4

Results

Objective 1

To observe the soil nitrogen and phosphorus mineralization:

- under water deficit condition
- as influenced by organic amendments under water deficit condition

Ammoniacal Nitrogen:

Drought at vegetative stage increased soil ammoniacal nitrogen under cultivation of *Vigna radiata* (up to 100%) followed by *Lathyrus sativus* (50%). In contrast, drought during the reproductive stage resulted in a significant reduction (up to 28%) of the same in both the crops.

Under well-watered conditions, biochar and FYM application increased soil ammoniacal nitrogen (up to 30%) at the vegetative stage (except for biochar application under cultivation of *Lathyrus sativus*). Whereas, both the tested soil amendments (biochar and FYM) reduced ammoniacal nitrogen content (up to 62% and 65%, respectively) under drought with a greater reduction under cultivation of *Vigna radiata*.

Increased (up to 65%) soil ammoniacal nitrogen was noted in both the crops when exposed to drought during the reproductive stage under application of soil amendments, with a higher increment from FYM application. However, irrespective of the crops, both the soil amendments significantly reduced ammoniacal N when exposed to drought at the reproductive stage.

At harvest, a decrease (up to 35%) in soil ammoniacal nitrogen was noted due to drought. However, drought at the vegetative stage of *Vigna radiata* revealed a 27% increase in soil ammoniacal nitrogen. Regardless of the crop, drought at the reproductive stage resulted in a decrease in ammoniacal N (up to 53%) under biochar application, whereas FYM addition increased (up to 40%) it.

Nitrate Nitrogen

Drought at the vegetative stage of *Vigna radiata* reduced soil nitrate nitrogen (up to 28%), but increased it (14%) when the crop was exposed to drought at the reproductive stage. In contrast, drought at vegetative stage of *Lathyrus sativus* increased (up to 63%) soil nitrate N when but decreased (up to 13%) when drought appeared at reproductive stage of the crop.

Application of biochar or FYM as soil amendment under drought (at either of the growth stages) resulted an increased soil nitrate content (up to 2.4x) with higher increment under application of FYM in both the crops. However, a decrease (up to 34%) in nitrate nitrogen content was observed under drought at vegetative stage of *Lathyrus sativus* from application of biochar or FYM as soil amendment.

Drought at either stages of crop growth resulted a decrease (up to 44%) in soil nitrate content at harvest under *Vigna radiata* cultivation. In contrast, increased soil nitrate content (up to 89%) was observed in soil under cultivation of *Lathyrus sativus* irrespective of the drought treatments.

Drought improved soil nitrate content at harvest (up to 115%) under cultivation of *Vigna radiata* with biochar or FYM as soil amendment. Similar results were obtained for *Lathyrus sativus* with FYM (increase of up to 61%) as soil amendment. However, a decline of up to 18% was recorded at harvest under cultivation of *Lathyrus sativus* with biochar as soil amendment.

Soil Organic Nitrogen

Drought at vegetative stage of *Vigna radiata* significantly increased soil organic nitrogen (up to 46%) content but decreased it by 30% when drought appeared at reproductive stage of the crop. Amending the soil with biochar or FYM and exposure to drought during vegetative stage increased soil organic nitrogen up to 33%. However, it decreased by 28% when drought was imposed during the reproductive stage of the crop.

Drought at the vegetative stage of *Lathyrus sativus* reduced soil organic nitrogen (up to 29%) but increased it by 27% when exposed to drought at the reproductive stage of the crop. Amending the soil with biochar or FYM resulted in a decline in soil organic nitrogen (SON) (up to 14%), except for FYM amended soils experiencing drought at the vegetative stage (58% increase) of the crop.

No significant difference in SON was noted at harvest due to drought at vegetative stage of *Vigna radiata*. However, a significant reduction of the same was found in *Lathyrus sativus* cultivated soils. Significant decline in soil organic nitrogen pool was recorded under the application of both the soil amendments under drought treatments in *Vigna radiata*. However, biochar or FYM as soil amendment under exposure to drought at either stage of *Lathyrus sativus* documented increased SON (up to 116%).

Soil Microbial Biomass Nitrogen

Drought at either stage of *Vigna radiata* increased soil microbial biomass N content (up to 116%). However, drought at the reproductive stage of *Lathyrus sativus* reduced it. Addition of biochar and FYM as soil amendment increased MBN up to 245%. Under drought treatment, this increase was up to 124% with a higher increment under FYM application in both the crops.

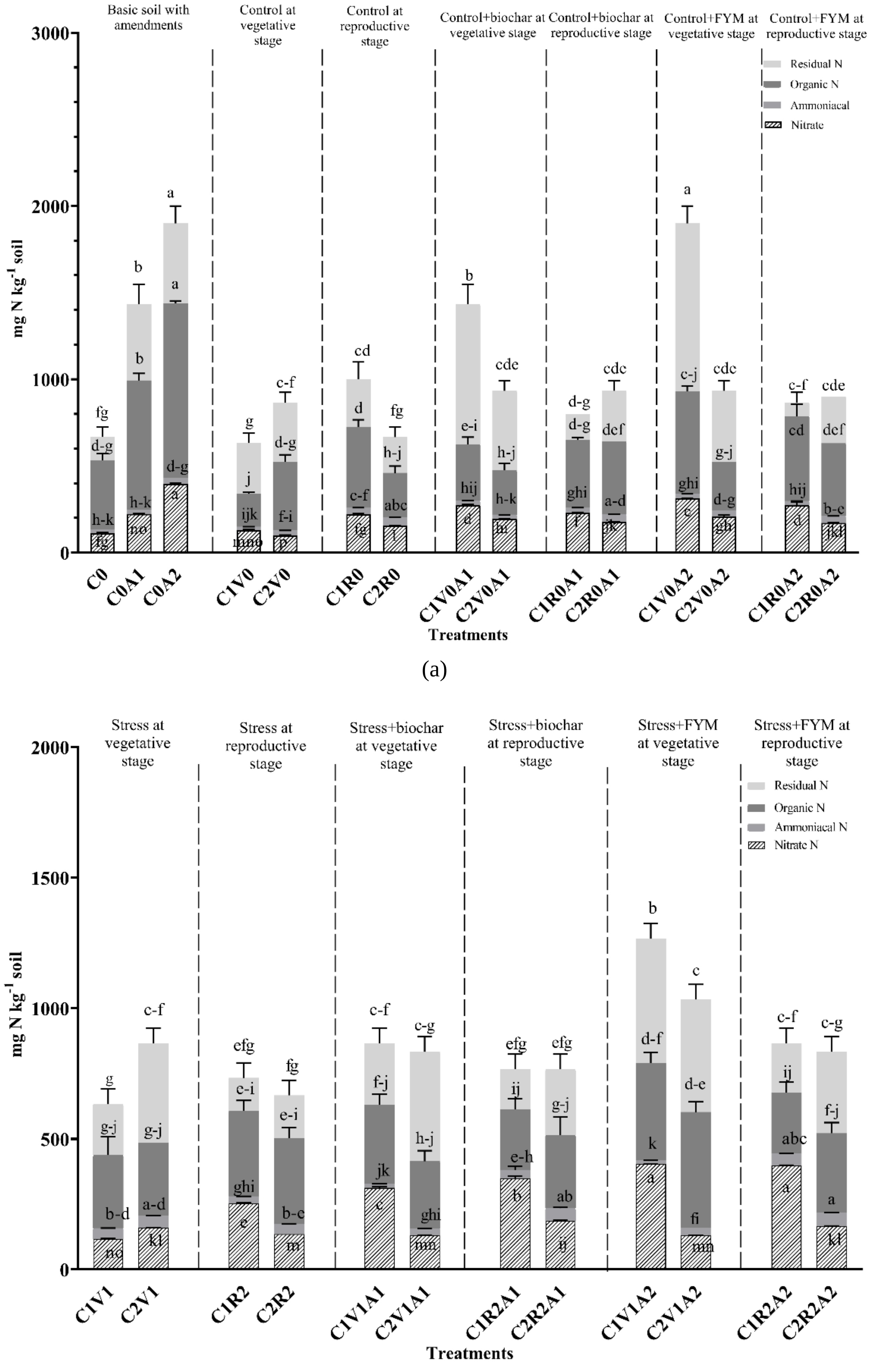
Both the crops when exposed to drought at either stage of crop growth revealed lower soil MBN (up to 45%) at harvest, with the exception from drought at the vegetative stage of *Lathyrus sativus* cultivated soil. Significant increase in MBN content was recorded (up to 3x) due to application of soil amendments (biochar or FYM) under drought with higher increment from application of FYM.

Soil Total Nitrogen

Exposure to drought at either growth stage of both the crops had no significant changes in total nitrogen pool of the cultivated soils. However, drought at the reproductive stage of *Vigna radiata* reduced total soil nitrogen pool (26% decrease),

Amending the soil with biochar or FYM in both the crops, followed by drought treatments resulted in an increase in total soil nitrogen content (up to 100%) with higher increment from FYM application. However, under cultivation of *Lathyrus sativus,* total N reduced (3%) due to drought at vegetative stage in biochar amended soils.

At harvest, increase in soil total nitrogen (of up to 23%) was recorded under drought treatments (at either stage) in both the crops with an exception from drought at reproductive stage of *Lathyrus sativus* cultivated soils (4% reduction). Soils amended with biochar when exposed to drought (at either growth stages of both the crops) experienced up to 26% reduction in total soil nitrogen content.

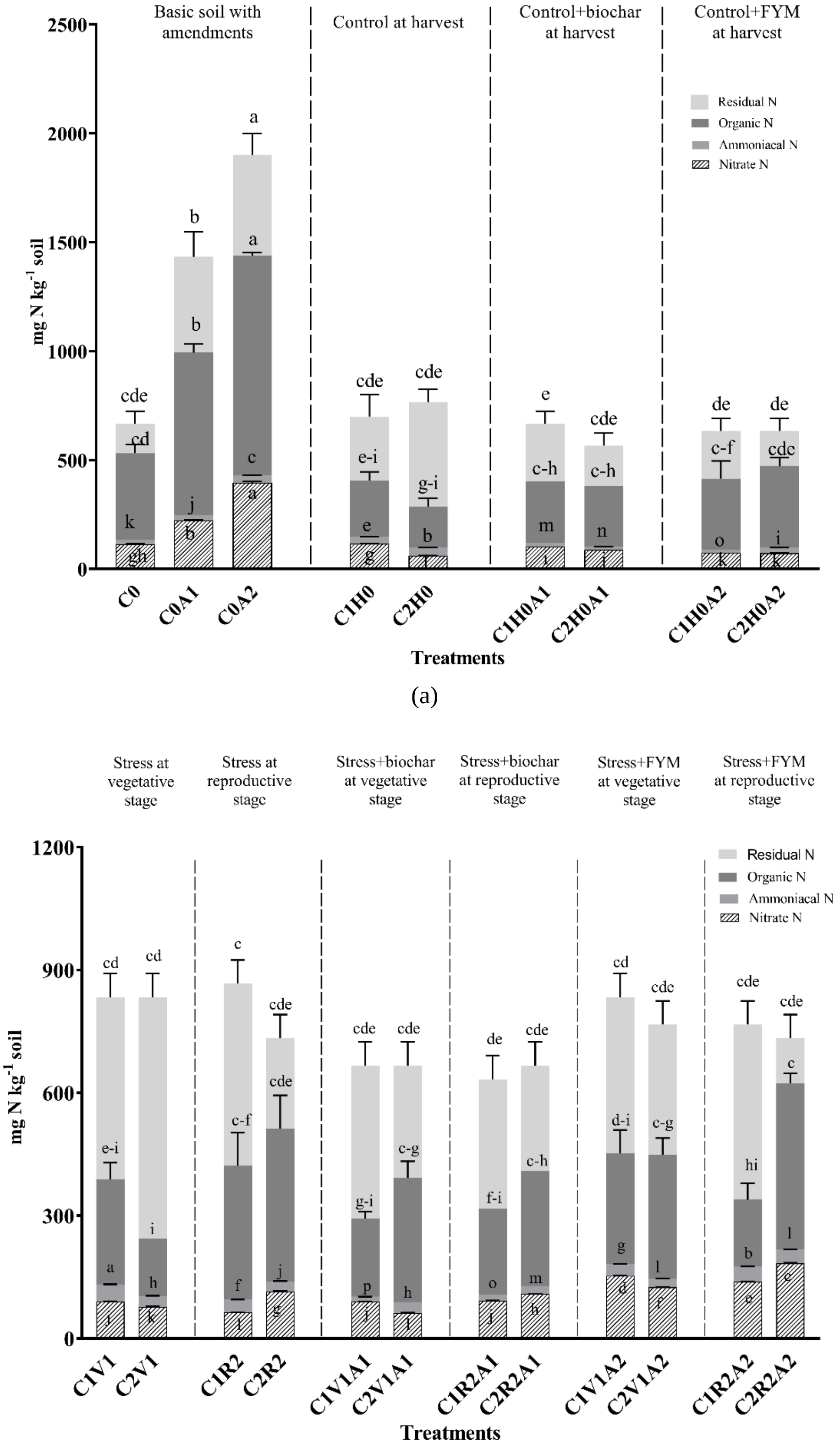


(a)

