ISSN No:-2456-2165

Adaptation of Onion Varieties and Their Agronomic Performance Under Tropical Zimbabwe Conditions

Jean K. Nzuma, Leonard Madzungaidzo, Prettimore Mafirakureva, Graciana C. Gandawa, Antony Maodzeka
Biotechnology Research InstituteScientific and Industrial Research and Development Centre (SIRDC).
1574 Alpes Road, Harare, Zimbabwe

Abstract:-

- **Aim**

The study was conducted to evaluate the yield performance of eleven (11) varieties of onion against the commonly grown variety Texas Grano.

- **Materials and Methods**

The eleven different cultivars were grown at three different agroecological regions and the experimental design was a complete randomized block design.

- **Results**

The results indicated that Crenola Digon was the best performing onion variety as it produced the highest yield of 17.35t/ha followed by Texas Grano (16.49 t/ha), then and Regent F1 and Star 5525 (15.53t/ha and 15.52t/ha respectively). Further, Crenola Digon had limited physiological disorders including less rotting upon storage which was comparable to Star 5525. Participatory Variety Selection studies on the farm were aligned with these findings.

- **Conclusion**

The study subsequently identified Crenola Digon, Regent F1, and Star 5525 as the most promising varieties adaptable to local farming systems. The project is now set to develop agronomic packages for enhancing the genetic potential of the adaptation varieties for productivity and profitability.

Keywords:- *Onion; Allium cepa; mulch, yield, sustainability, Africa, Integrated Crop Management.*

I. INTRODUCTION

Onion (*Allium cepa* L.) is one of the high-value crops commonly grown by small-scale farmers in Zimbabwe for nutrition security and income generation [1]. However, productivity remains lower (10 tha^{-1}) than the world average (19.9 tha^{-1}). In other regions such as the EU, productivity is around 35.3 t/ha indicating the potential yield of onion[2].Poor onion yields is attributed to the use of poor yielding varieties, declining soil fertility poor agronomic practices including water management. There is immense potential for farmers to improve bulb production and crop yields with appropriate crop management practices for both domestic and export markets.

Identification of Integrated Crop Management packages will enhance productivity with will also promote the sustainability of the farming business. The key areas of ICM research include standardizing cultivation practices from nursery to field production, developing efficient fertilizer recommendation packages, investigating the effects of mulching (plastic mulch, and grass straw, improving water management, pest, and diseases management, and other management practices. This will also greatly improve economic, social, and environmental sustainability [3].

In Zimbabwe, some of the economically important diseases that hinder onion production include white rot caused by *Sclerotium cepivorum* and also damping-off caused by *Rhizoctoniasolani*[1]. Management of diseases and pests and also post-harvest management practices play important roles in ensuring that farmers minimize losses of their yields[4].

This study seeks to introduce, identify and promote varieties with a higher yield performance under smallholder agro-ecologies. This will be complemented by the development and promotion of (ICM) packages to enhance the genetic potential of the varieties in terms of yield for profitability.

II. MATERIALS AND METHODS

A. *Research sites*

The study was carried out at SIRDC- Harare (Natural region (NR) II) on-station and on-farm at Chigondo irrigation scheme, Wedza district (NR III) and Fuve Panganai, Masvingo district, (NR IV) irrigation schemes for the farmer participatory variety selection process. Most of the rainfall is received from mid-November up to the end of February. The average annual summer and winter temperatures at the farm are 28 ℃ and 5.5 ℃, respectively. The sites are under clay loams, sandy loams, and loamy sandy soils commonly cultivated by smallholder farmers.

B. *Plant materials and experimental design*

A randomized complete block design with 3 replicates was used. Seeds of 15 varieties of bulb onion namely; ZGS Creole, ZGS Caprico, Texas Grano (traditional variety), Regent F1 hybrid, Star 5525 hybrid, KKS 1402, Radium, Kalunga plus hybrid, Neptune 1, Crenola Digon, Red Marvel, Hazera, Elad F1, Australian brown and Savannah sweet F1 were sown under float systems. (The last four varieties' failed to germinate, therefore only 11 out of 15 sown varieties were transplanted for adaptability and agronomic performance).

C. *Nursery establishment and transplanting*

The seeds were grown on float trays on–station and under seedbed on-farm. Six weeks old seedlings were transplanted in plot sizes of 10 m × 0.6 m ($6m^2$) per variety and replicated 3 times. Each plot comprised three 10m rows. Inter and intra row spacing was 20 x 10 cm respectively.

