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Effect of Rates and Time of Paclobutrazol Application on Growth, Lodging, and Yield and Yield Components of Tef [Eragrostis Tef (Zucc.) Trotter] in Adadistrict, East Shewa, Ethiopia

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Abstract
In Ethiopia, tef is valuable crop to achieve national economic stability, and improved livelihood of many farmers. The objective of the present study was to assess the effects of rates and time of paclobutrazol (PBZ) application on growth, lodging, yield and yield components of tef. Twelve entire factorial combinations of three rates (0, 1, 2 and 3 kg a.i.) and three growth stages (i.e. tillering, jointing and panicle emergence) of application of PBZ were evaluated in a field experiment on the research field of Debre Zeit Agricultural Research Center using randomized complete block design with three replication during the 2016 main season. Data were collected on plant height, number of tillers (fertile, unfertile and total) per plant, panicle length, culm length, lengthof the upper three culm internodes, days to Panicle emergence and physiological maturity, thousand seed weight, lodging index, grain yield, biological yield ,straw yield, harvest index (HI) and crude protein. The data were subjected to statistical analysis using SAS and mean differences were compared using Duncan's Multiple Range Test. The analysis of variance showed that time of application, PBZ rate, and the interaction of two had significant ($P \leq 0.01$) effect on all the characters except number of non fertile tiller and thousand seed weight. Spraying 1kg of PBZ at jointing stage could suppress vegetative growth and increased number of fertile tillers and grain yield and minimized the risk of lodging. Therefore, spraying 2kg a.i of PBZ ha^{-1}at jointing stage can be suggested as effective to maximize grain yield of tef.
Keywords: PBZ; Grain yield; Lodging

1. INTRODUCTION

Tef [*Eragrostis tef* (Zucc.) Trotter] is C4 self pollinated annual grass that belongs to the family *Poaceae* (Dejene *et al*., 2012). Tef is an indigenous unique cereal crop of Ethiopia, where it owes its center of both origin (the first domestication) and diversity (Vavilov, 1951). Also, it is thought to have been spread to Europe through the Portuguese contact in the 16th century (Taddesse, 1975).

In Ethiopia, tef is cultivated on an area of about 3 million hectares with tef and maize taking up about 24.02 % and 16.8% of the total grain crop area, respectively (CSA, 2015). This makes tef the first among cereals in the country in area coverage. However, out of the total cereal grain produced, maize and tef accounted for 26.76% (7.23 million tons) and 17.57% (4.4 million tons), respectively (CSA, 2015). Despite the aforementioned importance and coverage of large area, its productivity is very low. The average national yield of tef is about 1.64 tons per ha (CSA, 2015). Some of the factors contributing to the low yield of tef are low soil fertility and suboptimal use of fertilizers, weeds, and erratic rainfall distribution and drought particularly in the low altitudes areas, lack of high yielding cultivars, lodging and water-logging (Ermias *et al*., 2007).

Among these lodging is a more serious problems especially in areas subjected to high rainfall and strong winds and particularly more so under growing conditions favorable for the growth and yield of the crop. Tef possesses tall, weak stems that easily succumb to lodging caused by wind or rain. In addition, lodging hinders the use of high input husbandry since the application of increased amounts of nitrogen fertilizer to boost the yield results in severe lodging. When this occurs, both the yield and the quality of the grain and the straw are severely reduced and both manual and mechanical harvesting is impeded. Various attempts have been made by the research community to develop lodging-resistant tef cultivars (Zerhun and Kebebew, 2012) but presently no cultivar with reasonable lodging resistance has been obtained. Seyfu (1983) reported17 to 23% yield reduction of improved tef varieties due to natural lodging. In lodged crop, light utilization is insufficient which results in poor grain filling and reduced yield (Taiz &Zeiger, 2004).

Generally cereals like barley, oat, rice and tef have higher stem height and hence are more prone to lodging compared to semi dwarf crops. (Emam, 2011). Therefore, control of plant growth such as plant or culm height, can be achieved by using plant growth regulators (PGRs).

Among the gibberellins inhibitors that are used to control plant growth are the Amonium-type compounds, such as chlorocholin chloride (2-chloroethyl-N,N,N-trimethyl-ammonium chloride, CCC) and mepiquat-Cl, interfering with ent-kaurene synthesis at the early stages of gibberellin biosynthesis (Rademacher, 2000). A further group is nitrogen containing heterocycles such as triazoles and imidazoles. This includes paclobutrazol (PBZ) and the closely related uniconazole-P. Both compounds interferes the oxidation of ent-kaurene to ent-kaurenoic acid (Rademacher, 2000).

Paclobtrazol application on wheat, barley and rice extensively used to stimulation of tillering, redistribute biomass with increased root growth, reduce plant stature and increase stiffness of straw that limits the risk of lodging and improve grain yield (Rodrigues *et al*., 2003; Emam, 2011). PBZ and the closely related uniconazole-P are highly active PGRs with practical uses in rice, fruit trees and ornamentals (Rademacher, 2000), and about 84% of the winter wheat in UK is treated with PGRs (Berry *et al*., 2004).

Under the Ethiopian context, plant growth regulators as means of controlling lodging problem have not been used. However, greenhouse and field experiments were undertaken to investigate the efficacy of 2-chloroethyl trimethylammonium chloride (CCC) to reduce lodging problem and promising results were observed (Tekalign ,2007).

Lodging is a serious problem in major tef producing area of Oromia Region such as East Shewa and others. To this effect it would be imperative to see the effect of PBZ on the lodging percentage and yield of tef variety (Tekalign 2007).

Therefore, this study is initiated with the following objectives:

- ✓ To assess the effects of rates and time of PBZ application on growth, lodging, yield and yield components of tef and
- ✓ To determine the most economic rate and time of PBZ application for tef production

2. MATERIALS AND METHODS

2.1. Description of the Study Area

The study was conducted at Debre Zeit Agricultural Research Center in Oromia Regional State 45 Km East of Addis Ababa during the main cropping season of 2016. The place is located of 8^0-44'N and 38^0-58'E at altitude of 1900 meter above sea level. The area is characterized by monomodal rainfall pattern. The mean long-term annual rainfall recorded at the station is 660 mm and the average annual minimum and maximum temperatures are 12^oC and 27.4^oC, respectively (Fig.1) The type of soil is clay in texture which is known as Vertisols ("Koticha") or cracking clay soils and moderately acidic in reaction (6.5) with medium bulk density of the soil (1.34 g/m3) which might be associated with relatively higher content of clay (DZARC, 2016).

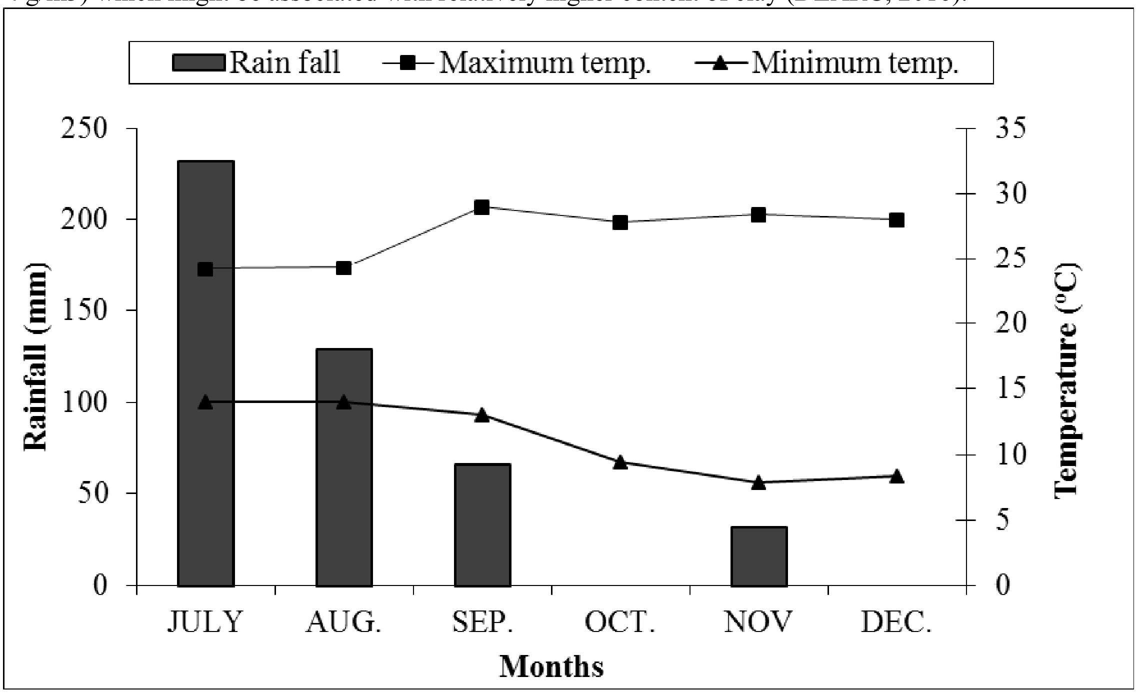

Fig. 1.Mean rain fall and temperature of the experimental area during 2016 period.
Source :DZARC (2016)