(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance ($P \leq 0.05$) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.1: Soil total N and its fraction at stress completion as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage

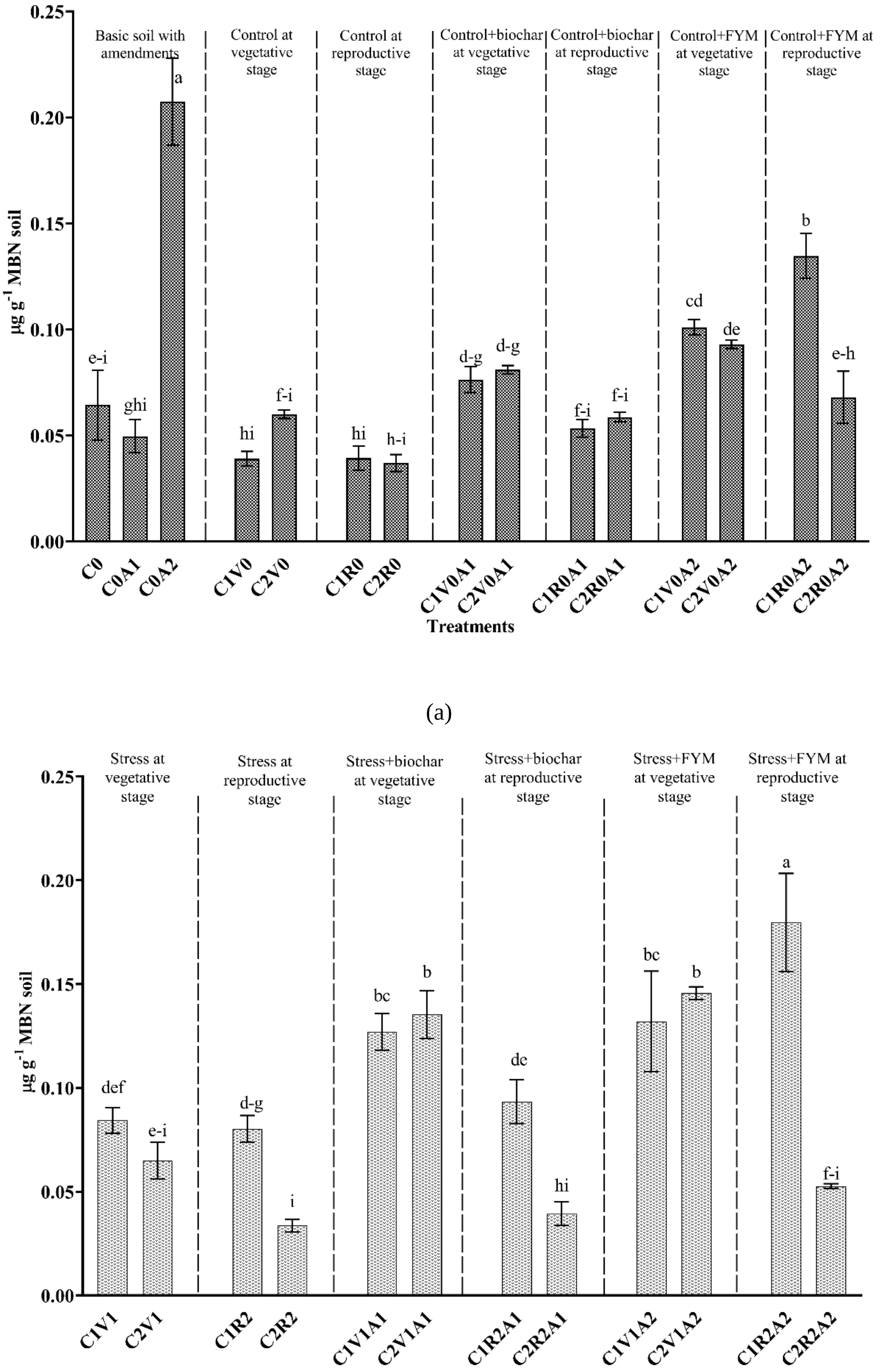


(a)

(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance ($P \leq 0.05$) according to Tukey's Honestly Significant Difference (HSD)

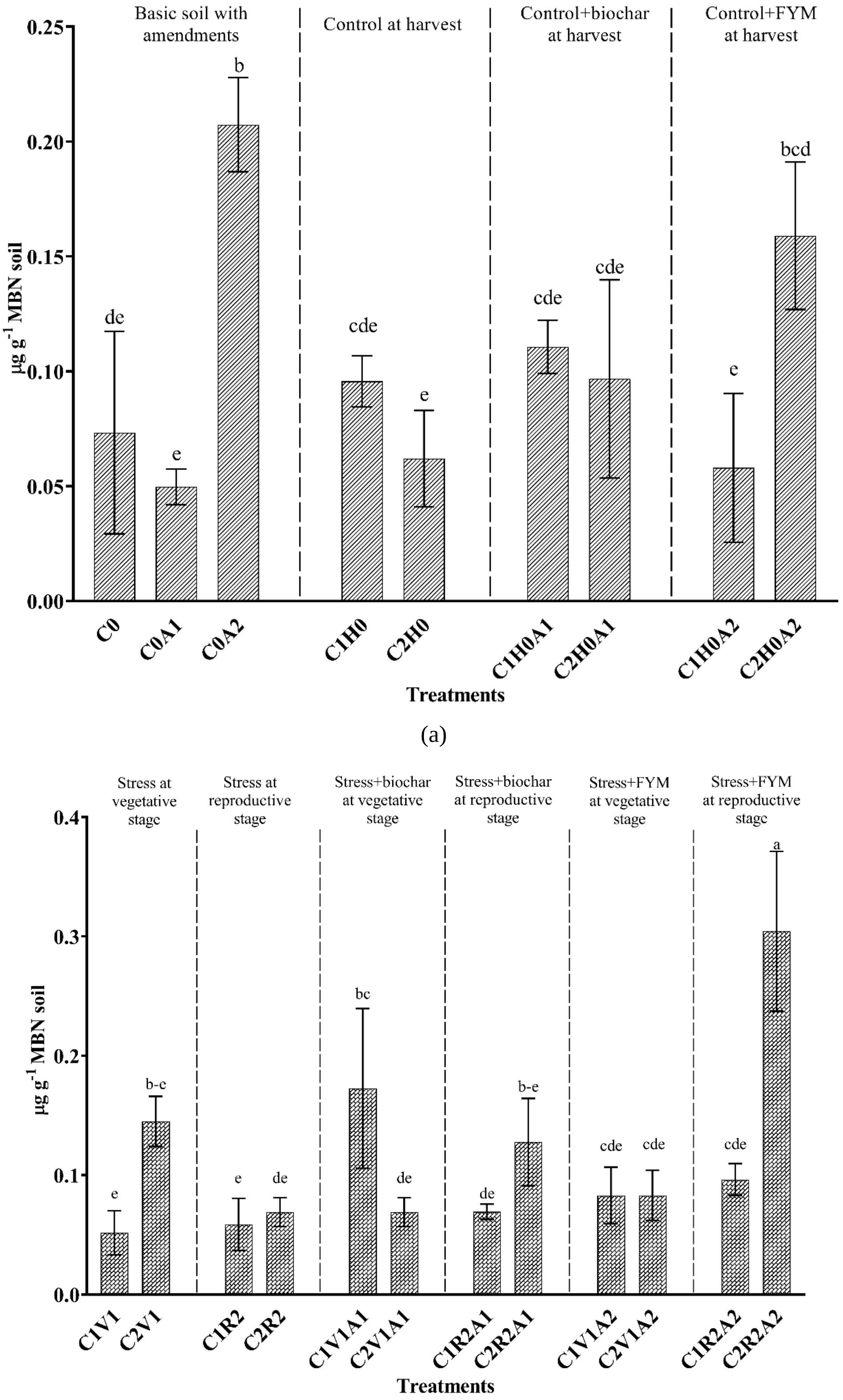
Figure 4.2: Soil total N and its fraction at harvest as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage



(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance (P≤ 0.05) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.3: Microbial biomass N at stress completion as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage



(a)

(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance (P≤ 0.05) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.4: Microbial biomass N at harvest as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage

Phosphorus Fractionation

a. *Labile Fraction*

Drought at the vegetative stage of *Vigna radiata* increased 50% of labile P in the cultivated soil, whereas drought at the reproductive stage revealed no significant difference in the same. Biochar application and drought exposure at either stage reduced labile P (up to 47%). However, under similar conditions, using FYM as a soil amendment increased labile P up to 9% in the cultivated soil.

Similarly, drought at vegetative stage of *Lathyrus sativus* increased 51% of soil labile P, but a decline of 61% was observed when drought appeared at reproductive stage of the crop. Using biochar or FYM as soil amendment under drought at vegetative stage resulted in a decrease of the same (up to 33%) with higher reduction under biochar application. However, an increase of up to 1.5x and 6x was documented under the application of biochar or FYM (respectively) for drought exposure during the reproductive stage of the crop.

At harvest, soils receiving drought at either stage under *Vigna radiata* cultivation showed an increase in soil labile P (up to 2.5x), whereas cultivation with *Lathyrus sativus* showed a decrease of up to 44% under the same conditions.

Using biochar or FYM as soil amendments with drought exposure to the vegetative stage of both the crops reduced soil labile P by up to 41% at harvest. However, the same treatment increased (up to 3x) labile P when drought was imposed at reproductive stage of the crop.

Aluminium bound P

Drought during the vegetative stage of *Vigna radiata* increased Al-P by 3% in the cultivated soil but decreased it by 64% when drought was imposed during the reproductive stage. Regardless of the drought treatments, addition of biochar or FYM as a soil amendment increased Al-P of up to 2.3x and 67% respectively under *Vigna radiata* cultivation.

Contrastingly, a decrease of the same was observed in *Lathyrus sativus* cultivated soils when exposed to drought during the vegetative stage (6%) of the crop. However, an increase was observed when subjected to drought during the reproductive stage (91%). Application of biochar or FYM in *Lathyrus sativus* cultivation with exposure to drought treatments resulted in a reduction of (up to 50%) Al-P, except at the drought during vegetative stage with biochar application (1% increase).