One-meter wide pathways were constructed within the treatment plots and two-meter pathways were constructed between the blocks (replications). Compound S (7%N: 21%P_2O_5: 7% K_2O: 9%S: 0.04%B) was applied as a basal fertilizer at 45g/m^2. Watering was done using drip irrigation. Lambda cyhalothrin at 200mL/ha was applied before planting to control cutworms.

D. Crop management

At 4 weeks after transplanting, ammonium nitrate (34.5%N) fertilizer was applied as a topdressing at a rate of 35g/m2. The crop was irrigated twice per week using drip irrigation so that soil moisture did not fall below 50% field capacity. Weeds were controlled by hand hoeing. Malathion 50EC was applied at 180mL/100 L of water as a full cover spray (F.C.S) and repeated as necessary at 7-10-day intervals to control thrips. This was alternated with Cartap hydrochloride applied at 400 g/100 L of water F.C.S every 2 weeks as necessary.

E. Harvesting, handling, and storage

All the varieties were harvested once as per their maturity stage (80% tops down). Onion bulbs were pulled out of the ground, left to dry in shade for a week, and then the leaves were removed to get the dry bulbs of onion.

F. Assessment of vegetative and reproductive parameters

Plant height was taken on 20 tagged plants starting at 8 weeks after transplanting. The measurement was taken from the base of the plant to the tip of the highest leaf using a ruler. The number of active leaves was also counted. This was done only on 20 tagged plants during data collection when the bulbs were fully formed. The mean number of leaves per plant for each plot was determined. The time from planting to harvesting was recorded based on days to 50% maturity.

Twenty plants per plot which were tagged and used for the determination of vegetative growth parameters were also used for the data collection on reproductive parameters. For measurement of bulb weight, 20 bulbs were weighed together, with an electronic weighing scale to obtain the fresh weight and the mean was calculated. This was expressed in g/m2 and converted to t/ha to estimate the appropriate yield of onion. A Caliper was used to determine the bulb height for the 20 recorded plants. The measurement was taken starting from the top point to the base of the bulb and the mean bulb length was calculated (Grant & Carter, 1997; Hasegawa et al., 2001).

G. Bulb Quality Parameters

For assessment of bulb shelf life, twenty randomly selected onion bulbs with similar weights were selected from each of the 11 varieties and were tested for the changes in the quality of onion bulbs for three months at an interval of 7 days/ a week. They were evaluated for physiological loss in weight. Other physiological changes that were assessed included sprouting, the appearance of black mold, and rotting. The physiological loss in weight percentage was also calculated.

Bulb yield was estimated based on the weight of 20 bulbs harvested per plot based on the method of Baba-Moussa et al., (2015). The value obtained was then converted into yield per hectare.

H. Statistical Analysis

Inferential and descriptive statistical methods were used for data analysis using the analysis of variance (ANOVA) for randomized complete block design (RCBD) with the help of the SPSS 19th Edition Software. Means which differed significantly were compared using the Fisher's Protected Least Significance Difference (LSD) at a probability level of 5% of significance (p = 0.05). (Steel and Torrie, 1980).

III. RESULTS AND DISCUSSION

A. Cultivar dependant variation in onion physiological characteristics

A two-way analysis of variance was conducted to examine whether the11 onion varieties differ significantly for their vegetative, reproductive, bulb quality, and yield components. The 11 onion varieties differed significantly in the different physiological parameters (p< .001) (Table 1 and Figure 1). This postulates that the 11 varieties which include ZGS Creole, ZGS Caprico, Texas Grano (local variety), Regent F1 hybrid, Star 5525 hybrid, KKS 1402, Radium, Kalunga plus hybrid, Neptune 1, Crenola Digon, Red Marvel, contribute differently to the total yield, marketable yield and percentage marketable yield of onion as seen with the differences in bulb weight and circumference (Figure 2).

The mean bulb weight was found to be 255.06 g. The diameter of the bulb was measured on the widest part of the bulb, to obtain the bulb circumference and the mean was found to be 25.53 cm. The mean plant height was found to be 36.62 cm whereas the mean number of leaves was found to be 7 leaves per plant (Table 1).

B. Vegetative characteristics of different onion parameters

The performance of the 11 studied varieties was estimated by the determination of selected vegetative growth indices namely: the number of leaves per plant, plant height, and stem diameter. Results obtained showed that onion varieties were significantly different from these plant and bulb morphological characteristics (p < 0.01); (Table 3).