2.2. Planting Material

The tef variety named Dukem (DZ- 01 - 974), developed and released by Debr Zeit Agricultural Research Center in 1995 was used for the experiment. Dukem is a high yielding pale white-seeded variety. Depending on the growing condition, its plant height ranges from 84 - 132 cm, the average being 108 cm. It is relatively late maturing variety that matures within 76-137 days after planting depending on the growing conditions. Due to its tallness, under favorable growing conditions it is found to be susceptible to lodging. (MoARD, 2008).

2.3 .Treatments and Experimental Design

The treatments consisted of entire factorial combinations of four rates (0, 1, 2 and 3kg ha^{-1}) active ingredient of PBZ and three growth stages (*viz*. tillering, jointing and panicle emergence) of application. The treatments were laid out in a random complete block design with three replications. A plot size of 2m x1.4 m (2.8 m^2) with 20 cm row spacing and a total of 7 rows were used. The net harvestable area was 1.8m x 1m and adjacent plots and blocks were spaced 0.5m and 1 m apart, respectively.

A given PBZ concentration was diluted in distilled water (50 ml per plot) and the aqueous solution was applied uniformly to each plant as fine foliar spray using an atomizer. The controls plants were treated with distilled water of equal volume.

The following three growth stages were used for paclobutrazol application on the basis of growth stages identified by Kebebew (1991).

1. **Tillering**: Thirty days after planting and the plants had an average of four developed leaves on the main stem.
2. **Jointing**: Forty-five days after planting. The plants had developed about five leaves on the main stem and the second node on the main culm of the plant was detectable.
3. **Panicle emergence**: Fifty-three days after planting. The plants had developed the maximum leaves (6 or more) on the main stem and the emergence of the tips of the panicle (about 3 cm long) through the flag leaf sheath was manifested

2.4. Experimental Management

Plots (2.8 m^2) was divided into 7 rows with inter-row spacing of 20 cm. Seeds were drilled within each row at a rate of 1.2 g per plot (5 kg ha^{-1}). NPS fertilizer at rate of 100kg $ha^{-1}$was used as source of nitrogen, phosphorus and sulphur, and it was applied at a time of planting by band method. Urea was applied at the rate of 90kg $ha^{-1}$of which1/3 was applied at planting and 2/3 at tillering by broadcasting method.

Land was prepared according to the local practice. It was ploughed five times before planting and the last plough was used for sowing tef plants. All other cultural practices were done as per recommendation of Seyfu (1987). Harvesting was done at physiological maturity when the vegetative parts of the plants turned to light yellow or straw color.

After good establishment, the main stems of ten randomly selected plants from each of the five central rows were tagged, and relevant data measurements were done on these selected plants.

2.5. Soil Sampling and Analysis

One representative composite sample was taken at a depth of 0-30 cm from five randomly selected spots diagonally across the experimental field using auger before planting and bulked. The sample was dried, grounded using a pestle and mortar and passed through a 2mm sieve. Working sample was obtained from the submitted sample and analyzed for selected physico-chemical properties mainly texture, bulk density, soil pH, cation exchangeable capacity (CEC), organic carbon, total N, and available P using standard laboratory procedures at Debre Zeit Agricultural Research Center soil laboratory. Organic carbon was determined by Walkley and Black oxidation method (Walkley and Black, 1934). Total nitrogen was analyzed by Kjeldhal method (Jackson, 1958). The pH of the soil was determined at 1:2.5 (weight/ volume) soil to water dilution ratio using a glass electrode attached to digital pH meter (Page, 1982).Cation exchange capacity was measured after saturating the soil with 1Nammonium acetate (NH4OAC) and displacing it with 1N NaOAC (Bremner and Mulvaney 1982). Available phosphorus was determined using the Olsen method (Olsen *et al*., 1954).

2.6. Data Collection

2.6.1 Phenologic traits

Days to panicle emergence: This parameter was determined by counting the number of days from sowing to the time when 50% of the plants started to emerge the tip of panicles through visual observation.

Days to physiological maturity: Days to maturity was determined as the number of days from sowing to the time when the plants reached maturity based on visual observation. It is indicated by senescence of the leaves as well as free threshing of grain from the glumes when pressed between the forefinger and thumb.

Grain filling period: Grain filling period was obtained by subtracting the days to panicle emergence from the days to maturity.

2.6.2. Growth parameters

Plant height (cm): It was measured at physiological maturity from the ground level to the tip of the main shoot panicle from ten randomly selected plants in each plot.

Panicle length (cm): It is the length of the main shoot panicle from the node where the first panicle branch emerges to the tip of the panicle and it was determine from an average of ten selected plants per plot.

Length of the upper three culm internodes (cm): This refers to the average length of three the uppermost internodes culm internodes of the maim shoot culm and was recorded from average of ten randomly selected plants.

Culm length (cm): This is the length from the base of the main shoot culm to the base of the panicle and was recorded from average of ten randomly selected plants.

2.6.3 Yield and yield components

Number of effective tillers: The numbers of tillers was determined by counting the tillers from an area of 0.25 m x 0.25 m plants by throwing a quadrat into the middle portion of each plot.

Grain yield (kg): It was measured by harvesting the crop from the net middle plot area of 1m x 1.8m to avoid border effects.

Biomass yield (kg): At maturity, the whole plant parts, including leaves and stems, and seeds from the net plot area were harvested and after drying for three days, the total biomass was measured.

Straw yield (kg): Straw yield was determined by subtracting grain yield from total above ground biomass.

Thousand kernel weight (g): One thousand kernels were counted after harvesting at random from each plot and their weights was measured with accurate balance at harvesting

Harvest index (%): It was calculated on a plot basis as the ratio of grain yield to the aboveground biomass yield and expressed as a percentage.

2.6.4. Lodging index

The degree of lodging was assessed just before the time of harvest by visual observation based on the scales of 1-5 where 1 (0-15^o) indicates no lodging, 2 (15-30^o) indicates 25% lodging, 3 (30-45^o) indicates 50% lodging, 4 (45-60^o) indicates 75% lodging and 5 (60-90^o) indicates 100% lodging (Donald, 2004). The scales were determined by the angle of inclination of the main stem from the vertical position to the base of the stem by visual observation. Each plot was divided based on the displacement of the aerial stem in to all scales by visual observation. Each scale was multiplied by the corresponding percent given for each scale and average of the scales represents the lodging percentage of that plot. Data recorded on lodging percentage was subjected to arcsine transformation described for percentage data by Gomez and Gomez (1984).

2.7. Crude protein (%)

It was determined on composite of 2g dried leaves and stem by using Kjeldhal method (Bremner, 1965).

2.8. Statistical Analyses

Data were subjected to analysis of variance (ANOVA) using General Linear Model (GLM) procedures of SAS 9.3 (SAS Institute, 2003).Whenever treatment effects were found significant, the differences among treatment means were compared using Duncan's Multiple Range Test (DMRT) at 5% level of significance and Linear Regression Analysis was done.

