53h | 77.40fg | 74.81def | 74.48b | 77.33a |
| R1304 | 71.00bc | 78.23cd | 75.20cd | 73.11cd | 76.81ab |

| Variety \ Site | Hectolitre | | | | |
|---|---|---|---|---|---|
| | Eldoret | Naivasha | Narok | Njoro | Timau |
| R1305 | 70.52cd | 77.26fgh | 75.10cde | 69.77j | 76.20ef |
| R1306 | 70.33de | 76.00kl | 75.40c | 72.61ef | 75.11ij |
| R1308 | 69.50fg | 78.41c | 74.37gh | 70.31i | 74.25k |
| R1309 | 71.27b | 77.61ef | 73.30i | 75.42a | 74.07k |
| R1312 | 71.30b | 78.42c | 72.00k | 74.29b | 75.83fgh |
| KIBIS | 69.30g | 75.64lm | 74.33h | 70.39i | 76.21def |
| ROBIN | 70.50cd | 76.30jk | 72.83j | 71.26h | 75.87fgh |
| NJOROII | 70.10def | 79.30b | 75.17cde | 73.41c | 76.33cde |

| Variety \ Site | Flour extraction | | | | |
|---|---|---|---|---|---|
| | Eldoret | Naivasha | Narok | Njoro | Timau |
| R1285 | 78.97cd | 76.67c | 72.20c | 68.47ef | 72.73a |
| R1286 | 78.10cde | 82.50a | 71.30d | 70.50cde | 70.50cde |
| R1287 | 76.90fg | 65.73i | 69.90e | 74.30b | 66.33i |
| R1288 | 75.20h | 75.30d | 72.67c | 70.93cd | 67.63hi |
| R1290 | 75.03h | 70.27g | 71.00d | 69.27def | 70.73bcd |
| R1291 | 76.07gh | 76.67c | 73.53b | 68.33f | 67.50hi |
| R1294 | 77.87def | 72.53f | 69.07f | 69.17def | 67.97gh |
| R1298 | 75.77gh | 72.00f | 69.20f | 73.53b | 69.17efg |
| R1301 | 75.53h | 70.00g | 67.10gh | 70.13cdef | 63.87j |
| R1302 | 79.20bc | 79.00b | 67.20gh | 70.73cd | 67.60hi |
| R1303 | 76.77fg | 77.20c | 70.00e | 71.43c | 72.20ab |
| R1304 | 75.30h | 75.30d | 67.60g | 69.83cdef | 67.67hi |
| R1305 | 80.30ab | 73.67e | 63.07j | 66.00g | 68.67fgh |
| R1306 | 79.07c | 70.30g | 61.10l | 69.27def | 71.77abc |
| R1308 | 78.43cde | 68.53h | 74.17a | 70.03cdef | 70.20de |
| R1309 | 77.30ef | 75.33d | 63.00j | 69.27def | 66.37i |
| R1312 | 79.07c | 69.23gh | 66.77h | 71.20cd | 69.97def |
| KIBIS | 77.80def | 73.07ef | 63.23j | 71.17cd | 64.83j |
| ROBIN | 80.50a | 73.10ef | 65.40i | 79.13a | 71.10bcd |
| NJOROII | 70.30i | 72.20f | 62.20k | 69.40cdef | 70.40cde |

| Variety \ Site | Starch | | | | |
|---|---|---|---|---|---|
| | Eldoret | Naivasha | Narok | Njoro | Timau |
| R1285 | 65.27f | 64.73jk | 66.27e | 63.27jk | 67.97ef |
| R1286 | 62.73g | 64.87ijk | 63.43j | 64.40ef | 66.83h |
| R1287 | 66.47cd | 65.47def | 65.43gh | 66.13a | 67.33g |
| R1288 | 65.73e | 66.63b | 64.57i | 64.27fg | 67.17gh |
| R1290 | 65.06f | 64.20l | 65.80f | 63.73hij | 69.80a |
| R1291 | 65.67e | 65.53de | 65.73f | 63.37ijk | 66.03i |
| R1294 | 68.23a | 65.20fgh | 66.23e | 63.80ghi | 69.70ab |
| R1298 | 65.03f | 65.47def | 65.43gh | 64.83de | 68.93cd |
| R1301 | 66.50cd | 64.93hij | 66.13e | 64.47ef | 67.60fg |
| R1302 | 68.37a | 65.67d | 67.13c | 65.83ab | 70.00a |
| R1303 | 66.63cd | 66.37bc | 68.03b | 65.67ab | 68.63d |
| R1304 | 66.50cd | 65.27efg | 65.27h | 64.90cde | 67.93ef |
| R1305 | 65.67e | 64.83jk | 67.07c | 65.47b | 69.63ab |
| R1306 | 66.30d | 64.63k | 70.07a | 65.40bc | 67.60fg |
| R1308 | 66.70c | 65.13ghi | 66.73d | 64.10fgh | 66.33i |
| R1309 | 66.70c | 67.53a | 67.17c | 65.80ab | 68.77d |
| R1312 | 65.23f | 66.53bc | 65.53fgh | 63.03k | 67.30g |
| KIBIS | 65.40ef | 65.17gh | 69.93a | 60.67m | 69.30bc |
| ROBIN | 67.77b | 67.53a | 65.57fg | 65.33bcd | 69.30bc |
| NJOROII | 65.27f | 66.27c | 66.30e | 61.90l | 68.07e |