The mean values for varieties (Table 1) showed that onion varieties were significantly different concerningthe number of leaves per plant at 4 weeks after transplanting. Data analysed showed that KKS 1402, Star 5525, and Texas Grano had the widest interquartile range (7 cm each), whilst Crenola had the lowest (3 cm). From the ANOVA analysis, varieties significantly determine the number of leaves which also influences the number of rings as shown below (Table 2 and 3). Previous work shows that onion varieties differ in different physiological parameters such as leaf number and also the number of rings [5].

ISSN No:-2456-2165

	N	Minimum	Maximum	Mean	STD
Number of leaves	930	4	14	7.35	1.363
Plant height	930	11.1	60.5	36.621	7.9637
Bulb circumference	930	11.0	37.0	25.529	4.2575
Bulb weight	930	30	710	255.06	105.804
Valid N (list-wise)	930				

Table 1. Significances of mean square values for 4 agronomic traits for onion varietie

Variety	Colour	Shape	No. of rings
Crenola Digon	White	Round	7
Radium	Medium straw with a creamy white interior	Deep flat round with moderate firmness and a medium-sized basal plate	10
KKS 1402	White	Round	6
Neptune F1	Firm and shiny deep red bulb.	Flattened globe	9
Star 5525	White	Round	8
ZGS Caprico	Brown with white interior	Globe	6
Kalunga Plus	White	Round	8
Red creole	Bright red to bronzy with white and red inner scales	Thick flat to flat round with moderate firmness and a medium-sized basal plate	9
Red marvel	Red	Round	6
Regent	Yellow with white interior	Slightly flattened globe	10
Texas Grano	Medium straw exterior with a white interior	Top shaped with moderate firmness and a medium sized basal plate	7

Table 2. Number of rings, colour and shape per variety

ISSN No:-2456-2165

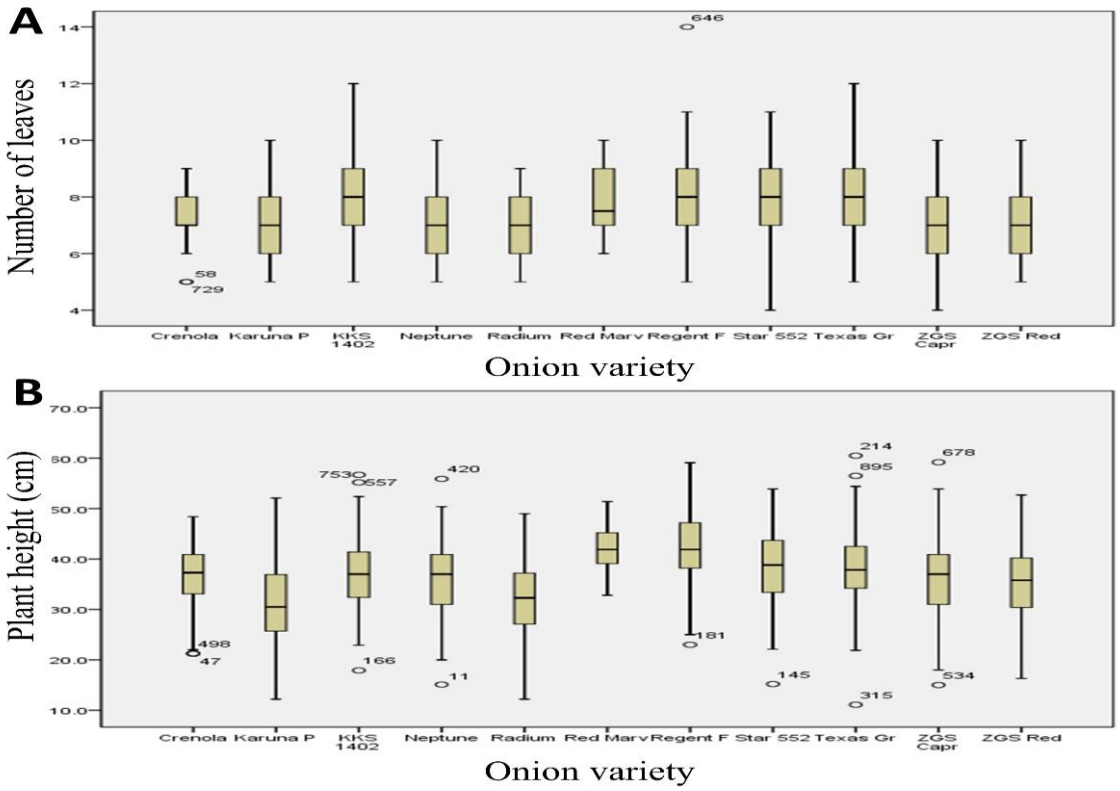

Fig 1. Box plots illustrating Cultivar dependent variations in number of leaves (A) and plant height (B).