3. RESULTS AND DISCUSSION

3.1. Soil physiochemical properties

The experimental soil was of silt loam texture composed of 14% clay, 32% sand and 54% silt. Its organic carbon content is 1.26%, which is low according to Roy *et al*. (2006) and medium OC in accordance with Sahlemedhin (2000). The CEC of the soil was 33.33 meq kg^{-1}, which could be considered as high (Landon, 1991). According to the rating of Olsen *et al.* (1954), P content (mg kg^{-1}) of < 3 is very low, 4 to 7 is low, 8 to 11 is medium, and > 11 is high. Thus, for the experimental site the available P content is high. The pH of the soil was 6.96, which is within the range of 4 to 8 suitable for tef production (FAO, 2000). The total N of the soil which is 0.17%, is medium in accordance with Havlin *et al*. (1999) who rated total N between 0.15 to 0.25% as medium (Table 1).

Table 1.Soil physicochemical properties of the experimental site.

Soil Parameters	value
Total N (%)	0.17
Available phosphors (mg kg $^{-1}$)	17.958
Organic carbon (%)	1.26
Organic matter	2.17
pH (H_20)	6.96
Exchangeable cation (cmol(+)kg^{-1}	0.54
Cation exchangeable capacity (meqkg^{-1})	33.33
Electric conductivity (µs)	54.9
Sand (%)	32%
Silt (%)	54%
Clay (%)	14%
Texture class	Silt loam

3.2. Effects on crop phenology

3.2.1. Days to panicle emergence

The analysis of variance showed that days to panicle emergence were significantly (P <0.01) affected by the main effects of rate (Table 2 and Appendix 3). Whereas the main effect time of PBZ application and the interaction effects of PBZ rate and time of application were not significant. (Appendix 3). The rate of PBZ application influenced days to panicle emergence in a comparison to the control by retarding the dates of panicle emergence such that the intermediate and higher rates with no significant difference between them extended days to panicle emergence by a week (Table 2).

The retardation of days to panicle emergence of tef plant due to PBZ treatments might be attributed to the synthesis cytokinins hormones which prolonged reproductive period. Similarly Opik and Rolf, (2005) reported that plant growth regulators like PBZ improve cytokinin level thereby, prolonged the vegetative and reproductive growth periods since cytokinin is known as a true shooting hormone.

Table 2.Means of days to panicle emergence of tef plants as affected by rate and stage of application of PBZ at Debre Zeit during the 2016 main season.

Treatments	Days to panicle emergence (days)
PBZ Rates (Kg ha^{-1}a.i)	
0	58.22^{b}
1	65.78^{a}
2	66.44^{a}
3	66.33^{a}
SEM (±)	1.00
CV (%)	1.57

SEM: standard error of mean

Means sharing the same superscript letter do not differ significantly as judged by DMRT at P≤0.05

3.1.2. Days to physiological maturity

Days to physiological maturity of tef plant was significantly (P<0.01) affected by the main effects of both rate and time of PBZ application as well as by the interaction of the two factors (Table 3and Appendix 3). Generally, it observed that the maturity of tef plants was delayed as the PBZ concentration increased. Increasing the rate of PBZ from 0 to 1 kg a.i was prolonged days to maturity by five days compared to the control. However increasing the rate of PBZ beyond1kg ha^{-1} did not further increase the number of days required to mature. Tef plants treated with PBZ at jointing, tillering and panicle emergence stages required 122.00, 119.00, 117.00 days to attain physiological maturity. On the other hand the interaction effects showed that lower rate of PBZ application at jointing stage prolonged days to physiological maturity by 7days in comparison to the control and the moderate and higher rate did not significantly influence days to physiological maturity when applied at jointing stage, followed by tillering stage with no significant difference among PBZ rates which delayed by 5 days, while late application of PBZ with rate of 1kg or 2kg and 3kg ha^{-1} delayed by 3 and 5 days respectively compared to untreated plants (Table 3).

These delayed in days to maturity of tef plants due to PBZ treatments may be PBZ enhancing the endogenous level of cytokinins which in turn promotes chlorophyll formation, by increased the activity of certain antioxidant enzymes (Synkova ,2006) which helps to prevent degradation of chlorophyll and retard maturity of tef. Similar result reported on tef (Tekalign, 2007) and camillena (Kumar *et al*., 2012) showed that application of synthetic growth retardant increased the level of cytokinins over senescence promoting hormone like ABA and ethylene in the plants their by delayed maturity of crops. Contradicting results was reported by Katz *et al*. (2003) and Chutichudet *et al*. (2006) where they observed that PBZ application highly reduced the number of days from initial to harvest. They justified, PBZ has a role in accumulation of carbohydrate thus it hasten a rapid growth of sink.

Table 3. Means of days to maturity of tef plants as affected by rate and stage of application of PBZ at Debre Zeit during the 2016 main season.

Rates (Kg ha^{-1}a.i)	Days to maturity (days)			Means of rates of PBZ (Overall growth stages)
	Time of application			
	Tillering	Jointing	Panicle emergence	
0	115.00[e]	115.00[e]	115.00[e]	115.00[b]
1	120.67 [bc]	124.67[a]	118.00[d]	121.11[a]
2	120.00 [bcd]	124.67[a]	118.67[cd]	121.11[a]
3	121.00 [b]	124.67[a]	120.00 [bcd]	121.89[a]
Means of growth stages (Over all rates)	119.33[b]	122.25[a]	117.92[c]	
SEM±	1.14			
CV (%)	0.96			

SEM: standard error of mean
*Means within the same column and within the same treatment category followed by different superscript letters are significantly different as judged by DMRT at P≤0.05.

3.1.3. Grain filling period

Grain filling period of tef plants was significantly (P < 0.05) affected by the main effects of both rate and time of PBZ application as well as by interaction of the two factors. (Table 4 and Appendix 3). From this experiment grain filling time decreased as PBZ rate increased. The highest grain filling period (57days) was obtained from the control treatment which extended grain filling period by two days compared to the other rates. On other hand time of application significantly (P< 0.01) affected grain filling period such that spraying PBZ at jointing stage had higher (57.67days) grain filling period than application at tillering (54.75days) and panicle emergence stage (54.41days). The interaction effects of the rate of PBZ and its time application revealed that the highest grain filling period (58.33days) was obtained from the application of 1kg a.i ha^{-1} at jointing stage and the lowest (54 days) grain filling period was recorded from late PBZ application with no significant difference among the rates (Table 4).

The improvement in grain filling period was obtained from PBZ application might be (i) from the prolonged in the days to maturity that means prolonged green condition might have concurrently improved the period of leaf photosynthesis in PBZ treated plants by keeping the leaves photosynthetically active for a longer time which in turn might have contributed to better grain filling period and (ii) from reduction of lodging risk since lodging is one of the factor that affect grain filling period. Similarly to this finding Sawan (2009) reported growth retardants like PBZ reduce plant lodging and improve plants architecture escalating efficiency in capturing solar radiation and other environmental resources due to these effects PBZ can possibly changes assimilate partition, improving grain filling period and consequently the physiological quality of seeds.

Table 4. Means of days to grain filling period of tef plants as affected by rate and stage of application of PBZ at Debre Zeit during the 2016 main season.