Means followed by the same letter in the same column are not significantly different at P<0.05 Level of significance. Means were separated using Fishers LSD.

### *3.4. Flour Water Absorption, Ash and Moisture Content*

The flour water absorption, ash and moisture content were significantly ($p<0.05$) influenced by variety, site and interaction of variety × cropping site. Flour water absorption levels ranged from 47.17 to 75.27%, ash 0.50 to 1.26% and moisture content 11.67 to 16.10%. The lowest water absorption level was recorded in R1298 at 47.17% while the highest levels were recorded in R1290 and R1286 at 73.47 and 75.27% all grown in Eldoret site. Highest ash content was recorded for wheat grown in Eldoret while the lowest were recorded for those grown in Timau site. R1286 recorded the highest values at 1.26% for crop grown in Eldoret while R1290, R1294 and K.Ibis recorded the lowest levels at 0.50%

for crop grown in Timau (Table 5). Highest moisture level was recorded in R1285 for crop grown in Naivasha while the lowest levels was recorded in R1291 for crop grown in Njoro (Table 5).

Wheat flour containing high protein levels absorb high levels of water to ensure the flour is hydrated to the required consistency [10]. Except for Timau cropping site, all our results were in agreement with those of [4, 11] which showed that water absorption increases with increase in protein content. Ash determination is of great value to the miller because it is a relatively accurate index of the separation of endosperm from pericarp and germ in any particular flour [20]. High rainfall after wheat physiological maturity negatively influences wheat quality due to increased severity of disease and enzyme activity [3]. From the moisture results obtained for all the varieties and lines across the five cropping sites, it is evident that their quality had not been affected by moisture since it was within the desired ranged when harvesting.

***Table 5.*** *Flour water absorption, ash and moisture content for wheat varieties grown in Eldoret, Naivasha, Narok, Njoro and Timau cropping sites.*

| Site / Variety | Flour water absorption | | | | |
|---|---|---|---|---|---|
| | **Eldoret** | **Naivasha** | **Narok** | **Njoro** | **Timau** |
| R1285 | 68.20e | 56.83l | 63.50def | 65.17c | 66.30fgh |
| R1286 | 75.27a | 64.83hi | 63.77cde | 67.97a | 69.53c |
| R1287 | 69.80cde | 66.93ef | 62.63efg | 64.87cd | 67.30de |
| R1288 | 71.97bc | 62.43k | 60.73ij | 67.40ab | 65.97gh |
| R1290 | 73.47ab | 66.47efg | 64.50bcd | 67.63ab | 57.60m |
| R1291 | 71.17bcd | 65.53gh | 60.73ij | 66.57b | 64.53j |
| R1294 | 61.67gh | 72.33b | 59.83jkl | 65.30c | 59.07l |
| R1298 | 47.17j | 69.70c | 63.87cde | 61.33h | 64.40j |
| R1301 | 65.17f | 73.63a | 66.57a | 63.97de | 70.47b |
| R1302 | 63.77fg | 73.33ab | 62.37efgh | 61.33h | 66.93ef |
| R1303 | 61.23gh | 64.07ij | 57.67m | 62.77fg | 73.03a |
| R1304 | 63.60fg | 66.63efg | 61.30ghij | 63.23efg | 65.00ij |
| R1305 | 62.10gh | 67.57de | 65.53ab | 63.33ef | 66.37fgh |
| R1306 | 62.67fg | 68.37d | 60.13jk | 64.00de | 65.93gh |
| R1308 | 63.73fg | 67.13ef | 65.17abc | 66.57b | 67.00ef |
| R1309 | 63.67fg | 66.00fgh | 58.43lm | 66.60b | 66.57efg |
| R1312 | 68.47de | 66.13fg | 60.87hij | 63.17efg | 67.93d |
| KIBIS | 60.23h | 64.17ij | 62.37efgh | 62.20gh | 63.20k |
| ROBIN | 55.83i | 66.07fg | 59.07klm | 63.33ef | 65.60hi |
| NJOROII | 64.93f | 63.27jk | 62.00fghi | 67.03ab | 62.83k |