At harvest, decreased Al-P in the cultivated soils was noted due to drought at either stage of *Vigna radiata* crop. Amending the soil with biochar or FYM under same condition resulted an increase (up to 60%) in Al-P, with an exception for drought at the reproductive stage of *Vigna radiata* with application biochar (4% reduction).

Similarly, reduced Al-P was recorded at harvest in *Lathyrus sativus* cultivated soil when exposed to drought during the vegetative stage. However, an increase of 10% was observed when drought was imposed at reproductive stage. Irrespective of drought treatments, the application of biochar and FYM in *Lathyrus sativus* cultivated soils resulted in a decrease of the same at harvest (up to 13%), with the exception of biochar applied treatments under exposure to drought at vegetative stage of the crop (5% increase).

Under well-watered conditions, application of tested soil amendments (biochar and FYM) decreased Al-P (up to 18%) content in soils of both the crop fields.

Fe bound P

Drought at either stage of *Vigna radiata* crop reduced the Fe-P in soil (up to 17%). With similar conditions, under cultivation of *Lathyrus sativus* showed a 3× increase in Fe-P in soil.

The application of biochar or FYM as well as exposure to drought at either of the crop growth stage increased Fe-P (up to 45%) in *Vigna radiata* cultivated soils, especially in biochar application. Whereas, under the similar treatments, cultivation of *Lathyrus sativus* resulted in a decline of Fe-P up to 63% with higher reduction from FYM addition. Regardless of crops or drought treatments, the tested soil amendments increased Fe-P (up to 2.8×) of the cultivated soil when plants received optimum water throughout the growth period.

Except for drought at the vegetative stage of *Vigna radiata* (7% increase), drought at either stage resulted in a decreased (up to 24%) Fe-P in cultivated soils of both the crops at harvest.

Moreover, in *Vigna radiata*-cultivated soils, application of biochar and FYM, as well as exposure to drought during the vegetative stage reduced the Fe-P (6% and 5%, respectively) at harvest. Whereas drought during the reproductive stage increased it (2%

and 5%, respectively). Similarly, in *Lathyrus sativus* cultivated soils increased Fe-P was recorded at harvest due to addition of biochar and FYM (32% and 47% respectively), with an exception in biochar amended soils exposed to drought during the reproductive stage (4% reduction) of the crop.

Reductant Soluble P

Reduced (up to 29%) reductant soluble P was observed in *Vigna radiata* cultivated soils due to drought (at either the vegetative or reproductive stage). Use of biochar or FYM under drought treatments further decreased it by 60% and 1.5×, respectively.

However, under cultivation of *Lathyrus sativus,* drought at the vegetative stage reduced (1.5%) reductant soluble P but increased it when drought appeared at the reproductive stage (4×). Drought at either crop growth stage of *Lathyrus sativus*, the use of biochar or FYM as soil amendment delineated reduced reductant soluble P with higher reduction under FYM application.

Imposition of drought at either stage of both the crops led to a reduction in reductant soluble P in cultivated soil at harvest (up to 60%). Under *Vigna radiata* cultivation, the application of biochar and FYM with drought exposure during the vegetative stage resulted in a decrease of the same (up to 7%), whereas drought during the reproductive stage increased reductant soluble P of the cultivated soil up to 7%.

However, in *Lathyrus sativus* cultivated soils, both the tested soil amendments (biochar or FYM) with drought exposure during the vegetative stage enhanced the reductant soluble P by up to 1.5×. But drought during the reproductive stage further reduced it by up to 1.9%.

Ca bound P

Drought reduced Ca-P (up to 25%) in *Vigna radiata* cultivated soils. Application of biochar or FYM under drought at either growth stage of *Vigna radiata* increased it (up to 37%) with an exception from FYM amended soils in exposure to drought at the vegetative stage (2% reduction) of the crop.

Drought at the vegetative stage of *Lathyrus sativus* increased soil Ca-P by 3%, but exposure to drought at the reproductive stage reduced it by 39%. Use of biochar or FYM under drought at vegetative stage of *Lathyrus sativus* increased the Ca-P (up to 2.6×) in the cultivated soil, but no significant effect was recorded when drought was imposed at reproductive stage of the crop.

Drought affected soils under *Vigna radiata* cultivation increased Ca-P by up to 6% at harvest. When drought was applied at the vegetative stage, soil amended with biochar or FYM resulted in a decrease in the Ca-P (6% and 2%, respectively), but an increase of the same (3% and 2% correspondingly) was observed when drought was applied at the reproductive stage (up to 3%) of the crop.

Under *Lathyrus sativus* cultivation, drought at vegetative stage increased soil Ca-P at harvest (by 21%) but decreased it by 12% when the drought was applied at the reproductive stage of the crop. Soil amended with biochar or FYM with drought treatments resulted in a 30% decrease in soil Ca-P at harvest of the crop, with the exception of FYM amended soils when drought was imposed during the reproductive stage (19% enhancement) of the crop.

Under *Vigna radiata* cultivation both the soil amendments (biochar and FYM) increased Ca bound P (22% and 4%, respectively) in the cultivated soil when plants were supplied with optimum water throughout the growth period. But decreased the same (14% and 21%, respectively) under the cultivation of *Lathyrus sativus*.

Soil Oxidizable Carbon

Reduced soil oxidizable C content (21%) was noted due to drought at vegetative stage of *Vigna radiata* cultivated soil. Whereas, similar conditions during its reproductive stage increased the oxidizable carbon by 9%.

Use of biochar and FYM as soil amendment under drought at vegetative stage of *Vigna radiata* resulted further drop in SOC (up to 13% and 8%, respectively). However, similar treatments at its reproductive stage with biochar or FYM application increased SOC by 50% and 8% respectively.

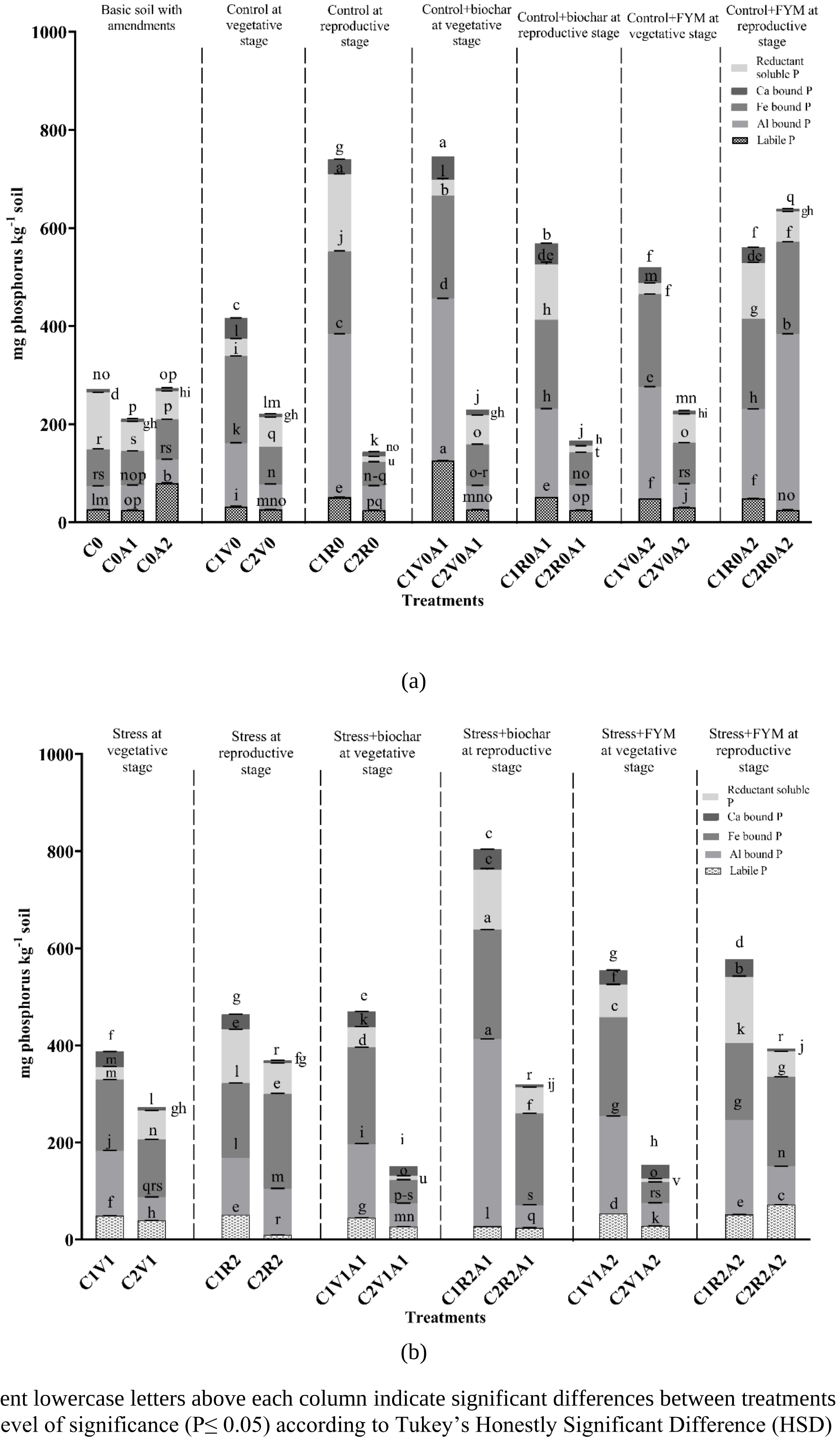
Appearance of drought at vegetative stage of *Lathyrus sativus* cultivation increased SOC by 51%, but no significant change in SOC was noted when drought appeared at the reproductive stage of the crop. Application of soil amendments (biochar or FYM) reduced SOC by 6% and 12%, respectively when drought was imposed at vegetative stage. However, increased (19%) SOC was noted from application of biochar under drought at reproductive stage and FYM in the same situation decreased (8%) SOC of the cultivated soil.

Increased SOC (up to 19%) at harvest was recorded under cultivation of *Vigna radiata* with drought treatments. Whereas, a decrease of the same (up to 11%) was observed under the same situation from *Lathyrus sativus* cultivated soils. Soils amended with biochar and FYM had higher SOC (up to 44%), regardless of the drought treatments and crops. However, drought at vegetative stage of *Vigna radiata* reduced SOC by 24% in the cultivated soil due to application of biochar.

Interactive effects

Total soil N had a strong positive correlation with soil organic N ($P \leq 0.01$; R=0.772), nitrate N ($P \leq 0.01$, R=0.550), MBN ($P \leq 0.05$; R=0.436) and labile P ($P \leq 0.05$; R=0.485). Moreover, soil nitrate N documented a strong positive correlation with MBN ($P \leq 0.01$; R=0.625), labile P, Al-P, Fe-P and Ca-P at $P \leq 0.01$ (R=0.468, 0.440, 0.426, and 0.421 respectively). Significantly strong positive correlation of Al-P was observed with Fe-P, Ca-P and reductant soluble P in cultivated soil. Furthermore, positive correlation of Ca-P was noted with nitrate N ($P \leq 0.05$; R=0.421), labile-P ($P \leq 0.05$; R=0.445), Al-P ($P \leq 0.01$; R=0.616) and Fe-P ($P \leq 0.01$; R=0.530) of the cultivated soil.

At harvest, a significantly strong negative correlation of Ca-P with Al-P ($P \leq 0.01$; R=-0.606) and Fe-P ($P \leq 0.01$; R=-0.717) was noted. Moreover, a strong positive correlation of Fe-P with Al-P ($P \leq 0.05$; R=0.863) and labile P ($P \leq 0.05$; R=0.512) was also documented. Al-P was also found to be positively correlated with labile-P ($P \leq 0.05$; R=0.507) of cultivated soil. Total soil N documented a strong positive correlation with nitrate N and organic N at $P \leq 0.01$ (R=0.885 and 0.874 respectively) of the cultivated soil. Furthermore, significant strong positive correlation was also noted between soil nitrate N and soil organic N ($P \leq 0.01$; R=0.868).