Rates (Kg ha^{-1}a.i)	Grain filling period (days)			Means of rates of PBZ (Overall growth stages)
	Time of application			
	Tillering	Jointing	Panicle emergence	
0	56.33[a bc]	56.67[a b]	58.00[a]	57.00[a]
1	54.67 [bcd]	58.33[a]	53.00[d]	55.33 [b]
2	53.33[d]	57.67[a]	53.00[d]	54.67 [b]
3	54.67 [bcd]	58.00[a]	54.00[cd]	55.56 [b]
Means of growth stages (Over all rates)	54.75 [b]	57.67[a]	54.51 [b]	
SEM±	1.42			
CV (%)	2.55			

SEM: standard error of mean
*Means within the same column and within the same treatment category followed by different superscript letters are significantly different as judged by DMRT at P≤0.05

3.2 Effect on Growth Parameters

3.2.1 Plant height

According to finding the interaction formed between the rate of PBZ and its time of application reduced plant height in comparison with control and the difference between the two factors were found to be significant (P<0.01) (Table 5 and Appendix 1).The highest plant height reduction was obtained from the plant that treated with 2 or 3 kg a.i of PBZ which reduced plant height by 50 % when applied at tillering stage, followed by the intermediate and higher rates of PBZ sprayed at jointing stage which reduced plant height significantly by 39.79% and 46.94% respectively compared to the control. The late application of PBZ at panicle emergence stage reduced plant height with no significant difference between the intermediate (2kg) and highest rates (3kg) by 33.22% and 36.98% respectively compared to the control and as such these treatments reduced plant height less compared to those applications at tillering and jointing stages (Table 5). Irrespective of stages application PBZ rate influenced plant height significantly (P <0.05). Increasing rates from 0 to 1, from 1 to 2 and from 2 to3kg a.i PBZ reduced plant height progressively by 32%, 13% and 7% respectively. This indicates that with further increment in concentration of PBZ plant height diminished significantly. On other hand early application of PBZ effectively reduced plant height than mid and late stage of application (Table 5).

Reduction in plant height is considered as the most important morphological outcome of PBZ application. The expressive reduction in tef plant height might be attributed to inhibition of ent Kaurene oxidase which catalyze the sequential oxidation from ent-kaurene to kaurenoic acid in the early sequence of gibberellins biosynthesis. Sun (2004) reported PBZ resulted in preventing the formation of stem elongation promoters for this reason the plant had develop dwarf effect. Many similar results reported in several crops that PBZ application effectively reduced plant height in tef (Endale *et al*., 2012), wheat (Assuero *et al*., 2012) Soybean (Zhang *et al*., 2006), and camillina (Kumar *et al*., 2012) without decreasing flowering quality and improves resistance to environmental stress conditions. Similar to this finding Bahrami *et al*. (2014a) on barley reported that application of plant growth regulators at early stage had lower plant height than those late applied.

Table 5. Means of Plant height of tef plants as affected by rate and stage of application of PBZ at Debre Zeit during the 2016 main season.

Rates (Kg ha^{-1}a.i)	Plant height (cm) Time of applications			Means of rates of PBZ (Overall growth stages)
	Tillering	Jointing	Panicle emergence	
0	99.00^{a}	98.00^{a}	97.33^{a}	98.11^{a}
1	55.33^{ef}	64.67^{c}	80.67^{b}	66.89^{b}
2	49.33^{gh}	65.00^{c}	59.00^{de}	57.78^{c}
3	48.00^{h}	52.00^{fg}	61.33^{cd}	53.78^{d}
Means of growth stages (Over all rates)	62.91^{c}	68.42^{b}	76.08^{a}	
LCR	3.79			
SEM±	2.24			
CV (%)	3.24			

SEM: standard error of mean
*Means within the same column and within the same treatment category followed by different superscript letters are significantly different as judged by DMRT at P≤0.05

3.2.2 Length of the Upper Three Culm internodes

The analysis of variance showed significant (P<0.05) interaction effects of time and rate of PBZ application length of the upper three culm internodes (Table 6 and Appendix 1). The length of the upper three culm internodes was significantly reduced by PBZ application compared to control. In the field observation the upper most three internodes were very short and compact particularly with the PBZ treatments at tillering stage. The highest reduction in the of the upper three culm internodes was obtained from plants that received 2, 3 and 1kg a.i of PBZ ha^{-1} when applied at tillering, jointing and panicle emergence stages that accounted 62%, 56% and 51% reduction in internodes length respectively compared to untreated plants. On the other hand increasing in the rate of PBZ treatment from 2 to 3kga.i ha^{-1} did not significantly influence the length of the upper three culm internodes with sprays both at tillering and jointing stage. Increasing rate of PBZ from 0 to 1,1to 2 and 2 to 3kg a.i ha^{-1} significantly reduced the length of the upper three culm internodes by 27%, 17% and 28% respectively when applied at panicle emergence (Table 6).

Table 6. Means of length of the upper three culm internodes of tef plants as affected by rate and stage of application of PBZ at Debre Zeit during the 2016 main season.

Rates (Kg ha^{-1}a.i)	Length of the upper three culm internodes (cm)			Means of rates of PBZ (Overall growth stages)
	Time of application			
	Tillering	Jointing	Panicle emergence	
0	13.33^{a}	14.33^{a}	13.67^{a}	13.78^{a}
1	10.00^{b}	7.00^{cde}	8.00^{cd}	8.33^{b}
2	5.00^{fg}	6.33^{def}	$8.3.00^{bc}$	6.56^{c}
3	4.33^{g}	6.00^{efg}	6.00^{efg}	5.44^{d}
Means of growth stages (Over all rates)	7.67^{b}	8.41^{b}	9.50^{a}	
SEM±	0.99			
CV (%)	5.29			

SEM: standard error of Mean; LCR: least critical range
*Means within the same column and within the same treatment category followed by different superscript letters are not significantly different as judged by DMRT at P≤0.05

The analysis of variance indicated that main effects of PBZ rate significantly (P<0.01) influenced the length of the upper three culm internodes. The highest reduction in the length of these internodes by 60%, 56% and 39% in a comparison to control were obtained from plant sprayed with 3, 2 and 1kg a.i of PBZ ha^{-1} respectively. Time application of PBZ significantly (P<0.01) affected the length of the upper three culm internodes. Applications of PBZ at tillering and jointing reduced the length of the upper three culm internodes effectively than applying at panicle emergence (Table 6).

Determination of length of internodes is crucial in relation to lodging index in which as length of internodes decrease, lodging index also decrease. The retardation of length of the upper three culm internodes might be associated with decreased level of gibberellins which control shoot growth, thus decrease level of gibberellins caused by PBZ application may be caused by blocking pathway for the production of gibberellins. This result is parallel with previous findings on tef (Endale *et al*., 2012) and peanut (Zheng, 2008) in which foliar application of plant growth regulators shortened internodes distance. Similarly, Taiz (2006) reported that the inhibition of gibberellins production does not affect the activity of cell division, but the new cells do not elongate further.

3.2.3 Culm and Panicle length

A significant (P<0.01) interaction between time and rate of PBZ application was observed with respect to culm and panicle length reduction of plants by shortening of internodes (Table 7 and Appendix 1). The highest reduction of culm length by 66.67% was observed from plants treated with 1kg a.i PBZ ha^{-1} at tillering and jointing stages followed by the highest rate of PBZ spray at panicle emergence stage which reduced culm length by 58% compared to the control. On the basis of results intermediate and highest rates at tillering, the lowest and intermediate rates at jointing and the intermediate and highest rate at panicle emergence did not significantly influence the culm length of plants (Table 7). In general, increasing the rates of PBZ treatment caused a linear decline in culm length and the relationship between PBZ concentration and culm length were found linear. Culm length was described by the equation $Y= -9.667x + 42.83$ which means that for every unit increase in the concentration of PBZ (kg ha^{-1}), culm length decreased by 9.667 units (Fig.2).

The main effects of rate and time of PBZ application were found significant (P< 0.01) with respect to culm length. Plants treated with 2 and 3kg a.i of PBZ ha^{-1} reduced culm length with statistically comparable amounts of 57% and 64%m, respectively, and the lowest culm length shortening was obtained with the lowest rate of 1 kg PBZ ha^{-1}spray, which reduced culm length by 42% in comparison to the control (47.67cm). On other hand, PBZ application significantly (P<0.01) reduced culm length when applied at tillering (26.17cm) followed by spray at jointing (27.5cm) and panicle emergence (31.33cm) stages (Table 7).