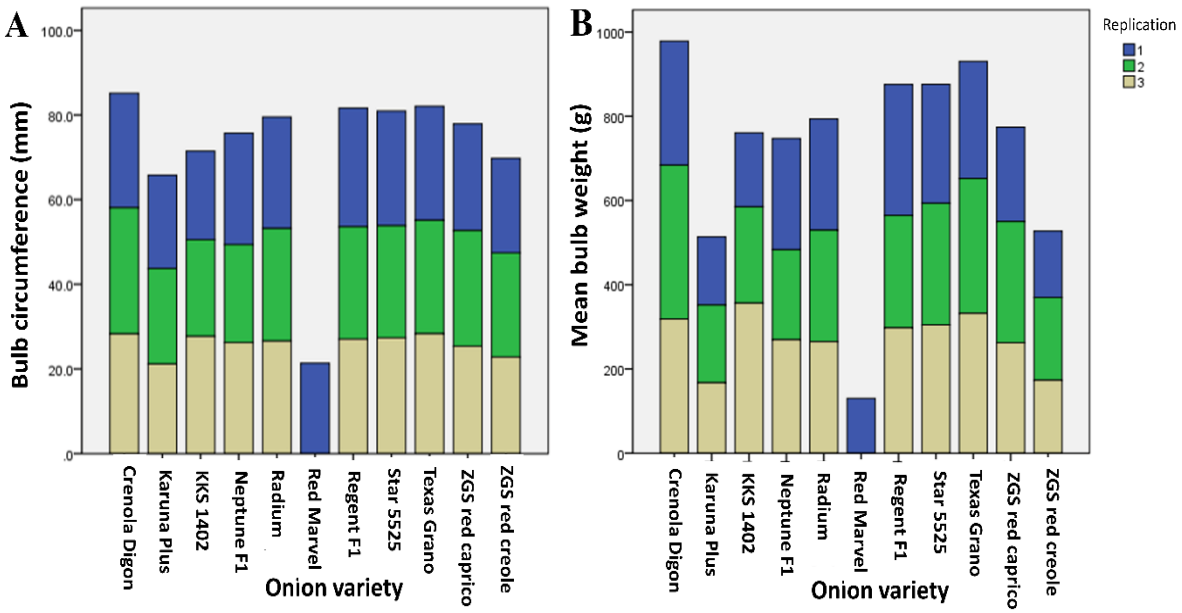

Fig 2. Comparison of bulb physiological parameters across onion varieties.
Effect of replication on bulb circumference (A) and weight (B).

ISSN No:-2456-2165

Fig 3. Photographic illustrations of the dry onion bulbs of the 11 different varieties.

		Sum of Squares	df	Mean Square	F	Sig.
Plant height	Between Groups	4332.150	2	2166.075	36.785	.000
	Within Groups	54585.623	927	58.884		
	Total	58917.773	929			
Number of leaves	Between Groups	113.503	2	56.752	32.637	.000
	Within Groups	1611.922	927	1.739		
	Total	1725.425	929			
Bulb circumference	Between Groups	238.576	2	119.288	6.661	.001
	Within Groups	16600.677	927	17.908		
	Total	16839.253	929			
Bulb weight	Between Groups	317181.778	2	158590.889	14.581	.000
	Within Groups	10082559.315	927	10876.547		
	Total	10399741.092	929			

Table 3. ANOVA of various physiological parameters of different onion cultivars.

ISSN No:-2456-2165

C. Variation in onion yields and yield components

The results indicated that Crenola Digon was the best performing onion variety as it produced the highest yield of 17.35t/ha followed by Texas Grano (16.49 t/ha) then and Regent F1 and Star 5525 (15.53 t/ha and 15.52 t/ha respectively). These findings suggest that bulb yield is significantly dependent on onion cultivars ($p< 0.01$) and have an impact on bulb quality which affects the marketable yield (healthy yield) of onions.Soleymani and Shahrajabian (2012), showed that the total yield of different onion varieties was significantly influenced by cultivars while good management and agronomic practices were contributory effects (Pal Baliyan 2014).