| Site / Variety | Ash | | | | |
|---|---|---|---|---|---|
| | **Eldoret** | **Naivasha** | **Narok** | **Njoro** | **Timau** |
| R1285 | 1.17abcd | 1.07a | 0.67cde | 0.83a | 0.60bc |
| R1286 | 1.26a | 0.97bc | 0.70bcd | 0.77abc | 0.63b |
| R1287 | 1.13abcde | 0.80f | 0.63de | 0.80ab | 0.63b |
| R1288 | 1.10bcde | 0.87def | 0.67cde | 0.73bc | 0.60bc |
| R1290 | 1.13abcde | 0.90cde | 0.70bcd | 0.73bc | 0.50d |
| R1291 | 1.03def | 0.97bc | 0.77ab | 0.70cd | 0.60bc |
| R1294 | 0.93fg | 1.00ab | 0.67cde | 0.77abc | 0.50d |
| R1298 | 1.23ab | 0.93bcd | 0.67cde | 0.80ab | 0.60bc |
| R1301 | 1.13abcde | 1.07a | 0.67cde | 0.73bc | 0.70a |
| R1302 | 1.00efd | 0.87def | 0.67cde | 0.63d | 0.60bc |
| R1303 | 1.10bcde | 0.80f | 0.67cde | 0.70cd | 0.70a |
| R1304 | 1.07cdef | 0.80f | 0.70bcd | 0.70cd | 0.60bc |
| R1305 | 1.03def | 0.83ef | 0.70bcd | 0.70cd | 0.60bc |
| R1306 | 1.13abcde | 0.90cde | 0.73abc | 0.70cd | 0.60bc |
| R1308 | 1.13abcde | 0.90cde | 0.80a | 0.70cd | 0.60bc |
| R1309 | 1.03def | 0.80f | 0.60e | 0.70cd | 0.60bc |
| R1312 | 1.07cdef | 0.80f | 0.60e | 0.70cd | 0.60bc |
| KIBIS | 1.20abc | 0.83ef | 0.60e | 0.77abc | 0.50d |
| ROBIN | 0.87g | 0.90cde | 0.60e | 0.77abc | 0.60bc |
| NJOROII | 0.67h | 0.60g | 0.73abc | 0.73bc | 0.57c |

| Site / Variety | Moisture | | | | |
|---|---|---|---|---|---|
| | **Eldoret** | **Naivasha** | **Narok** | **Njoro** | **Timau** |
| R1285 | 13.17cdef | 16.10a | 13.03abc | 11.83ef | 13.37b |
| R1286 | 13.20cdef | 13.17c | 12.93bcd | 11.80ef | 13.17cd |
| R1287 | 13.23bcde | 12.77ef | 13.07ab | 12.23bc | 13.23bc |
| R1288 | 13.17cdef | 12.13l | 12.70e | 12.07cd | 13.17cd |
| R1290 | 13.13def | 12.20kl | 12.83de | 12.17bc | 13.13cd |