Table 7. Means of culm length of tef plants as affected by rate and stage of application at Debre Zeit during the 2016 main season

Rates (Kg ha^{-1}a.i)	Culm length(cm)			Means of rates of PBZ (Overall growth stages)
	Time of application			
	Tillering	Jointing	Panicle emergence	
0	48.00[a]	47.67[a]	47.33[a]	47.67[a]
1	22.33[cd]	24.33[a]	47.33[c]	27.44 [b]
2	18.33[de]	21.00[cde]	22.00[cd]	20.44[c]
3	16.00[e]	17.00[de]	20.33[cde]	17.78[c]
Means of growth stages (Over all rates)	26.17 [b]	27.5 [b]	31.33[a]	
SEM±	2.97			
CV (%)	10.49			

SEM: standard error of mean
*Means within the same column and within the same treatment category followed by the same superscript letters are not significantly different as judged by DMRT at P≤0.05

Stage and rate of PBZ application interacted significantly (P< 0.01) on panicle length (Table 8 and Appendix 1). The highest panicle reduction of 35% compared to untreated plant (50cm) occurred on plants treated with 1kg a.i of PBZ applied at tillering stage, and it was also observed that further increase in concentration of PBZ at this stage did not any further significantly influence panicle length. The second highest panicle length reduction was obtained from plants that received 2kg a.i PBZ at jointing stage (40cm) and panicle emergence (45cm). In contrast, panicle length to culm length ratio was 1.5, 1.7 and 2 with application of 1, 2 and 3kg a.i ha^{-1} of PBZ treatments, respectively. These ratios indicate that PBZ had a stronger effect on culm length than on panicle length (Table 7 and 8).

The main effects of both PBZ concentration and time of application were also significant (P<0.01) on panicle length. Application of PBZ at the lowest rate of 1 $kgha^{-1}$ reduced panicle length by 22% in comparison to the control (50cm). Further increase in rates of PBZ from lower to intermediate and from the intermediate to the highest rates did not bring appreciable change with respect to panicle length reduction. Regarding the time of application, PBZ treatment reduced panicle length effectively when sprayed at tillering (36.75cm) stage and then followed by jointing (40.83cm) and panicle emergence (44.75 cm) stage (Table 8).

Table 8. Means of panicle length of tef plants as affected by rate and stage of application at Debre Zeit during the 2016 main season

Rates (Kg ha^{-1}a.i)	Panicle length (cm)			Means of rates of PBZ (Overall growth stages)
	Time of application			
	Tillering	Jointing	Panicle emergence	
0	51.00[a]	50.33[a]	50.00[a]	50.44[a]
1	33.00[f]	40.00[cd]	45.00[b]	39.33 [b]
2	31.00[f]	38.00[ed]	45.00[b]	37.33 [bc]
3	41.00[bcd]	35.00[ef]	32.00[f]	36.00[c]
Means of growth stages (Over all rates)	36.75c	40.83 [b]	44.75[a]	
SEM±	2.15			
CV (%)	11.71			

SEM: standard error of Mean
*Means within the same column and within the same treatment category followed by the same superscript letters are not significantly different as judged by DMRT at P≤0.05

PBZ application greatly reduced culm and panicle length of tef plant particularly when it applied at early tillering stage. The retardation of culm and panicle length might be attributed from the reduction of gibberellins biosynthesis which resulted decrease internodes elongation. These findings were also consistent with finding of (Endale *et al*., 2012; Tekalign 2007) on tef and sunflower (Koutroubas *et al*., 2014). A given PBZ application astonishingly influences culm length than panicle length of tef plants, which indirectly entail higher demand of endogenous gibberellins, may exist for elongation culm than panicle. PBZ might have resulted in reduction in cell merstematic activity and cell elongation in the intercalary meristem (kelbert *et al*., 2004). Many studies reported that culm length increment associated positively with lodging of plants. Minimizing culm length associated with improvement of yield will able to minimize the risk of lodging (Mansuroglu *et al*., 2009; Currey and Lopez, 2010).

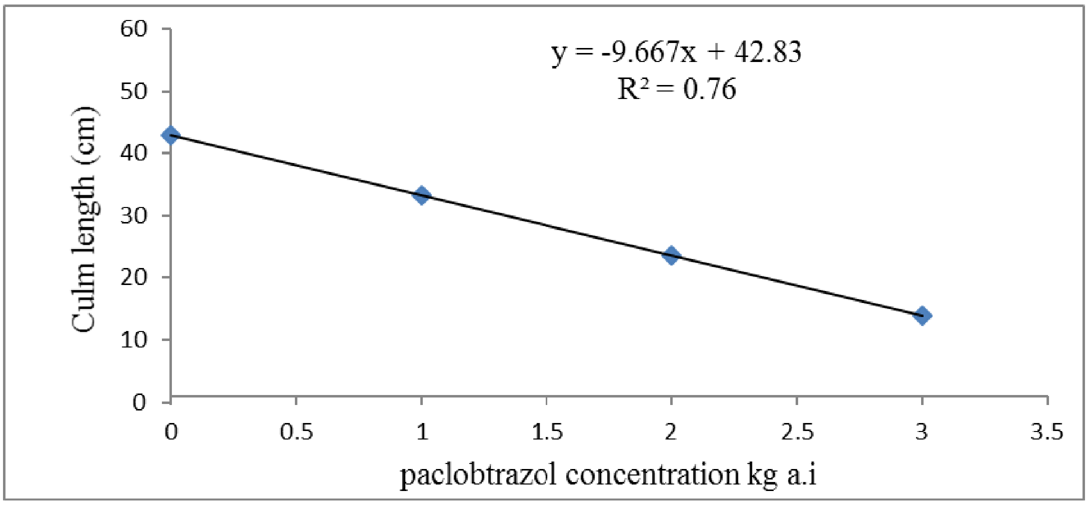

Fig. 2. Relationship of PBZ Concentration and Culm length.

3.3 Effect on Yield and Yield components

3.3.1 Number of Tillers

A significant (P<0.01) interaction between time and rate of PBZ application was observed on number of fertile (Table 9 and Appendix2) and total tillers (Table 10 and Appendix 2). The highest number of fertile tillers (15.67) was obtained from the lower rate of PBZ spray at jointing stage while the lowest number of fertile tillers (9.00) occurred from the nil and late time of PBZ application(Table 9). Likewise the highest number of total tillers was obtained (19.00) from the lower rate of PBZ spray at jointing stage and the lowest total tillers (11.67) was obtained from nil and late time of PBZ application (Table 10).

The main effects of PBZ rate were significant (P<0.01) on the number of fertile tillers (Table 9 and Appendix 2). The highest number of fertile tillers (15.56) was obtained from plants treated with 1kg a.i PBZ ha^{-1} and further application beyond this rate did not bring any appreciable change in the number of fertile tillers, while the lowest number of fertile tillers (9.00) obtained with no PBZ application. Tef plants treated with PBZ at jointing, tillering and panicle emergence stages gave 14.08, 11.75, 9.00 fertile number of tillers respectively (Table 9).

Table 9. Means of fertile tiller of tef plants as affected by rate and stage of application at Debre Zeit during the 2016 main season

Rates (Kg ha^{-1}a.i)	No. of fertile tillers Time of application Tillering	 Jointing	 Panicle emergence	Means of rates of PBZ (Overall growth stages)
0	8.67^{c}	9.30^{b}	9.00^{c}	9.00^{c}
1	14.30^{b}	15.67^{ab}	9.00^{c}	13.00^{a}
2	14.67$^{a b}$	15.00$^{a b}$	8.67^{c}	12.78^{a}
3	9.33^{c}	16.33^{a}	9.33^{c}	11.67^{b}
Means of growth stages (Over all rates)	11.75^{b}	14.08^{a}	9.00^{c}	
SEM±	1.01			
CV (%)	8.69			

SEM: standard error of mean

*Means within the same column and within the same treatment category followed by the same superscript letters are not significantly different as judged by DMRT at P≤0.05

It was observed that PBZ rate increased number of total tiller. The highest number of total tiller (15.56) was obtained from lower rate of PBZ and the lowest number of total tiller (12.10) was obtained from nil application of PBZ (Table 10). Similar to the rates, time of application affected total number of tillers significantly (P<0.01) and the highest amount of total tillers (17.17) was obtained when PBZ was applied at jointing stage followed by spray at tillering (14.75) and panicle emergence stages (11.58) (Table 10). On the other hand, neither the main effects of both rate and time of PBZ application nor their interaction effects were significant (P > 0.05) on the number of non-fertile tillers (Appendix 2).