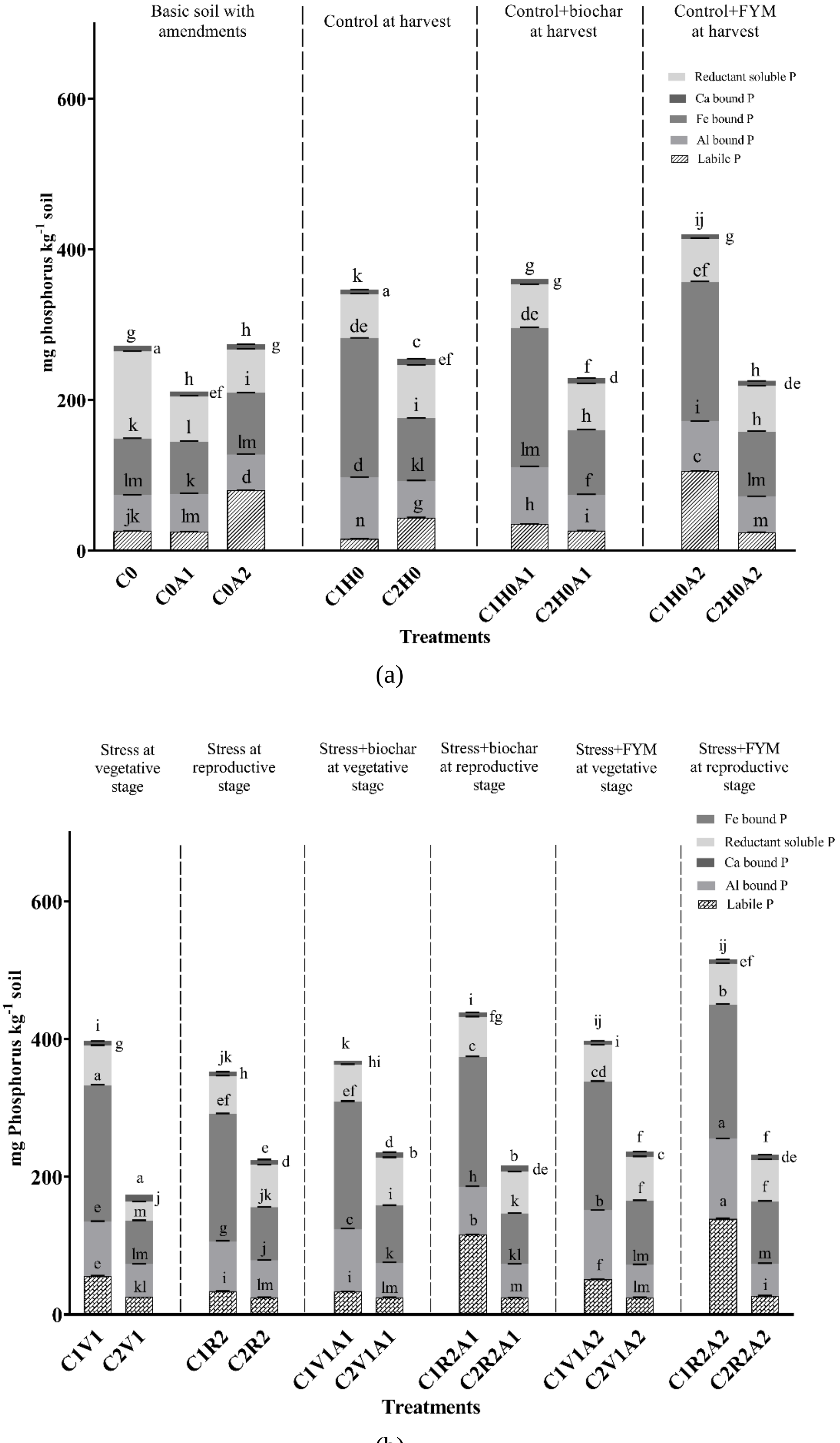


(a)

(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance ($P \leq 0.05$) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.5: Soil phosphorus fractions at stress completion as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage

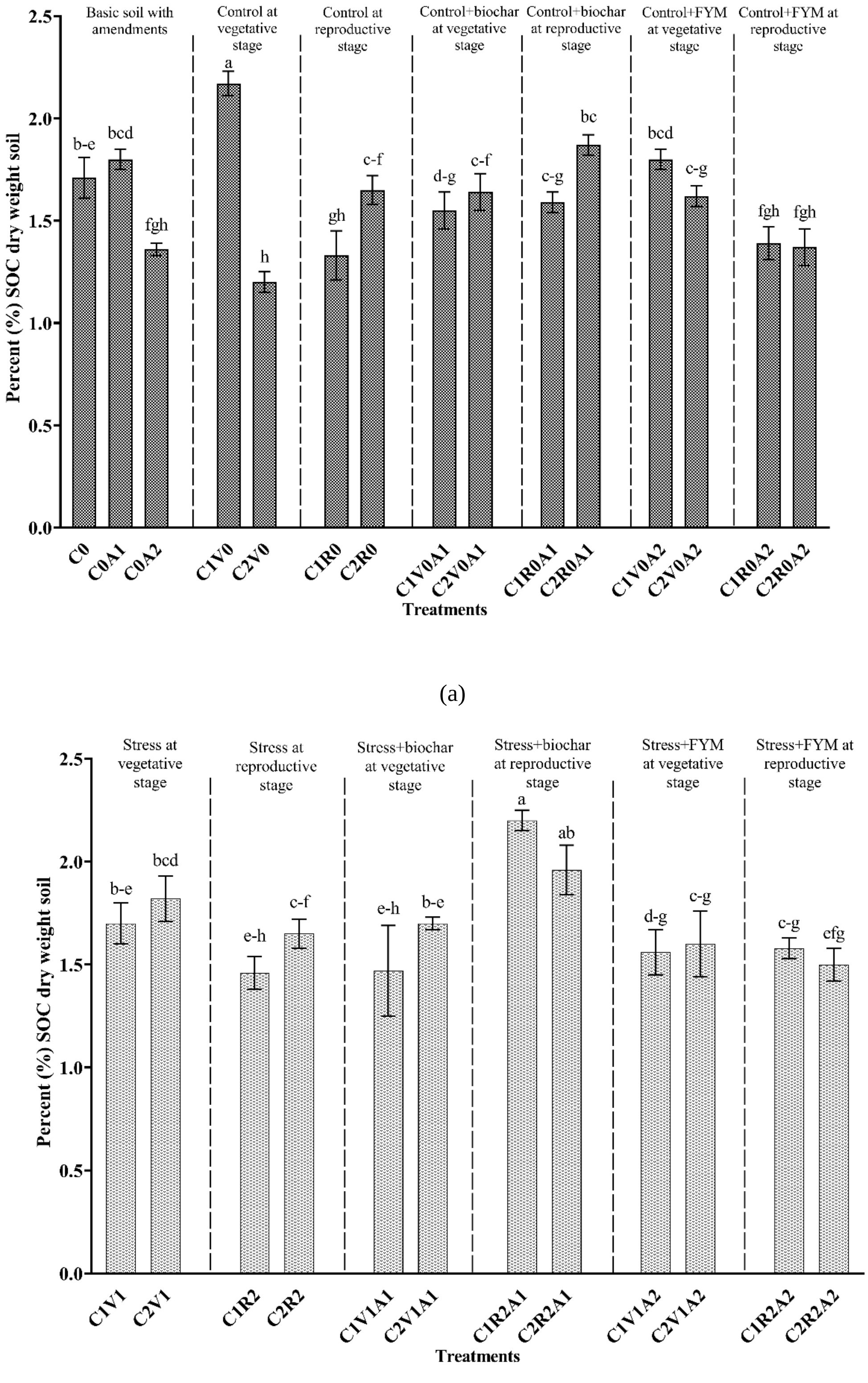


(a)

(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance (P≤ 0.05) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.6: Soil phosphorus fractions at harvest as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage

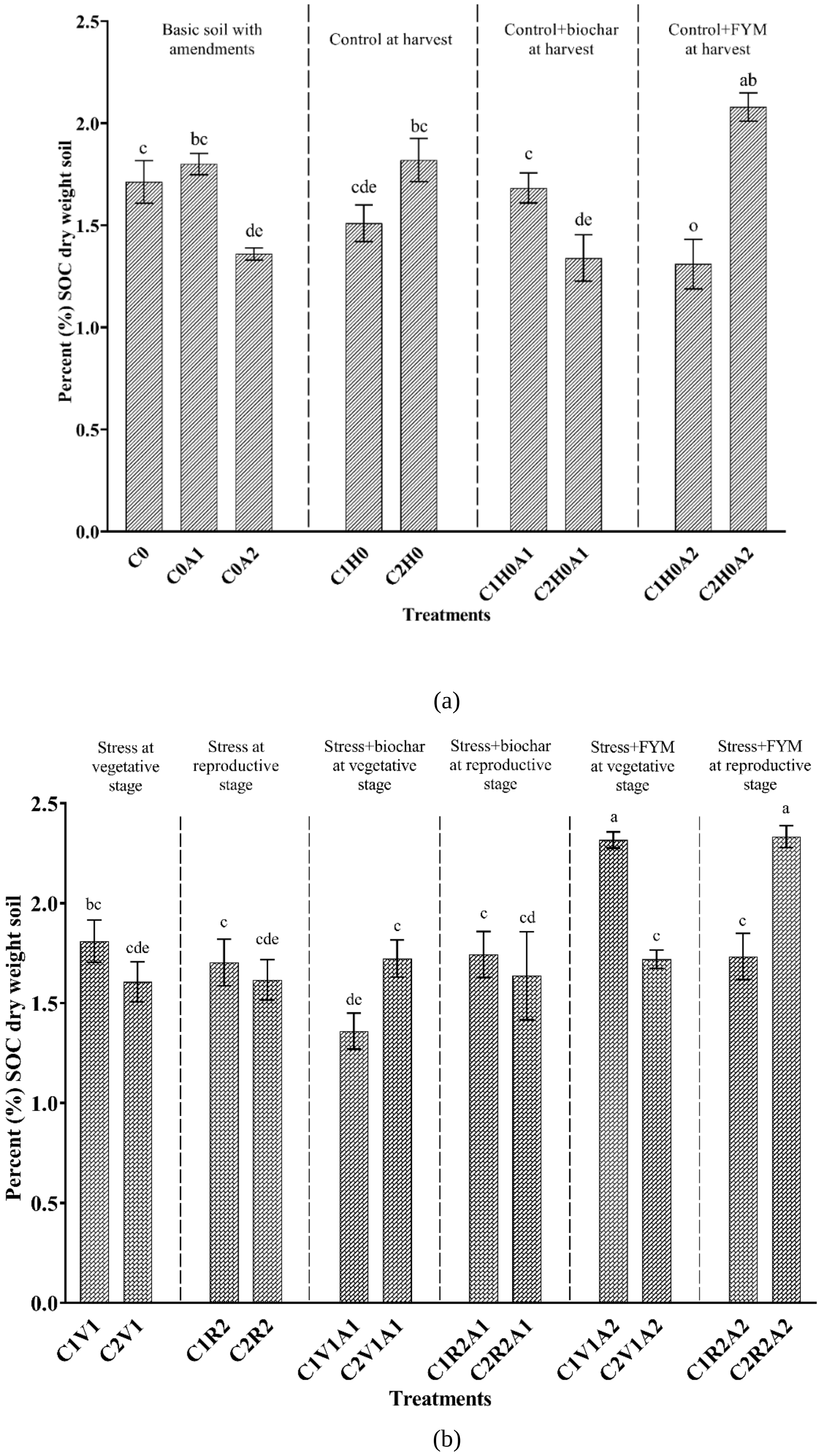


(a)

(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance ($P \leq 0.05$) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.7 Soil oxidizable C at stress completion as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage



*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance (P≤ 0.05) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.8: Soil oxidizable C at harvest as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage

Table 4.1: Table showing correlation matrix amongst soil nitrogen fractions, phosphorus fractions and SOC affected by drought and application of soil amendments at stress completion.