D. Assessment of the different bulb quality parameters

Bulb colour is important in onions as previous studies show that red coloured onions are mostly used for cooking whereas white onions are mostly preferred in salads [8]. The present study indicated that the colour of the onion bulb may be cultivar-related (Table 2). The genetic basis of onion bulb colour is very complex and influenced by a plethora of genes with some that are involved in flavonoid synthesis [8]. Another study also showed that onion bulb colour is controlled by at least three loci [9].

The bulb shape also differed significantly between the different onion varieties (Table 2 and Figure 3). Different onion varieties have characteristic bulb types or shapes ranging from flat, torpedo, and globe, and bulb shape is also a heritable characteristic [10,11]. The bulb shape is influenced by plant population, as well as sowing date[10].

E. Correlations between different morphological parameters

The results showed that bulb yield had a positive association with plant morphological characteristics i.e. number of leaves, plant height, and stem diameter (Table 5). Whereas it had a negative and non-significant correlation with bulb firmness. Bulb yield again had significant and strong significant positive association respectively with reproductive components and particularly bulb length and bulb average weight, bulb weight, and bulb diameter (Figure2). Trivedi and Dhumal (2010) also reported a similar association. Bulb yield had a positive and highly significant association with plant height, number of leaves, root numbers, and root length per plant (Fig 1 and 2). The growth parameters differed significantly ($p< 0.001$) across the different varieties (Table 8) agreeing with the results from other studies[12,13].

ISSN No:-2456-2165

Onion variety		Number of leaves	Plant height	Bulb circumference	Bulb weight
Crenola Digon	Mean	7.17	36.980	28.382	326.09
	N	90	90	90	90
	Std. Deviation	.939	6.1398	2.8003	85.721
Kalunga Plus	Mean	7.00	31.871	21.922	171.22
	N	90	90	90	90
	Std. Deviation	1.236	8.6701	2.9980	56.361
KKS 1402	Mean	8.06	37.424	23.828	253.56
	N	90	90	90	90
	Std. Deviation	1.718	7.4631	4.6953	115.385
Neptune F1	Mean	6.97	36.060	25.239	249.06
	N	90	90	90	90
	Std. Deviation	1.136	7.2500	4.3854	98.585
Radium	Mean	6.87	32.123	26.517	264.50
	N	90	90	90	90
	Std. Deviation	.950	7.4076	4.4831	105.358
Red Marvel	Mean	7.67	42.067	21.367	130.10
	N	30	30	30	30
	Std. Deviation	1.093	4.8255	2.9418	47.292
Regent F1	Mean	7.99	41.953	27.222	291.89
	N	90	90	90	90
	Std. Deviation	1.386	7.5255	3.7093	98.991
Star 5525	Mean	7.97	38.418	26.983	291.94
	N	90	90	90	90
	Std. Deviation	1.394	6.8051	2.6547	66.863
Texas Grano	Mean	7.77	38.466	27.356	310.11
	N	90	90	90	90
	Std. Deviation	1.399	7.7419	3.6321	111.823
ZGS Caprico	Mean	6.72	35.354	25.972	258.07
	N	90	90	90	90
	Std. Deviation	1.290	8.1802	4.1660	105.467
ZGS Red Creole	Mean	6.89	35.747	23.261	175.78
	N	90	90	90	90
	Std. Deviation	1.136	7.5094	3.4333	61.543
Total	Mean	7.35	36.621	25.529	255.06
	N	930	930	930	930
	Std. Deviation	1.363	7.9637	4.2575	105.804

Table 3: Mean and Standard Deviation across the measured parameters of the 11 onion varieties

Onion Variety	Scores (number of lesions/plant (%))					
	0-No damage (no lesions)	1-<25% leaf damage	2->26%<50% leaf damage	3->51%<75% leaf damage	4->76% leaf damage	5-100% Leaves completely damaged with lesions
ZGS Creole				✓		
ZGS Caprico				✓		
Texas Grano			✓			
Regent F1					✓	
Star 5525			✓			
KKS 1402			✓			
Radium					✓	
Kalunga Plus				✓		
Neptune F1				✓		
Crenola digon			✓			
Red Marvel						✓
Red creole				✓		