Application of PBZ with lower doze strongly promoted higher fertile and total tiller number without affecting the number of unfertile tillers compared to those untreated plants. Similar result reported in promoting of higher tiller number on tef (Endale *et al.*, 2012), barley (Bahram *et al.*, 2014a), sun flower (Ribeiro *et al.*, 2011). This might be attributed due (i) PBZ application limits height reduction a tillering stage and photoassimilation there by reducing the energy required for rapid growth. The reserved carbohydrate directly involved to produce more tiller production and enhance fertile tiller (ii) the other possible reason for the notable augmentation in fertile tillers number might be attributed to the high levels of cytokinins accompanied by low level of IAA which led to limitation of apical dominance and there by prevent excessive vegetative growth. Also Mekki and Orabi (2007) reported that PBZ application may prevent excessive vegetative growth and improve translocation of photosynthates from source to sink. Similar to this finding Bahrami *et al*. (2014a) found that height reduction led to higher tiller survival and enhanced fertile tillers, which resulted in greater yield in barley.

Table 10. Means of total tiller of tef plants as affected by rate and stage of application at Debre Zeit during the 2016 main season

Rates (Kg ha^{-1}a.i)	No. of total tillers			Means of rates of PBZ (Overall growth stages)
	Time of application			
	Tillering	Jointing	Panicle emergence	
0	12.33^{c}	12.30^{b}	11.67^{c}	12.10^{b}
1	16.67^{b}	19.00^{ab}	11.00^{c}	15.56^{a}
2	17.33^{ab}	17.67^{ab}	11.33^{c}	15.44^{a}
3	12.67^{c}	17.67^{ab}	12.33^{c}	14.89^{a}
Means of growth stages (Over all rates)	14.75^{b}	17.17^{a}	11.58^{c}	
SEM±	1.36			
CV (%)	9.43			

SEM: standard error of mean

*Means within the same column and within the same treatment category followed by same letters are not significantly different as judged by DMRT at P≤0.05

3.3.2 Thousand seed weight

The analysis of variance showed that the main effect as well as the interaction effects of rate and time of PBZ application was not significant (P > 0.05) on thousand seed weight (Appendix 3).

From this result thousand seed weight of tef was not affected by PBZ application time and rates as well as by their interaction effect. Rajala (2003) opined that grain weight remain unaffected or slightly reduced by plant growth regulators. According to Khaje *et al*. (2008) thousand seed weight mainly depends on carbohydrate reserved at initiation of grain filling and plant genotype. Cultivar affects on increased weight of thousand grains, maximum weight of each grain is among the properties dependant on plant genotype. In his study, it was indicated that plant growth regulators didn’t show significant difference in respect of weight of thousand grains of barley. From the result of this study it can be concluded that the weight of thousand seed weight of tef is affected by genotype of plant and not by utilized input that was used. In general mean thousand weights of cereals in almost stable yield components of cereals and in lower rate affected by environmental factors (Pirasteh *et al*., 2016). In teff, PBZ application increased thousand seed weight of by enhancing starch synthesis (Tekalign, 2007).

3.3.3 Biomass yield

The biomass yield was significantly (P<0.01) influenced by the interaction effect of rate and time of PBZ application (Table 11 and Appendix 4). Biomass yield generally decreased significantly and progressively with increase in the rate of PBZ treatments especially when applied at tillering and jointing stages. The highest biomass yield (13,090kg) was obtained from the plants that are not treated with PBZ followed by plants sprayed with 1kg a.i ha^{-1} of PBZ at panicle emergence (12,110kg). Whereas the lowest biomass yield was obtained from plants treated with 2 or 3kg a.i ha^{-1} of PBZ at tillering stage which reduced biomass yield by 24% over the control. Following this application of the higher rate of PBZ at jointing stage reduced biomass by 18% in comparison to the control. Generally, further increase in rate of PBZ application significantly reduced biomass yield except at panicle emergence stage (Table 11).

The main effects of PBZ rate were significant (P<0.01) on biomass yield. The highest biomass reduction was recorded from plants receiving 3kg a.i of PBZ ha^{-1} which reduced biomass yield by 17%, followed with 2kg and 1kg a.i of PBZ ha^{-1} which reduced biomass yield by 17% and 11% in comparison to the control (Table 11). The analysis of variance also showed that main effects of time application of PBZ significantly (P<0.01) reduced biomass yield. The highest biomass yield (12,160kg) was recorded from plants that receive PBZ at panicle emergence; the next highest biomass yield (11,660kg) was recorded from jointing stage of application of PBZ while the lowest (10,880kg) was obtained from the earliest stage of application of PBZ (Table 11).

PBZ application decrease total biomass yield of tef particularly when applied at tillering and jointing stage. Similar results have been reported on potato biomass yield reduction due to application of PBZ (Tekalign and Hammes, 2005). This might be attributed due to the collective effect of having shorter plants with reduced culm length and plant height. Contradicting results have been reported by Mohammadi *et al.* (2011) on Canola

(*Brassica napus* L.) and Hagazi and Elshraiy (2007) on bean found that foliar applications of PBZ increased biomass yield. Some of the reasons which cause inconsistency between this experiment and the result given by the other researchers might be the concentration of growth moderators, application method, application time, application number, the formula of used substance, and type of plant growth regulators (Pirahmadi *et al*., 2016).

Table 11. Means of biomass of tef plants as affected by rate and stage of application of PBZ at Debre Zeit during the 2016 main season.

Rates ($Kg\ ha^{-1}a.i$)	Biomass yield ($kg\ ha^{-1}$) Time of application			Means of rates of PBZ (Overall growth stages)
	Tillering	Jointing	Panicle emergence	
0	13090^{a}	13050^{a}	12830^{a}	12990^{a}
1	10760^{d}	11730^{b}	12110^{b}	11530^{b}
2	9930^{e}	11170^{c}	11880^{b}	10990^{c}
3	9730^{e}	10700^{d}	11810^{b}	10740^{d}
Means of growth stages (Over all rates)	11570	11660^{b}	12160^{a}	
SEM±	0.22			
CV (%)	1.97			

SEM: standard error of mean

*Means within the same column and within the same treatment category followed by the same superscript letters are not significantly different as judged by DMRT at P≤0.05

3.3.4. Grain Yield

The analysis of variance showed that grain yield of tef was significantly ($P < 0.01$) influenced by the interaction effect of rate and time of PBZ application (Table 12and Appendix 4). The highest grain yield (3,800kg) was obtained from the plants treated with rate of 1kg a.i of PBZ ha^{-1}at jointing stage which increased grain yield by 20.7% (Table 12). This was followed by plants treated with 2 kg a.i of PBZ ha^{-1}at jointing stage (3,470kg). But further increase in rate of PBZ spray at tillering stage, there was no appreciable change with respect to yield (Table 12). At panicle emergence stage application, PBZ concentration did not cause any increment in the grain yield, rather the grain yield was found to decrease with increased rate of PBZ spray.

Table 12. Means of grain yield of tef plants as affected by rate and stage of application of PBZ at Debre Zeit during 2016 main season.

Rates ($Kg\ ha^{-1}a.i$)	Grain yield ($kg\ ha^{-1}$) Time of application			Means of rates of PBZ (Overall growth stages)
	Tillering	Jointing	Panicle emergence	
0	3110^{cde}	3010^{e}	2980^{e}	3030^{d}
1	3420^{b}	3800^{a}	3140^{cde}	3460^{a}
2	3180^{cd}	3470^{b}	3070^{ed}	3240^{b}
3	3120^{cde}	3250^{c}	3050^{ed}	3140^{c}
Means of growth stages (Over all rates)	3210^{b}	3380^{a}	3060^{c}	
SEM±	0.08			
CV (%)	2.76			

SEM: standard error of mean

*Means within the same column and within the same treatment category followed by the same superscript letters are not significantly different as judged by DMRT at P≤0.05

In general further increase in rate of PBZ spray reduced yield and applying lower rate resulted in higher yield than intermediate and highest rates (Table 12). Likewise, the main effects of both rates and time of application influenced yield significantly ($P<0.01$). The lower rate of PBZ at 1kg a.i ha^{-1} gave highest yield (3,460kg) followed by the intermediate (3,240kg) and highest rate (3,140kg). This implies that further increase in the doze of PBZ was found to decrease yields. On the other hand, time of application significantly affected yields, among the three different stages of application PBZ spray at jointing stage (3,380kg) give the highest grain yield than that at tillering (3,210kg) panicle emergence (3,060kg) stages (Table 12).