Parameters	Total N	Ammoniacal N	Nitrate N	SON	MBN	Labile P	Al-P	Fe-P	Red-P	Ca-P	SOC
Total N	1										
Ammoniacal N	-0.230	1.000									
Nitrate N	.550**	-0.235	1.000								
SON	.436*	-0.236	.625**	1.000							
MBN	.772**	-0.131	0.323	0.348	1.000						
Labile P	.485*	-0.077	.468*	0.300	0.224	1.000					
Al-P	0.130	-0.129	.440*	0.015	-0.076	0.356	1.000				
Fe-P	-0.022	-0.063	.426*	-0.100	-0.222	0.350	.715**	1.000			
Red-P	-0.178	-0.047	0.360	0.019	0.013	0.061	.418*	0.365	1.000		
Ca-P	0.029	-.428*	.421*	0.218	-0.227	.445*	.616**	.530**	0.234	1.000	
SOC	-0.177	0.025	-0.088	-0.267	-0.324	-0.321	-0.036	0.087	-0.194	0.155	1.000

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

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

Table 4.2: Table showing correlation matrix amongst soil nitrogen fractions, phosphorus fractions and SOC affected by drought and application of soil amendments at harvest.

Parameters	Total N	Ammoniacal N	Nitrate N	SON	MBN	Labile P	Al-P	Fe-P	Red-P	Ca-P	SOC
Total N	1										
Ammoniacal N	0.360	1									
Nitrate N	$.885^{**}$	0.274	1								
SON	$.874^{**}$	0.141	$.868^{**}$	1							
MBN	0.179	0.107	0.428	0.248	1						
Labile P	0.117	0.066	0.167	-0.024	-0.128	1					
Al-P	-0.155	0.155	-0.103	-0.380	-0.183	$.507^{*}$	1				
Fe-P	-0.233	0.029	-0.218	-0.376	-0.237	$.512^{*}$	$.863^{**}$	1			
Red-P	-0.137	-0.051	-0.020	0.136	-0.207	-0.105	-0.216	-0.217	1		
Ca-P	-0.058	0.012	-0.139	-0.143	0.158	-0.378	$-.606^{**}$	$-.717^{**}$	-0.159	1	
SOC	-0.109	0.389	-0.018	-0.091	0.219	-0.134	0.055	-0.041	0.050	0.003	1

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

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

Objective 2

To study the management induced changes in soil biological properties under water deficit conditions.

Soil Arylsulphatase Activity

Imposition of drought reduced soil arylsulphatase activity up to 25% under cultivation of crops *Vigna radiata* and *Lathyrus sativus*. Amending the soil with FYM revealed a higher soil arylsulphatase activity in *Vigna radiata* cultivated soils drought at either stage of the crop (up to 40%) growth as compared to biochar (24%). However, under cultivation of *Lathyrus sativus*, similar treatments resulted a decline of soil arylsulphatase activity (up to 42% and 18% under biochar and FYM, respectively).

Exposure to drought at either vegetative or reproductive stages of both the crops brought contrasting results on soil arylsulphatase activity at harvest. Under *Vigna radiata* cultivation, drought at either stage enhanced soil arylsulphatase activity (up to 1.4×) but reduced the same up to 31% under *Lathyrus sativus* cultivation. Amending the soils with biochar in both the crops and drought at vegetative stage led to a higher (up to 29%) reduction in soil arylsulphatase activity compared to FYM (23%). However, drought at reproductive stage of both the crops with biochar as amendment led to a higher enhancement of soil arylsulphatase activity (up to 63%) as compared to FYM (32%).

Soil *ß*-Glucosidase Activity

Drought reduced (up to 63%) the activity of soil *ß*-Glucosidase under *Vigna radiata* cultivation especially when appeared at reproductive stage of the crop growth. Contrastingly, under *Lathyrus sativus* cultivated soils same treatments led to an increased soil *ß*-Glucosidase activity (up to 100%). With biochar as soil amendment, exposure to drought during the vegetative stage of *Vigna radiata* decreased soil *ß*-glucosidase activity (22%) compared to FYM (27%). However, same treatments increased it up to 1.7× when drought was imposed at reproductive stage of *Vigna radiata*. Under *Lathyrus sativus* cultivation, the use of biochar or FYM as soil amendments reduced *ß*-glucosidase activity by up to 39% regardless of drought treatments. However, same found to increase (9%) under application of biochar with drought at the vegetative stage of the crop.

Significant reduction of soil *ß*-glucosidase activity at harvest (up to 21%) was documented due to drought at either stage of crop growth, except under cultivation of

Vigna radiata exposed to drought at vegetative stage (113% increase). Amending the soil with biochar or FYM reduced soil ß-glucosidase activity under cultivation of both the crops (up to 37%) except in FYM amended soil with cultivation of *Lathyrus sativus* (26% increase). However, both the soil amendments revealed a positive response in ß-glucosidase activity when the crops experienced drought at reproductive stage (up to 90%) with higher increment under FYM application.

Soil Dehydrogenase Activity

Drought at the vegetative stage of *Vigna radiata* cultivation significantly decreased (7%) soil dehydrogenase activity but had no significant effect under drought at reproductive stage of the crop. Application of FYM followed by exposure to drought at either crop growth stages led to a significantly higher enhancement of soil dehydrogenase activity (up to 123%) as compared to biochar (95%).

Imposition of drought during the vegetative stage of *Lathyrus sativus* reduced dehydrogenase activity in the cultivated soils but increased the same under drought at reproductive stage of the crop. Use of biochar or FYM as soil amendment followed by exposure to drought at either growth stage enhanced dehydrogenase activity (up to 9%) with higher increment under FYM application.

Significant increase in soil dehydrogenase activity was noted at harvest of the crop when exposed to drought at either stages of growth. As compared to biochar application, FYM significantly increased (up to 9%) the dehydrogenase activity when drought appeared at either stage of *Vigna radiata* or *Lathyrus sativus*.

Soil FDA Hydrolysis activity

Drought at either growth stages of *Vigna radiata* significantly increased soil FDA hydrolysis activity (up to 49%). Biochar application followed by drought exposure at either stage resulted increased (up to 27%) FDA hydrolysis activity as compared to FYM amended soils. Under well-watered conditions, both the soil amendments increased soil FDA hydrolysis activity (up to 52%) regardless of drought treatments.

Drought at the vegetative stage reduced FDA hydrolysis activity (18%) in *Lathyrus sativus* cultivated soils, but enhanced it when drought appeared during the reproductive stage (6%) of the crop. FYM application and drought at either stage led to a higher (up to 71%) increment in soil FDA hydrolysis compared to biochar (up to 12%). The soil FDA hydrolysis activity increased under well-watered conditions, regardless of crops and drought treatments.

Significant reduction of soil FDA hydrolysis (up to 10%) at harvest was noted due to drought treatments in both the crops. However, in *Vigna radiata* cultivation, drought at vegetative stage increased (22%) the same. Under cultivation of both the crops, amending the soils with FYM revealed higher enhancement (up to 82%) in FDA hydrolysis (regardless of growth stage) activity of soil as compared to biochar (up to 49%). However, an exception of biochar amended soils under exposure to drought at the vegetative stage (up to 31% reduction) was noted.

Phosphomonoesterase Activity

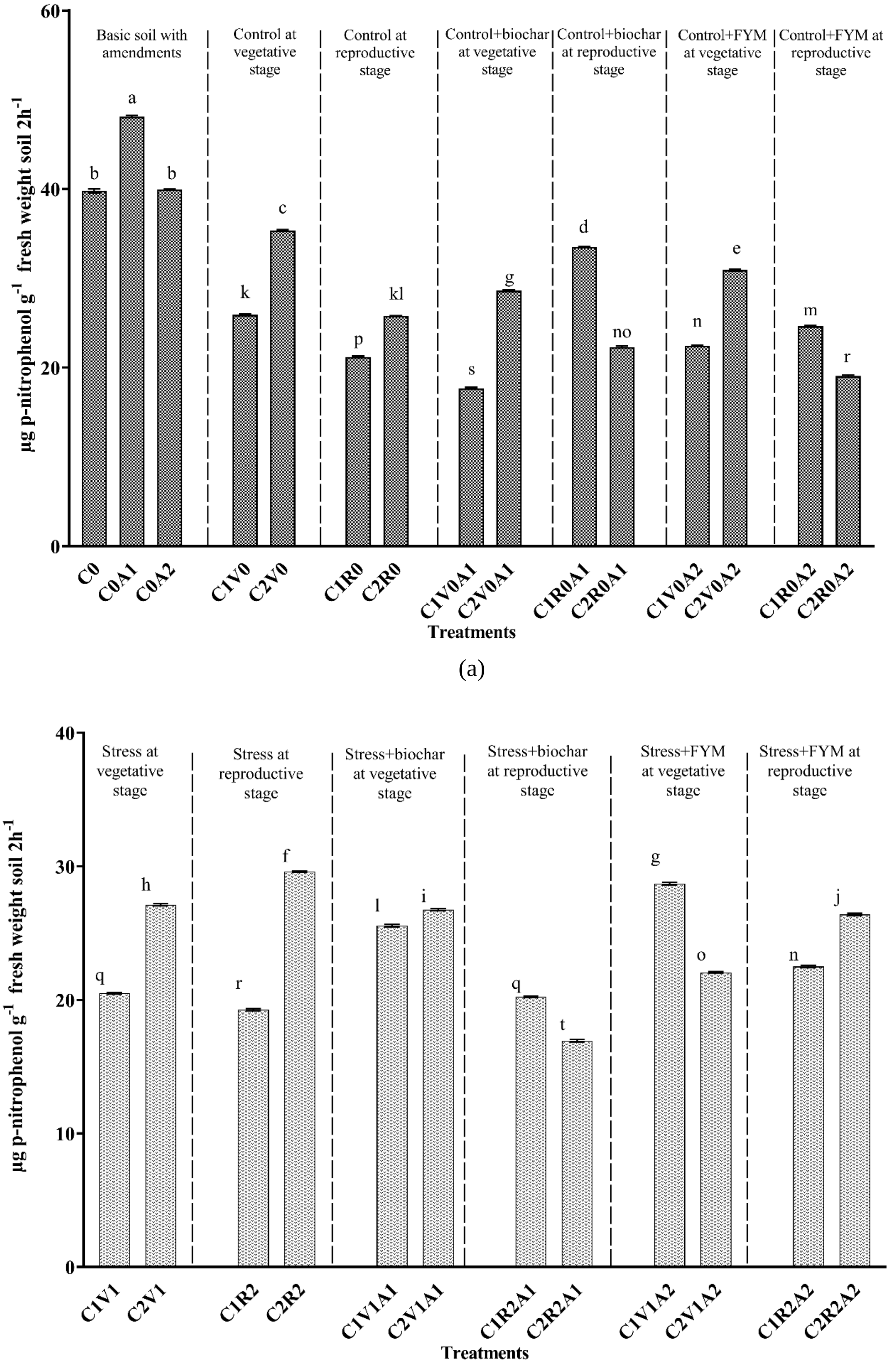
a. *Acid phosphomonoesterase activity:*

Drought at either growth stages of *Vigna radiata* increased the acid phosphomonoesterase activity of the cultivated soil. When exposed to drought at either growth stages, FYM amended soil recorded higher acid phosphomonoesterase activity (47%) compared to biochar (33%) amended soil.