Table 4. Susceptibility and magnitude of Thrips amongst varieties

orrelations

		Onion variety	Bulb weight	Bulb diameter	Plant height	Number of leaves
Onion variety	Pearson Correlation	1	-.034	.037	.095**	-.005
	Sig. (2-tailed)		.300	.254	.004	.871
	N	930	930	930	930	930
Bulb weight	Pearson Correlation	-.034	1	.898**	.112**	.117**
	Sig. (2-tailed)	.300		.000	.001	.000
	N	930	930	930	930	930
Bulb diameter	Pearson Correlation	.037	.898**	1	.085**	.078*
	Sig. (2-tailed)	.254	.000		.009	.017
	N	930	930	930	930	930
Plant height	Pearson Correlation	.095**	.112**	.085**	1	.572**
	Sig. (2-tailed)	.004	.001	.009		.000
	N	930	930	930	930	930
Number of leaves	Pearson Correlation	-.005	.117**	.078*	.572**	1
	Sig. (2-tailed)	.871	.000	.017	.000	
	N	930	930	930	930	930

Table 5. Correlation relationships between the different parameters

**Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Replication	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	94.460	128	.738	1.106	.215
Within Groups	534.572	801	.667		
Total	629.032	929			

Table 6. ANOVA showing effect of replications

Variety	20 Nov	27 Nov	4 Dec	Overall Percentage loss
Regent	3		1	20%
Radium		1		5%
Red Marvel	1	1		10%
Red Creole		1		5%
Crenola Digon		1		5%
Caprico		1	2	15%
Texas Grano	2	1	2	25%
Star 5525	1			5%
Neptune F1	1		1	10%
KKS 1405	1			5%
Kalunga Plus	1			5%
Total losses	10	6	6	10%

Table 7. Assessment of onion rotting per variety

Variety	Physiological Loss in weight (%)
Regent F1	18.91%
Radium	19.14%
Red Marvel	38.88%
Red Creole	31.76%
Crenola Digon	16.35%
Caprico	17.97%
Texas Grano	30.66%
Star 5525	13.5%
Neptune F1	13.34%
KKS1405	10.32%
Kalunga Plus	18.59%

Table 8. Physiological weight loss of the varieties under the study

Variety	Yield	Colour	Shape	Size	Total	Ranking
Crenola Digon	1	2	1	1	5	2
Kalunga Plus	8	6	5	8	27	8
KKS 1402	7	8	1	5	21	7
Neptune F1	5	4	5	5	19	5
Radium	9	8	8	9	33	9
Red Marvel	11	10	10	10	41	10
Regent F1	3	4	1	1	9	3
ZGS Caprico	4	6	5	5	20	6
Texas Grano	1	1	1	1	4	1
Star 5525	6	2	5	1	14	4
ZGS Red Creole	10	11	11	11	43	11

Table 9. Ranking of onion varieties based on farmers' perceptions Wedza, Chigondo Irrigation scheme

Variety	Yield	Colour	Shape	Size	Total	Ranking
Red onion	5	6	6	3	20	5
Regent F 1	3	1	4	8	16	3
Crenola Digon	1	2	3	1	7	1
Caprico	6	5	5	6	22	6
Star 5522	4	7	2	5	18	4
KKS 1402	7	4	7	7	25	7
Radium	8	8	8	4	28	8
Texas Grano	2	3	1	2	8	2

Table 10. Ranking of onion varieties by farmers in ZakaFuvePanganai Irrigation scheme

Variety	Marketable Yield (t/ha)		Total Yield (t/ha))		Unmarketable Yield (t/ha))	
	Winter	Summer	Winter	Summer	Winter	Summer
Crenola Digon	16.48e		17.35f		0.87a	
Kalunga Plus	8.79b		9.25b		0.46a	
KKS 1402	13d	2.16b	13.69c	2.16b	0.69a	0
Neptune F1	12.11cd	3.27d	13.45c	3.38c	1.35b	0.11a
Radium	13.57d	2.45bc	14.28cd	2.45bc	0.71a	0
Red Marvel	6.38a		7.02a		0.7a	
Regent F1	12.42cd	1.63a	15.53d	1.88a	3.12d	0.25a
ZGS Caprico	11.84c	2.11b	13.93c	2.11b	2.09c	0
Texas Grano	12.37cd	2.86c	16.49e	5.01d	4.12e	2.15b
Star 5525	14.74de		15.52d		0.78a	
ZGS Red Creole	8.98b	2.46bc	9.45b	2.54bc	0.47a	0.08a
Irati Hybrid		2.02b		2.08b	0.06a	
King onion		5.08e		5.24d	0.16a	