The positive effect of PBZ application on grain yield improvement of tef relies on a number of yield attributing traits including number of fertile tiller, fertile florets and better plant canopy has been showing in number of studies evaluating the production potential of cereals. The increment in grain yield of tef, due to PBZ treatments might be (i) through the initiation of more fertile tiller per plant resulting in more grain yield production. Similar studies indicated that PBZ increased grain yield of winter wheat (Shekoofa and Emam, 2008) by increasing fertile tiller and higher grain number. In field experiments, application of growth regulators at mid-tillering stage increased grain yield of spring barley 10 %to 17% and increased grain yield of winter barley 12 to

18 %. The reason for this increase in grain yield was the increase of spike number per unit area (Heidari and kavousi, 2013), (ii) the other possible reason for increment of grain yield might be due to altered phenology (days to maturity) that might have enhanced photosynthesis for longer time which in turn contributed to better plant productivity in tef (iii) decreased plant height can cause increase plants resistance against factor like lodging and plants reducing which itself cause the decrease of yield (Mohaghegh *et al*., 2007). Contradicting result has been reported by El-Khallal *et al*. (2009) who found foliar application of PBZ under favorable moisture conditions decrease maize grain yield due to an increase in the concentration of abscisic acid hormone. The mentioned hormone (Abscisic acid) reduces grain yield through reducing the number of endosperm cells, followed by decreasing grain size and also motivating for embryonic loss, and decreasing grain number.

3.3.5 Straw yield

Straw yield was significantly (P<0.01) affected by both main effects as well as the interaction effects of rate and time of PBZ application (Table 13 and Appendix 4). It was observed that application of PBZ reduced straw yield. The highest straw yield (10,000kg) was obtained from untreated plants followed by late application with combinations of 1 or 2 kg a.i of PBZ ha^{-1} (8,840kg) and the lowest straw yield (6,670kg) was obtained from plants that treated with 2 or 3kg and1kg a.i of PBZ ha^{-1} at tillering stage. In general it was observed that further increase in concentration of PBZ reduced straw yield at tillering stage and no appreciable change occurred with applications at jointing and panicle emergence stages (Table 13).

It was observed that increase the rate from 0 to 1kg and 1 to 2kg a.i of PBZ reduced straw yield by 18.9 % and 4%. But further increase in concentration did not significantly reduced straw yield. Regarding, the time of application PBZ treatment was decreased straw yield more when sprayed at tillering (7,670kg) followed by application at jointing (8,280kg) and panicle emergence stages (9,100kg) (Table 13).

Table 13. Means of straw yield of tef plants as affected by rate and stage of application of PBZ at Debre Zeit during the 2016 main season.

Rates (Kg ha^{-1}a.i)	Straw yield (kg ha^{-}) Time of application			Means of rates of PBZ (Overall growth stages)
	Tillering	Jointing	Panicle emergence	
0	9980^{a}	10040^{a}	9850^{a}	9960^{a}
1	7340^{d}	7930c	8970^{b}	8070^{b}
2	6750^{e}	7700^{cd}	8810^{b}	7750^{c}
3	6610^{e}	7450^{d}	8760^{b}	7600^{c}
Means of growth stages (Over all rates)	7670^{c}	8280^{b}	9100^{a}	
SEM±	0.21			
CV (%)	2.54			

SEM: standard error of mean; LCR: least critical range

*Means within the same column and within the same treatment category followed by the same superscript letters are not significantly different as judged by DMRT at P≤0.05

The reduction in straw yield due to the application of PBZ might be attributed from shorter plant height and from better assimilate portioning, which favor the grain development since PBZ inhibit vegetative growth. Similar result reported by Espindula *et al*. (2009) who said that PBZ can alter the growth and developmental processes, leading to reduce vegetative growth (plant height and straw) ,increased yield, improved grain quality or facilitated harvesting.

3.3.6 Harvest index

Harvest index was significantly (P<0.01) affected by the interaction of rate and time of PBZ application (Table 14 and Appendix 4). The highest harvest index (32%) was obtained from plants treated with the lowest rate of 1kg a.i ha^{-1} PBZ application at jointing stage and tillering stages which improved harvest index by 28% in comparison to the control. The lowest harvest index (23%) was obtained with late stage PBZ application (25%) with no significant difference among rates. The analysis of variance also indicated that the main effects of both time and rate of PBZ application were significant on harvest index (Table 14 and Appendix 4). Harvest index was improved by concentration of PBZ application and the highest harvest index (30.01%) was obtained from plants treated with 1kg a.i of PBZ ha^{-1} which increased harvest index by 23% in comparison to the control (Table 14). But with increased rates of PBZ application harvest index was not significantly affected. Overall rates of PBZ application harvest index values of statistically comparable and highest for applications at tillering (29.84%) and jointing stage (29.28%) and lowest (25.24%) for sprays at panicle emergence (Table 14).

Harvest index of tef plants was found increased due to PBZ application .This might be attributed to better partitioning coefficient in which plant growth regulators are known to promote distribution of photoassimilate and changed the pattern of assimilate distribution towards reproductive part especially to upper parts of the plant thus increasing their sink capacity which leading higher yield, improved harvest index. Similar to this result PBZ application altered the distribution of dry matter in favor the grain and increased grain yield and harvesting index

(Hussain *et al*., 2009).

Table 14. Means of harvest index of tef plants as affected by rate and stage of application of PBZ at Debre Zeit during the 2016 main season.

Rates (Kg ha^{-1}a.i)	Harvest index (%) Time of application Tillering	Jointing	Panicle emergence	Means of rates of PBZ (Overall growth stages)
0	23.76^{d}	23.07^{d}	23.23^{d}	23.33^{b}
1	31.79^{ab}	32.03^{a}	25.93^{c}	30.01^{a}
2	32.03^{a}	31.07^{ab}	25.85^{c}	29.49^{a}
3	32.07^{a}	30.38^{b}	25.83^{c}	29.24^{a}
Means of growth stages (Over all rates)	29.51^{a}	28.99^{a}	25.17^{b}	
SEM±	0.57			
CV (%)	2.09			

SEM: standard error of mean

*Means within the same column and within the same treatment category followed by the same superscript letters are not significantly different as judged by DMRT at P≤0.05

3.4 Straw crude Protein Content

The analysis of variance showed significant (P<0.05) interaction between rate and time of PBZ application with respect to straw crude protein content (Table 15 and Appendix 3). The highest straw crude protein content (9.21%) was obtained from plants that treated with 1 kg ha^{-1}a.i. PBZ at jointing stage followed by the intermediate rate of 2 kg a.i. ha^{-1}(9.13%) applied at jointing. The main effects of PBZ rate significantly influenced straw crude protein content of the tef plants. Applying a.i of PBZ from 0 to 1kgha^{-1} increased crude protein content of tef straw by 31% and further increase from 2 to 3kg PBZ increased it only by 6% while further increased in PBZ rates from 2kg a.i. ha^{-1} didn't influence straw crude protein content. On the other hand, time of application also affected straw crude protein content such that averaged overall rates the highest mean value of 8.16% occurred with application at jointing followed by significantly diminishing order with sprays at tillering (7.21%) and at panicle emergence (6.34%) (Table 15).