Drought during the vegetative stage of *Lathyrus sativus* increased acid phosphomonoesterase activity (11%) of soil, but it decreased when drought appeared during the reproductive stage (13%). When exposed to drought at either stages of crop, FYM amended soils resulted higher acid phosphomonoesterase activity (up 69%) as compared to biochar (23%). However, an exception was noted in FYM amended soils when the drought was imposed at the vegetative stage of the crop growth.

At harvest, drought showed significant increase in acid phosphomonoesterase activity (28%) in *Vigna radiata* cultivated soils, but a 21% decrease of the same was noted when the drought was applied at the reproductive stage of the crop. FYM addition followed by drought at either stage of *Vigna radiata* recorded higher acid phosphomonoesterase activity (up to 20%) compared to biochar.

No significant change in acid phosphomonoesterase activity was noted at harvest in soils subjected to drought at either stages of *Lathyrus sativus* cultivation. Biochar amended soils exposed to drought at reproductive stage enhanced the acid phosphomonoesterase activity by (33%). In contrast, FYM addition reduced acid phosphomonoesterase activity when subjected to drought during the vegetative stage but increased it when drought appeared at the reproductive stage (10%).

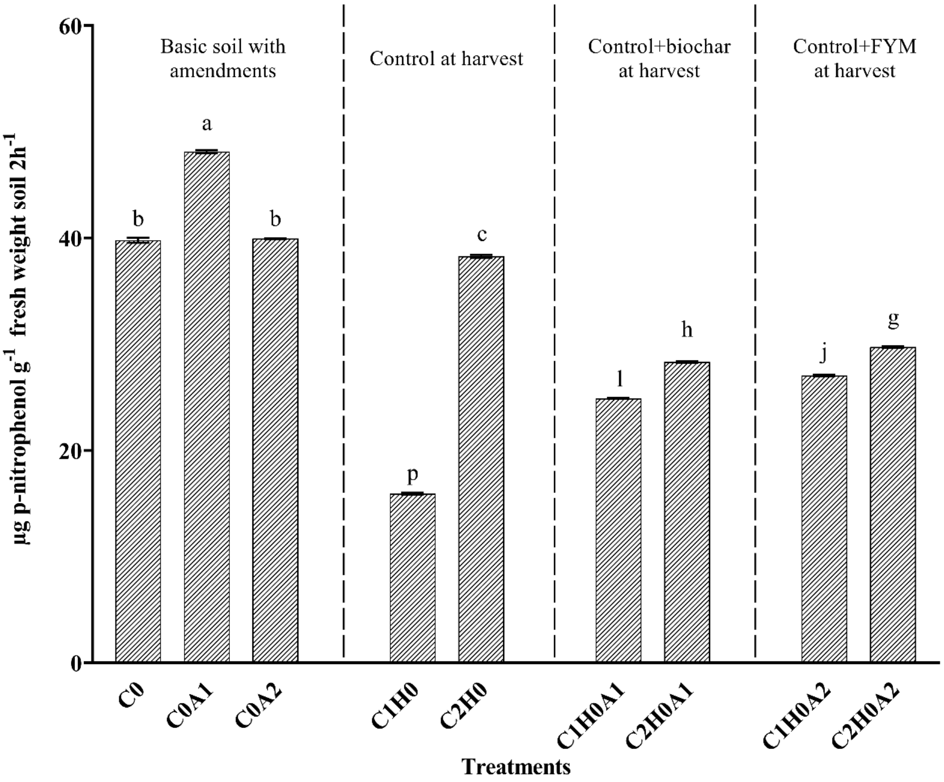


(a)

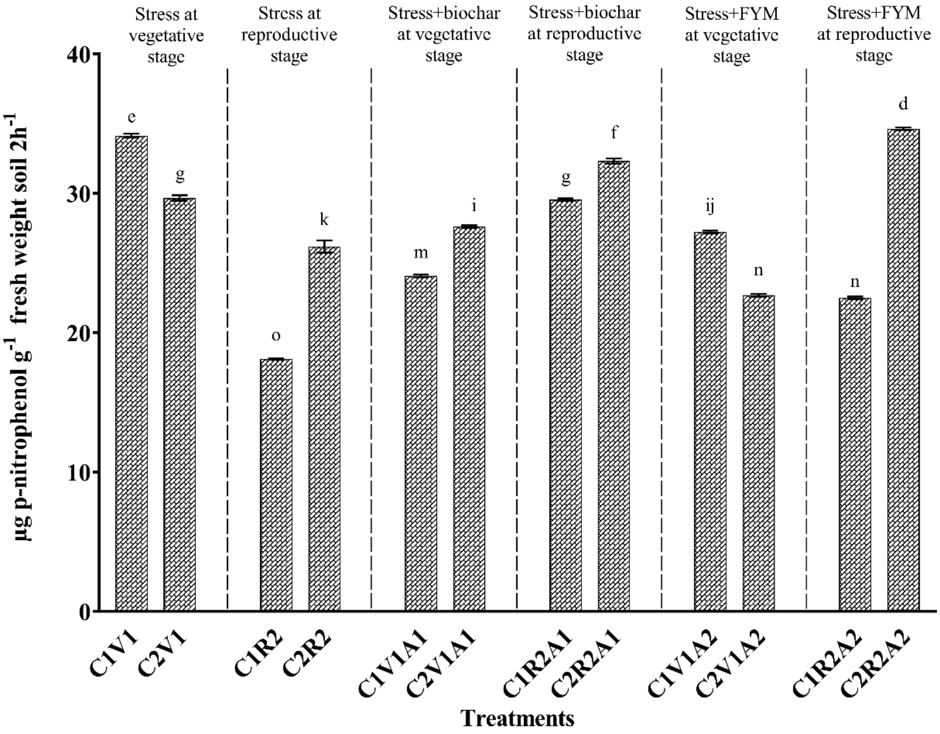
(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance ($P \leq 0.05$) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.9: Arylsulphatase activity at stress completion as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage



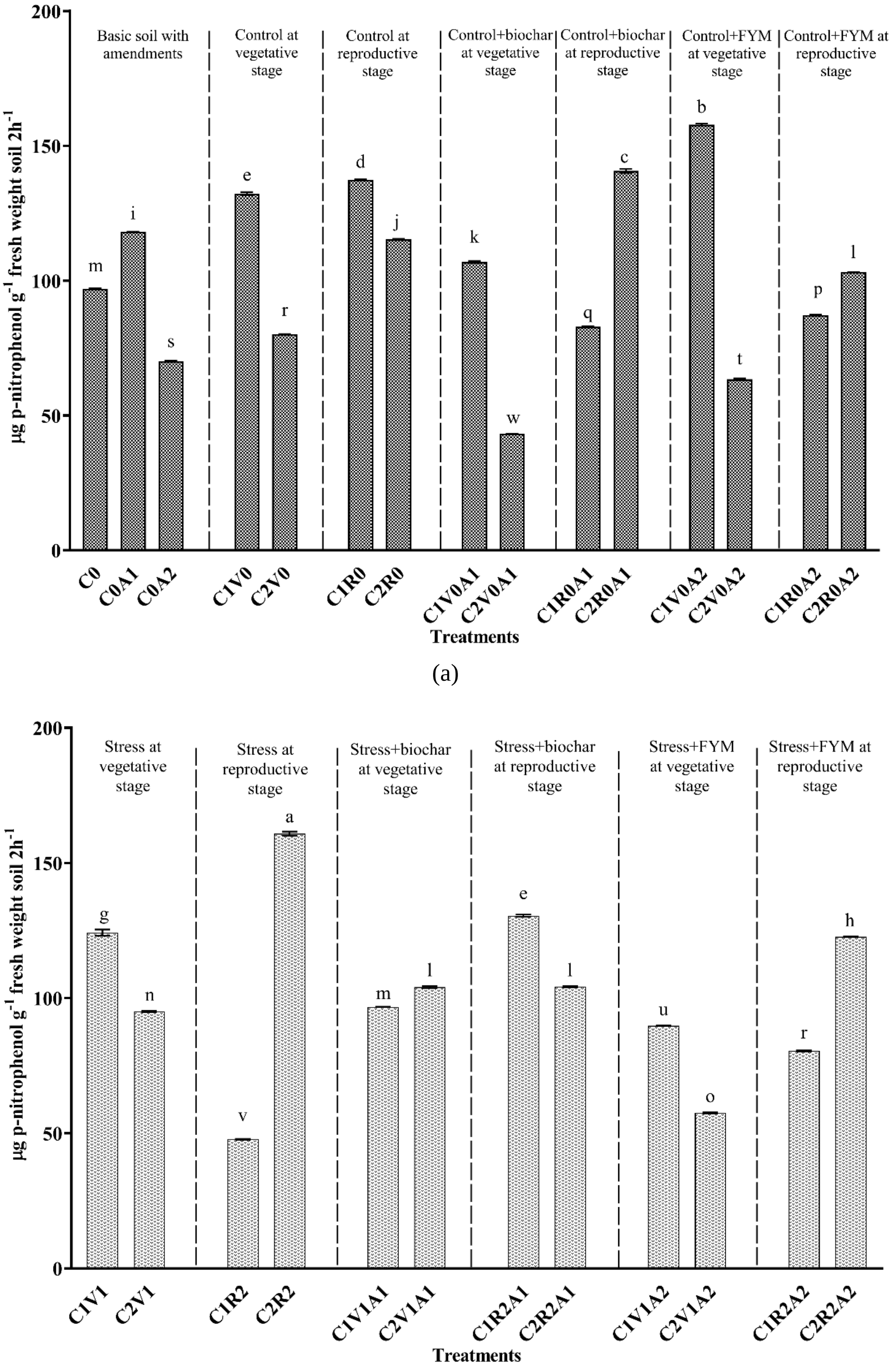
(a)



(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance (P≤ 0.05) according to Tukey’s Honestly Significant Difference (HSD)

Figure 4.10: Arylsulphatase activity at harvest as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage

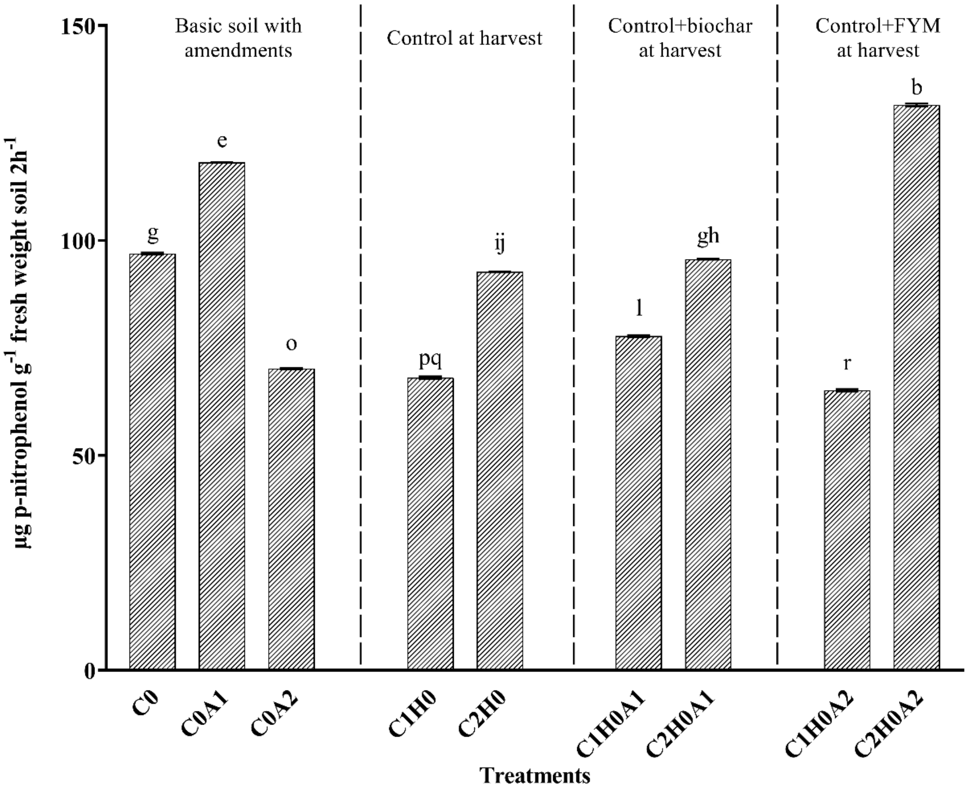


(a)