Table 11: Marketable and Total Yield (t/ha) and percentage Marketable Yield of Onion Varieties

Means within a column followed by same letter (s) are not significantly different according to LSD-Test (P<0.05)

F. Major pests encountered

Thrips (*Thrips tabaci*Lindeman) are the major pests that can cause significant losses of commercially produced onions through extensive feeding which results instunted plant growth and reduced bulb weight[14]. In the present study, thrips populationswere determined on randomly selected plants. The number of lesions per onion variety was determined as the percentage of the leaf surface exhibiting lesions and was rated on a scale of 0 to 5 in each plot (Table 4). Red Marvel was highest in susceptibility to thrips followed by Regent F1 and Kalunga Plus. Other cultivars which include Texas Grano, Star 5525, KKS 1402, and Crenola Digon were the least affected by Thrips. Due to the deleterious effects of thrips on onions, total marketable yield in susceptible cultivars such as Red Marvel may be significantly reduced [14].

G. Variety susceptibility to bolting

The different cultivars exhibited great variation in bolting. Red Marvel had the highest percentage bolting (87%), followed by the commonly grown variety, Texas Grano. The variety Crenola Digon recorded the lowest bolting (1.9%) and this was comparable to Radium. Several

ISSN No:-2456-2165

studies show that onion varieties differ in their resistance potential to bolting particularly Cramer (2001), who showed that some open-pollinated onion varieties are more resistant to bolting [5]. Other studies suggest that bolting is associated with nitrogen availability by extending the vegetative growth period of the plant [15]. Some varieties are particularly susceptible to bolting during cold spells [16]. Bolting reduces the marketable yield by hindering bulb growth [16].

H. Storability assessment of the different varieties

The greatest physiological weight losses were observed in Red Marvel (38.8%), Red Creole (31.76%), and Texas Grano (30.66%) (Table 8).The greatest loss to rotting was observed in Texas Grano (25%) and Regent F1 (20%) (Table 7). Bulb weight loss was more pronounced in the first 4 weeks after the initiation of the drying process – 20 November 2020 whereas in the following two weeks, was gradual. No rotting was observed after 4 Dec 2020 which implies that, if no rotting occurs within 4-6weeks, it is highly likely that no rotting will occur as the onions will have dried correctly and completely(Table 7).

I. On-farm (farmer-managed) identification of adaptation varieties

Farmer-led trials hosted by Lead Farmers under the supervision of extension frontline staff presented a clear understanding of farmers' variety needs through Participatory Variety Assessments (PVA) approaches. Farmers provided their perceptions of the eleven varieties on yield, bulb color, shape, and size, and based on this, the different varieties were ranked (Table 9, Table 10). Texas Grano, Crenola, Regent FI, and Star 5525 were identified as the most preferred varieties. The variety preferences were well aligned to findings reported from researcher-managed trials on-station where the four varieties were superior in yield to the rest of the varieties.

J. Effect of winter and summer season on onion productivity

Climatic conditions can be a determining factor in productivity performance of the onion varieties and therefore the effects of planting in summer and winter on yield of onion varieties were investigated.The results from this study showed significant differences among the different seasons with regard to growth, yield and quality parameters. The highest yield per hectare were obtained from winter planted onion varieties (Figure4, Table 11). Total yield significantly lower in summer season ($p<0.05$) and the yields were reduced by over 90%. Total bulb yields ranged from 13.45 t/ha to 16.49 t/ha in the dry/winter season and from 1.86 t/ha to 4.94 t/ha in the wet/summer season. The differences observed were very significant ($p< 0.05$). In the dry season, the highest total yields were recorded for Crenola Digon and the lowest were recorded for Radium variety. Therefore, based on the findings of the current study, winter planting (May to August) was identified and recommended as the optimum planting time for onion production of the 11 varieties under tropical climatic conditions in Zimbabwe. High yielding onion varieties suitable for summer cultivation should be identified in order to make several varieties available to producers.