| Site / Variety | Moisture | | | | |
|---|---|---|---|---|---|
| | **Eldoret** | **Naivasha** | **Narok** | **Njoro** | **Timau** |
| R1291 | 13.10ef | 12.20kl | 12.97bcd | 11.67f | 13.23bc |
| R1294 | 13.27bcde | 12.87ed | 13.13a | 12.07cd | 13.17cd |
| R1298 | 13.10ef | 12.50ghij | 13.13a | 12.13cd | 12.90e |
| R1301 | 13.03fg | 12.67fg | 12.27f | 12.23bc | 13.0\d |
| R1302 | 12.90g | 11.93m | 12.90cd | 12.17bc | 12.77e |
| R1303 | 13.03fg | 12.53ghi | 13.13a | 12.47a | 13.33b |
| R1304 | 13.30bcd | 12.43ij | 12.87d | 12.07cd | 13.33b |
| R1305 | 13.20cdef | 12.33jk | 13.07ab | 12.17bc | 13.27bc |
| R1306 | 13.20cdef | 12.73ef | 13.03abc | 11.93de | 13.27bc |
| R1308 | 13.33bc | 12.50ghij | 13.17a | 12.17bc | 13.37b |
| R1309 | 13.53a | 12.63fgh | 13.13a | 11.93de | 13.57a |
| R1312 | 13.40ab | 12.97d | 12.87d | 12.23bc | 13.37b |
| KIBIS | 13.33bc | 12.43ij | 13.13a | 12.37ab | 13.17cd |
| ROBIN | 13.17cdef | 13.73b | 12.93bcd | 12.17bc | 13.13cd |
| NJOROII | 13.23bcde | 12.47hij | 13.07ab | 12.37ab | 13.17cd |

Means followed by the same letter in the same column are not significantly different at P<0.05 Level of significance. Means were separated using Fishers LSD

### *3.5. Biplot and Cluster Analysis for Proximate and Rheological Parameters*

Cluster analysis for proximate and rheological parameters was done to analyse variance in the multiple variables among varieties and across the cropping sites. The first component was the cause of the most available variance while the second component justifies less variance. Multivariate comparison was done by comparing the Eigen values of PC1 and PC2 of principal component analysis (PCA) for both the genotypes and the quality traits across the five sites. The PC1 and PC2 accounted for 56.6% of the total variability (PC1=36.8% and PC2=19.8%). In the biplot, vectors of dough stability, dough development time, water absorption, zeleny, protein and gluten content were positively correlated (Figure 1A).

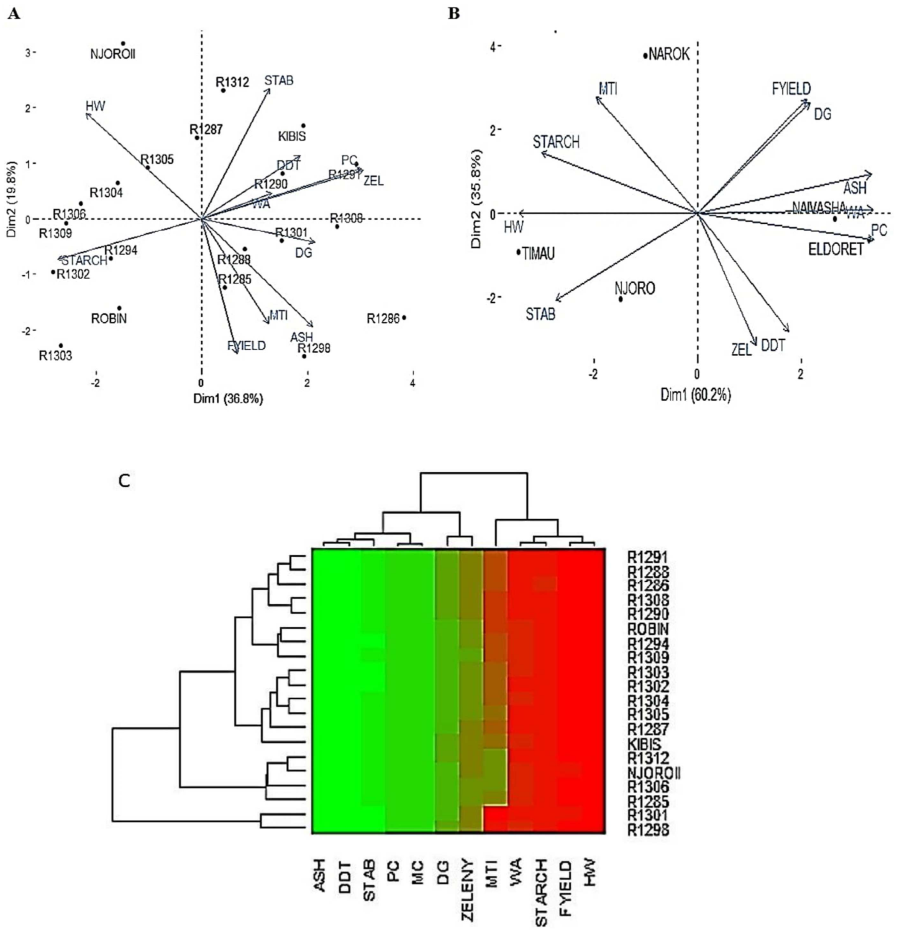


***Figure 1.*** *A-PCA biplot analysis for genotypes and quality traits: B-PCA biplot analysis for site and quality traits and C-Heatmap and bi-dimensional clustering of quality traits and genotypes.*