The increased value of straw crude protein content of tef plant due to PBZ application might be attributed from PBZ which help to releases their amino acid from their storage and there by increases protein. Sawan (2008) reported that the primary effect of plant growth regulators is affecting GA, sterols and ABA biosynthesis and they indirectly affects starch percentage; as result protein increased. There are similar reports which indicate that PBZ increases the amount of proteins in wheat (Nouriyani, 2012), brassica (Razavizadeh and Amu, 2013). Also Campell (2008) observed that PBZ enhance level of cytokinin which in turn prevents protein degradation and promotion of protein synthesis which have resulted an increase protein content of the plant.

Table 15. Means of straw crude protein content of tef plants as affected by rate and stage of application of PBZ at Debre Zeit during the 2016 main season.

Rates (Kg ha^{-1}a.i)	Straw crude protein content (%) Time of application Tillering	Jointing	Panicle emergence	Means of rates of PBZ (Overall growth stages)
0	5.22^{f}	5.19^{f}	5.18^{f}	5.19^{c}
1	7.35^{c}	9.21^{a}	6.16^{e}	7.57^{b}
2	8.12^{b}	9.13^{a}	7.02^{d}	8.09^{a}
3	8.14^{b}	9.12^{a}	7.00^{d}	8.09^{a}
Means of growth stages (Over all rates)	7.21^{b}	8.16^{a}	6.34^{c}	
SEM±	0.06			
CV (%)	2.27			

SEM: standard error of mean; LCR: least critical range

*Means within the same column and within the same treatment category followed by the same superscript letters are not significantly different as judged by DMRT at P≤0.05

3.5 Effects on lodging index

A significant interaction between time and rate of PBZ application was observed with respect to lodging index (Fig.2).Remarkable reduction (36.7%) in lodging due to PBZ application with sprays rate of 2kg a.i ha^{-1} at tillering and jointing in comparison to the control, while late application of 3kg a.i of PBZ ha^{-1}reduced lodging by 20% (Fig.3). It was also observed that further increase in the concentration of PBZ leads to linear reduction in lodging index (Fig. 4). In addition, intermediate and higher rate of PBZ application did not significantly influence lodging when sprayed at tillering and jointing stages, while late application of PBZ significantly affect lodging in all rates.

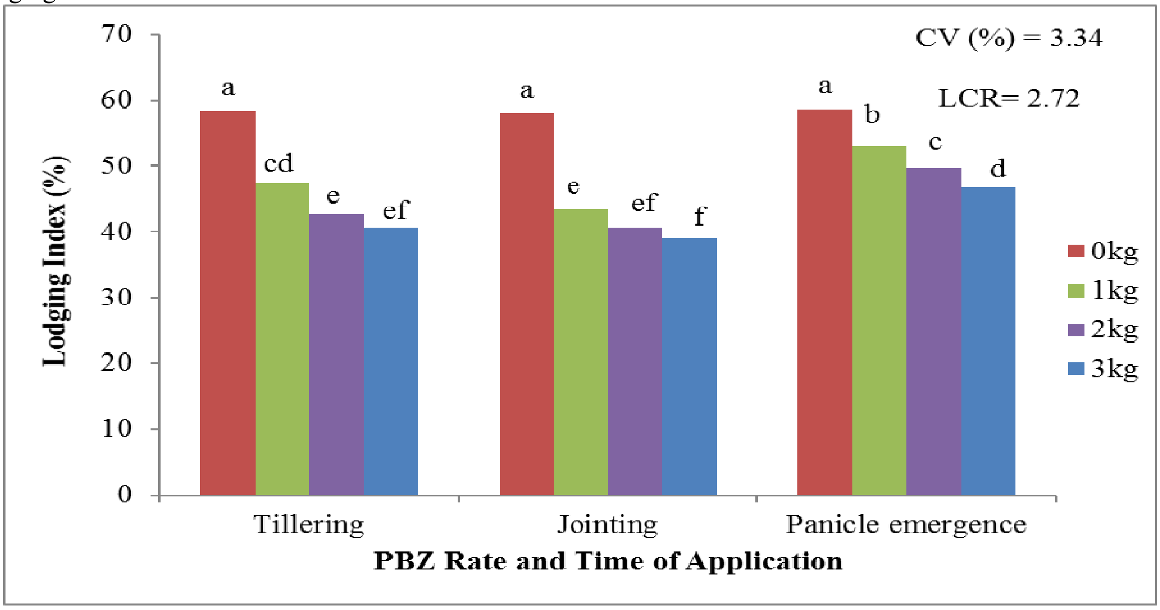

Fig 3. Lodging index as affected by PBZ rate and time of application.

The main effects of both rate and time of application were also significant in affecting lodging index. The highest lodging reduction was observed from plants that treated with 3kg a.i of PBZ which reduced lodging by 27.8%, followed 2kg a.i of PBZ which reduced lodging by 24%.The lower rate of PBZ application at 1 kg a.i ha^{-1} PBZ contributed 18% reduction in lodging index in comparison to the control. Regarding stage of application PBZ treatment reduced lodging effectively when applied at the jointing stage (45%) compared to the other two stages. Next to jointing application of PBZ at earlier at tillering stage (47%) reduced lodging of tef plants more than late application (52%).

The relationship between PBZ concentration and lodging index are linear. Lodging index was described by the equation Y= -5.22x + 56 which means that for every unit increase in the concentration of PBZ (kg), lodging index decreased by 5.22 unit (Figure 4).

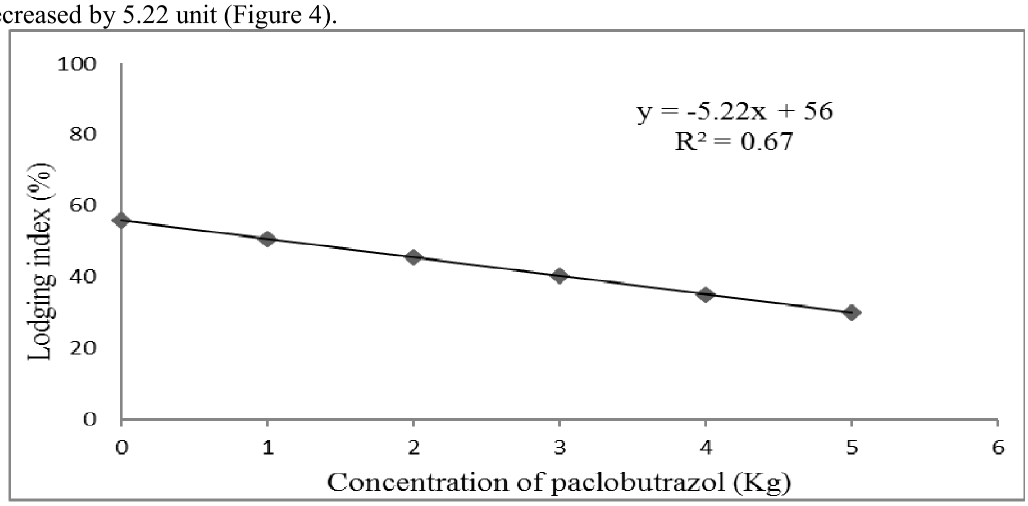

Fig .4. Relationship of PBZ concentration and lodging index

Lodging incidence during grain filling time considerably reduces grain filling capacity of crop and PBZ application reduces the lodging intensity (Rajala, 2003). The reduction of lodging due to PBZ application might be associated with reduction of excessive vegetative growth and plant height. This idea strengthen by Espindula *et al*. (2009) who reported that using short stature cultivars or plant growth regulators have more strength to resist lodging than tall stems.. Similar reports on different crop depicted that foliage application of PBZ at early stage reduced lodging and improved grain yield in tef (Tekalign, 2007), wheat (Toyota *et al*.,2010) and pea (Elkoca and Kantar, 2006).

4. CONCLUSIONS

In conclusion plants treated with 1kg a.i of PBZ at jointing stage resulted in more number of fertile tillers, high grain yield and minimized lodging risk. Therefore, this treatment combination can be suggested for use by tef in the study area. However, further validation and demonstrations across multiple environments would be necessary in order to make conclusive recommendation.

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