IV. CONCLUSION

The main objective of the study was to evaluate the yield potential and physiological qualities of different onion varieties against the commonly grown cultivar, Texas Grano. The results showed that Crenola Digon was the best performing variety (17.35 t/ha) followed by the commonly grown Texas Grano (16.49t/ha) and then Regent F1 (15.53 t/ha) and Star 5525 (15.52 t/ha). Apart from the higher yield, Crenola Digon exhibited limited physiological disorders characterized by less rotting upon storage. This study can be a reference for the selection of varieties that are well adapted to the different agro-ecological zones which increases sustainability through promoting the adoption of better performing varieties. However, there is need to identify the best sowing dates for the winter season given the yield potential of onion which can be as high as 35.6 t/ha in regions such as the EU, and in addition, there is need to identify varieties that can perfom better in summer season.

V. ACKNOWLEDGMENTS

This study was supported by the Korea-Africa Food and Agriculture Cooperation Initiative (KAFACI). We would also like to thank the Scientific and Industrial Research and Development Centre (SIRDC) which hosted some trials for the experiment.

REFERENCES

[1.] Made, J. M., Wright, B. S. & Maramba, P. Onion Production and Constraints in Zimbabwe: With Specific Reference To the Agricultural Development Authority (Ada). *Acta Horticulturae* 349–352 (1994).

[2.] Gebretsadik, K. & Dechassa, N. Response of Onion (Allium cepa L.) to nitrogen fertilizer rates and spacing under rain fed condition at Tahtay Koraro, Ethiopia. *Sci. Rep.***8**, 1–8 (2018).

[3.] Choudhary, A. K. *et al.* Integrated crop management technology for enhanced productivity, resource-use efficiency and soil health in legumes - A review. *Indian J. Agric. Sci.***90**, 1839–1849 (2020).

[4.] Bekele, D. Advances in Crop Science and Technology Role of Postharvest Management for Food Security : A Review. *Adv. Crop Sci. Technol.***9**, (2021).

[5.] Cramer, C. S. Comparison of open-pollinated and hybrid onion varieties for new Mexico. *Horttechnology***11**, 119–123 (2001).

[6.] Soleymani, A. & Shahrajabian, M. H. Effects of different levels of nitrogen on yield and nitrate content of four spring onion genotypes. *Int. J. Agric. Crop Sci.***4**, 179–182 (2012).

[7.] Pal Baliyan, S. Evaluation of Onion Varieties for Productivity Performance in Botswana. *World J. Agric. Res.***2**, 129–135 (2014).

[8.] Khandagale, K. & Gawande, S. Genetics of bulb colour variation and flavonoids in onion. *J. Hortic. Sci. Biotechnol.***94**, 522–532 (2019).

[9.] Khar, A., Jakse, J. & Havey, M. J. Segregations for onion bulb colors reveal that red is controlled by at least three loci. *J. Am. Soc. Hortic. Sci.***133**, 42–47 (2008).

[10.] Grant, D. G. & B. V. Carter. A study of bulb shape in onions (Allium cepa L.). *Proc. Agron. Soc. N. Z.***21**, 19–22 (1991).
[11.] Anning, D. K. & Addai, I. K. Response of onion (Allium cepa L.) to bulb size at planting and NPK 15:15:15 fertilizer application rate in the Guinea Savannah agroecology of Ghana. *J. Agron.***14**, 304–309 (2015).
[12.] Trivedi, A. P. & Dhumal, K. N. Variability and correlation studies on bulb yield, morphological and storage characters in onion (Allium cepa L.). *J. Pure Appl. Sci.***18**, 1–4 (2010).
[13.] Asmirew, B., Gedamu, Y. & Ayalew, A. Bulb Quality and Storability of Onion (Allium cepa L.) as Affected by Varieties and Intra-Row Spacing in Antsokia Gemza, Ethiopia. *Turkish J. Agric. - Food Sci. Technol.***8**, 580 (2020).
[14.] Gill, H. K., Garg, H., Gill, A. K., Gillett-Kaufman, J. L. & Nault, B. A. Onion thrips (Thysanoptera: Thripidae) biology, ecology, and management in onion production systems. *J. Integr. Pest Manag.***6**, 1–9 (2015).
[15.] Abdissa, Y., Tekalign, T. & Pant, L. M. Growth, bulb yield and quality of onion (Allium cepa L.) as influenced by nitrogen and phosphorus fertilization on vertisol I. growth attributes, biomass production and bulb yield. *African J. Agric. Res.***6**, 3252–3258 (2011).
[16.] Kwon, Y. S., Kim, C. W., Kim, J. S., Moon, J. S. & Yoo, K. S. Effects of bolting and flower stem removal on the growth and chemical qualities of onion bulbs. *Hortic. Environ. Biotechnol.***57**, 132–138 (2016).