This was in agreement with a study [18] which demonstrated that traits showing acute angles were positively correlated, whereas those which formed obtuse or straight angles are negatively correlated, and those with right angle have no correlation. In the upper right square comprising R1312, K.Ibis, R1290 and R1291 recorded the highest values for dough stability, dough development, water absorption, protein and zeleny content. R1312 and R1291 outscored the other two for the traits in that group. R1285, R1286, R1288, R1298, R1301and R1308 scored highest values for gluten, ash, mixing tolerance index and flour yield with R1286 recorded the highest values for the traits followed by R1298 and R1308. In the upper left square, Njoro BWII, R1287, R1304, R1305 and R1306 recorded overall highest levels for hectolitre weight with Njoro BWII outscoring all the others. In the lower left square, varieties/lines Robin, R1294, R1302, R1303 and R1309 highest values for starch with R1303 scoring the highest followed by Robin (Figure 1A).

Site and traits interaction showed high variation accounting for 96% (PC1=60.2% and PC2=35.8%) (Biplot). The high dough stability observed in Timau and Njoro cropping site could be attributed to almost similar weather conditions experienced in both the cropping sites. Narok cropping site recorded the highest levels for mixing tolerance index and starch while hectolitre weight recorded almost same levels as when the varieties were grown in Njoro cropping site. Eldoret and Naivasha cropping sites recorded the highest values for protein, gluten, zeleny, dough development time, water absorption, flour yield and ash content. Eldoret emerged as the best site followed by Naivasha, Narok, Njoro and finally Timau (Figure 1B).

Cultivars/ wheat line classification based on variety, quality traits a heat map was generated in combination with bi-dimensional hierarchical clustering using PCA Eigen values (Figure 1C). Horizontal clustering grouped the varieties into two sub clusters and four distinct clades indicating close similarity among the analysed varieties. The first sub cluster comprised of two lines R1298 and R1301 while the second sub cluster comprised of all the remaining lines. A closer look on the physiochemical and rheological properties revealed the two lines had almost similar properties which could be an indicator that they did not segregate during cross breeding. The second sub-cluster had two clades in which all the other lines and varieties clustered. The first clade was composed of R1285, R1306, R1312 and Njoro BWII cultivars/lines which recorded high levels of protein, gluten and zeleny values across the five study sites. The second clade also consisted of two released varieties K.Ibis and Robin which have been classified as hard red grains an indicator that the second cluster was composed of hard wheat varieties/ cultivars with superior bread baking properties.

The 20 study cultivars grouped into 2 clusters and 3 sub clusters indicating a closer but distinct relationship for the variables analysed. All the varieties/cultivars showed high stability for water absorption, flour yield, starch and hectolitre weight characterised by the solid red colour which clearly brings out the effect of genotypes on these parameters. Ash, dough development time, dough stability, moisture and protein content were also stable for all the varieties/ lines characterised by the solid green colour (Figure 1C).

## 4. Conclusions

Environments conditions play a major role in determining the quality of wheat and this influences the end use of wheat. As clearly observed from our data, when wheat lines and varieties were grown in regions/environments characterised by much lower temperatures and high rainfall throughout the year such as Timau, they recorded lower protein levels and enhanced starch levels compared to the same varieties when grown in areas with much warmer temperatures and slightly lower rainfall such as Narok. This trend was also observed for gluten content and zeleny content as shown by our data. Previous studies have shown that G*E interaction impacts heavily on the quality of wheat varieties, this was also clearly observed from results for protein, gluten and zeleny content across the five study sites. These results offer an insight of not only the varieties/lines with highest qualities but also the regions in which respective end use qualities can be maximized. Wheat grown in Timau would be best suited for making soft wheat products due to the low protein and gluten quantities while wheat grown in Njoro would be best suited for hard wheat products due to the high protein and gluten qualities

## 5. Recommendations

Baking quality screening of new lines/cultivars in wheat breeding programmes in different agroclimatic regions should be an important aspect integrated in the selection of individual lines/cultivars best suited for certain regions.

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