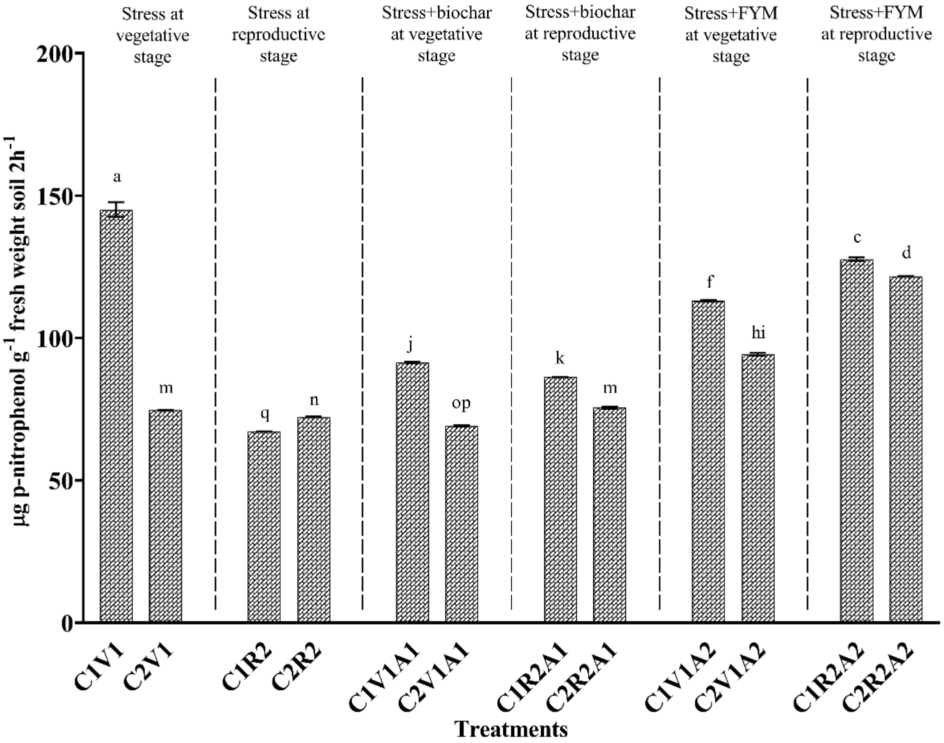
(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance ($P \leq 0.05$) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.11: *ß*-glucosidase activity at stress completion as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage



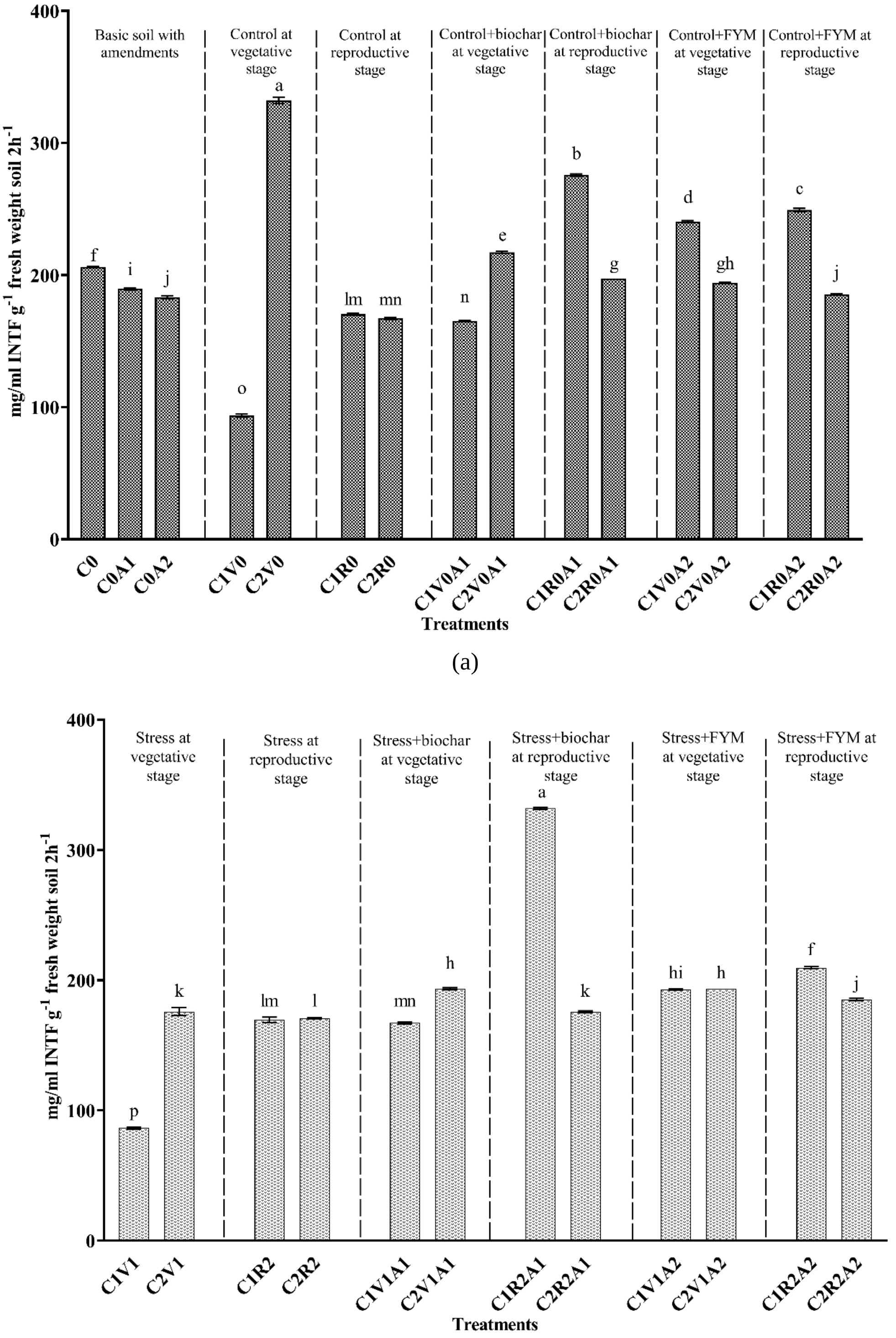
(a)



(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance ($P \leq 0.05$) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.12: *ß*-glucosidase activity at harvest as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage

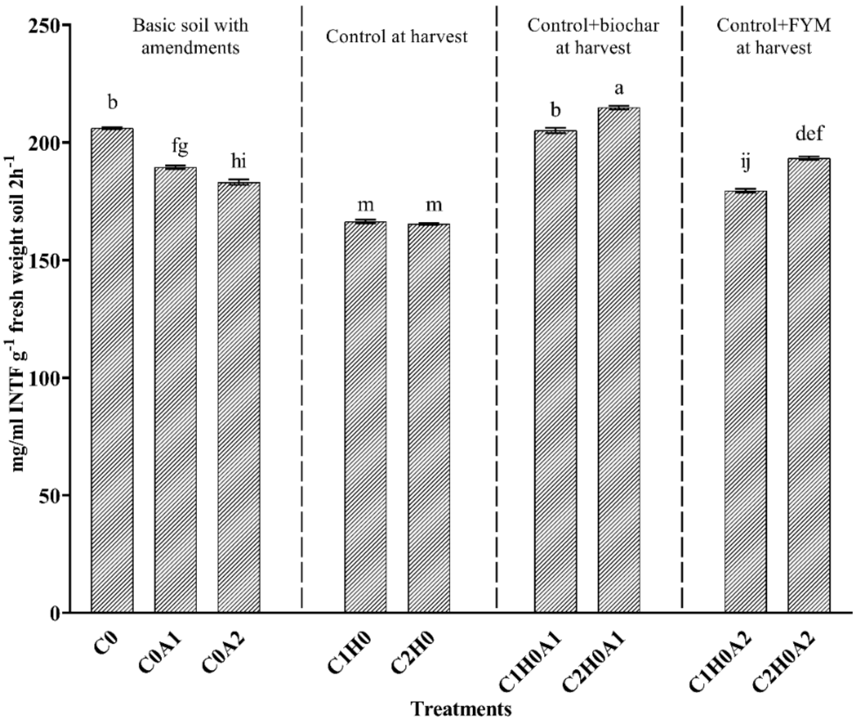


(a)

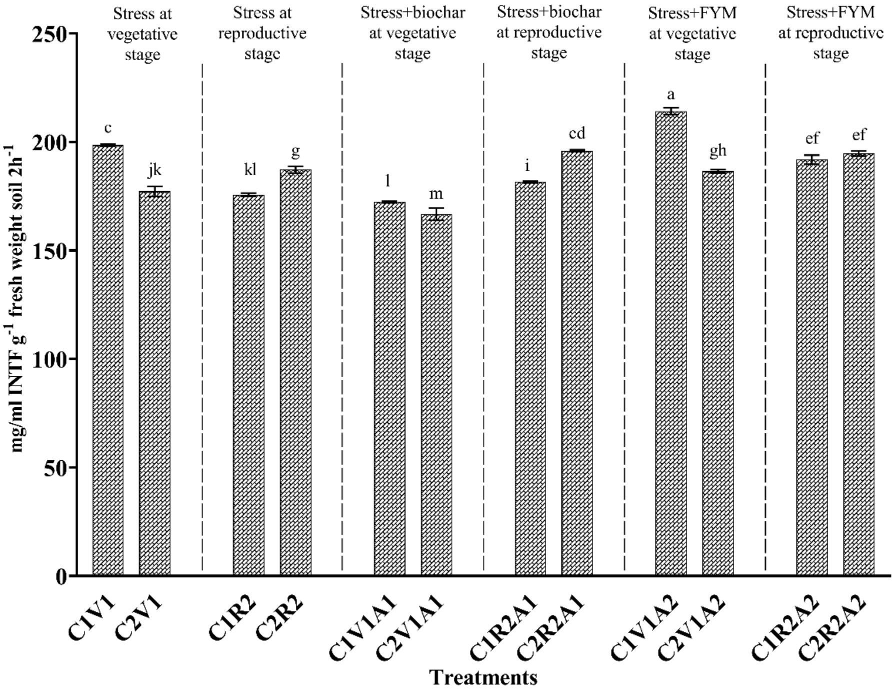
(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance (P≤ 0.05) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.13: Dehydrogenase activity at stress completion as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage



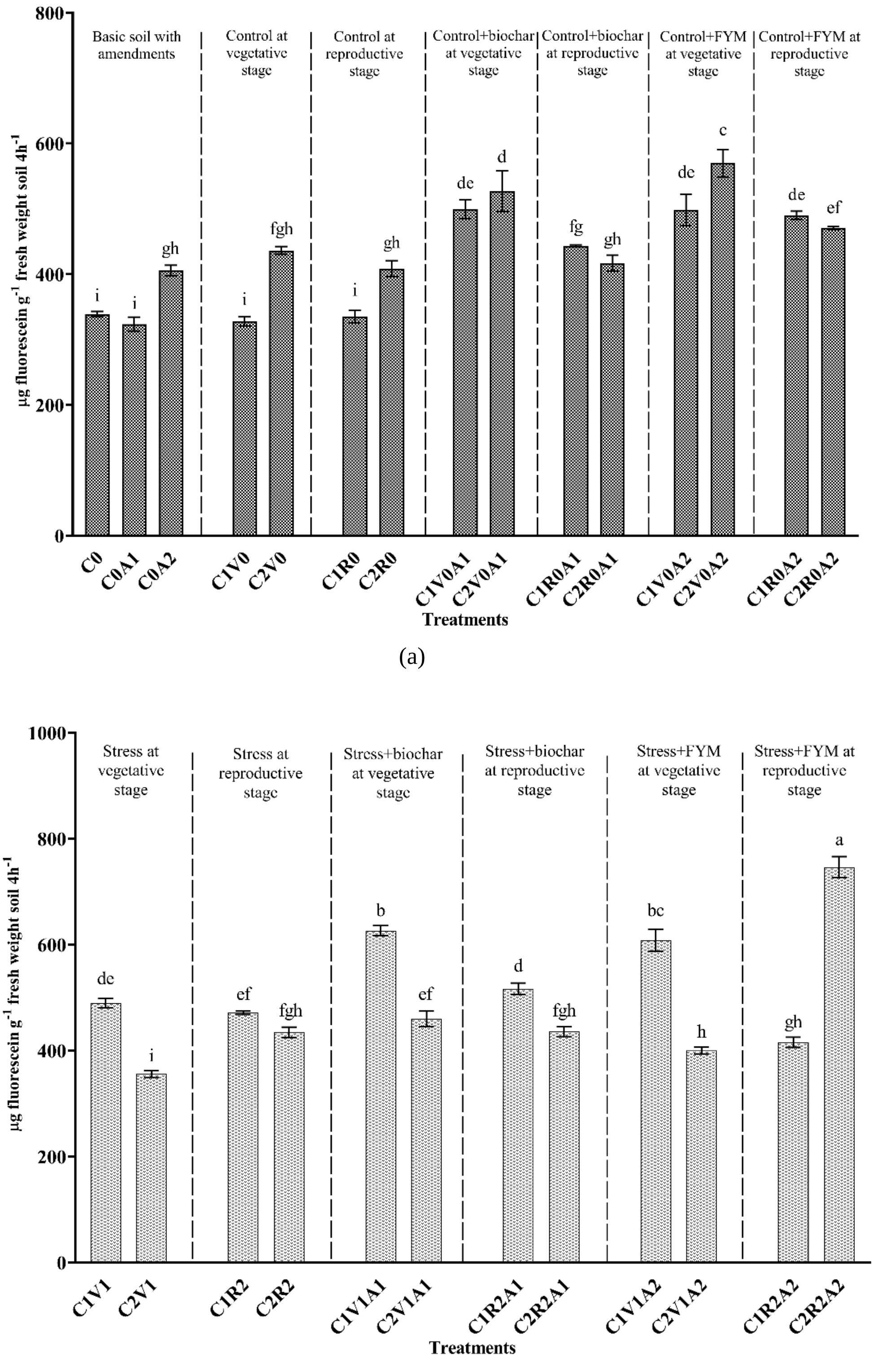
(a)



(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance ($P \leq 0.05$) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.14: Dehydrogenase activity at harvest as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage

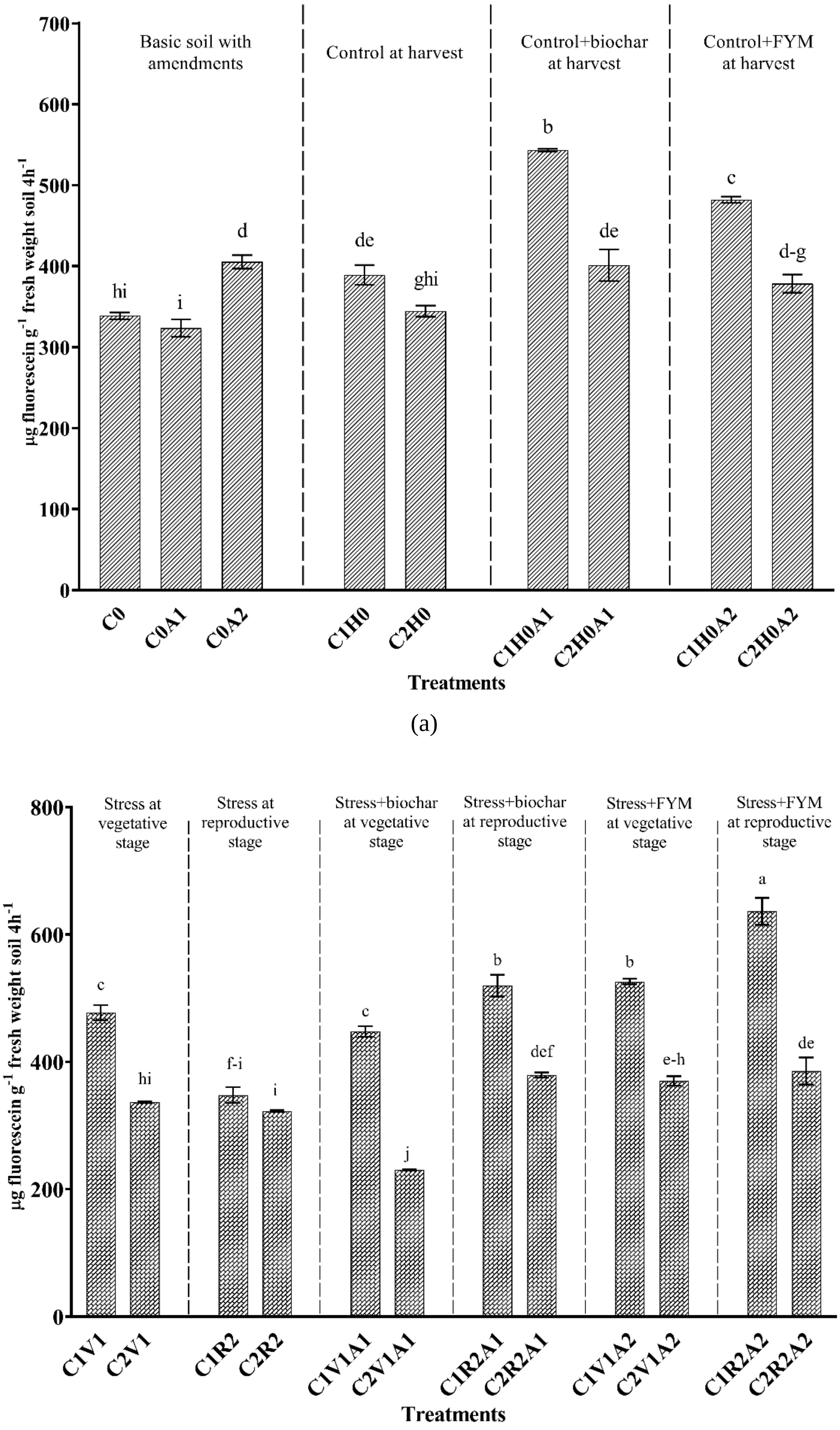


(a)

(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance ($P \leq 0.05$) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.15: Fluorescein di-acetate hydrolysis activity at stress completion as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage

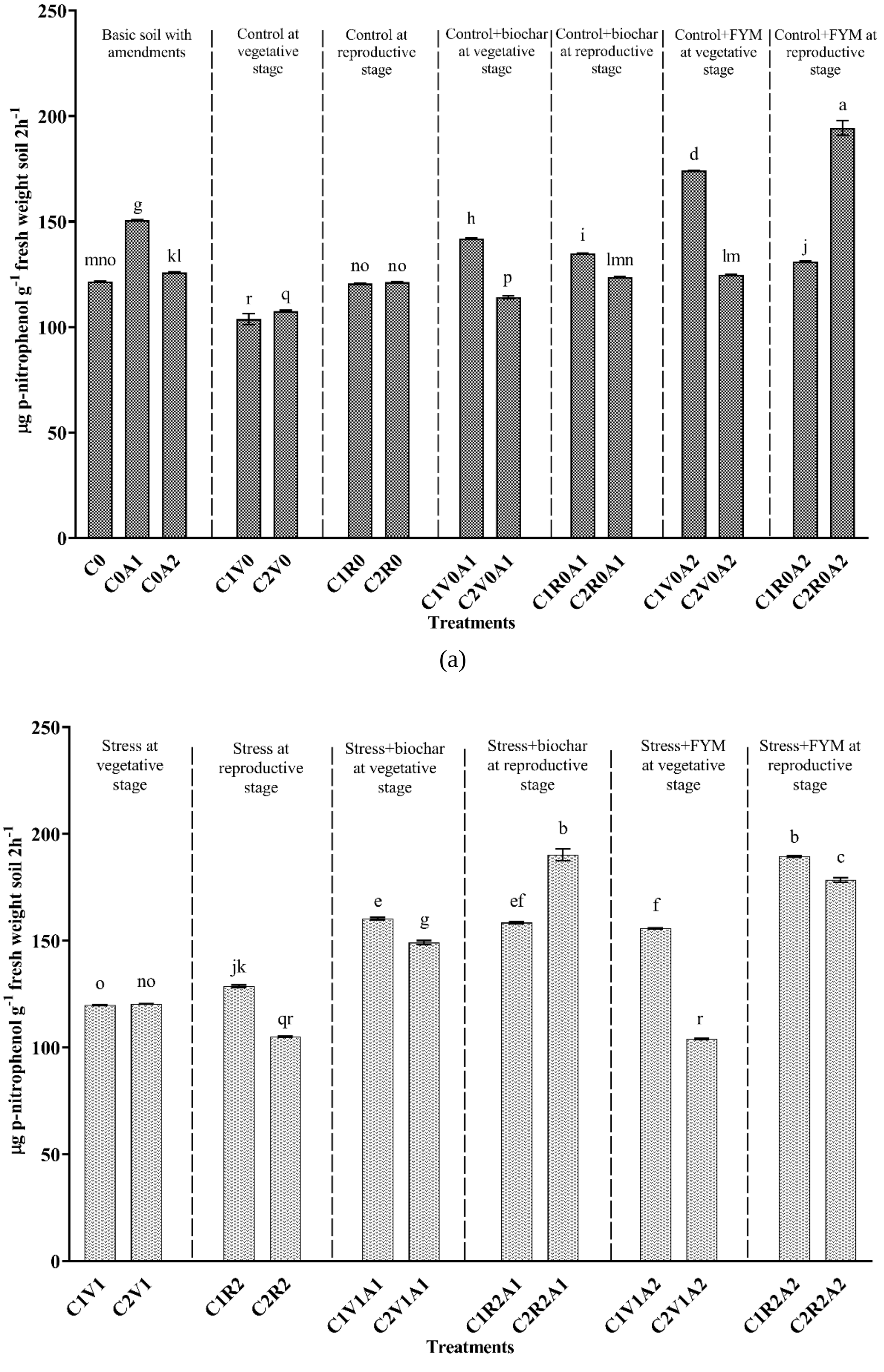


(a)

(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance (P≤ 0.05) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.16: Fluorescein di-acetate hydrolysis activity at harvest as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage

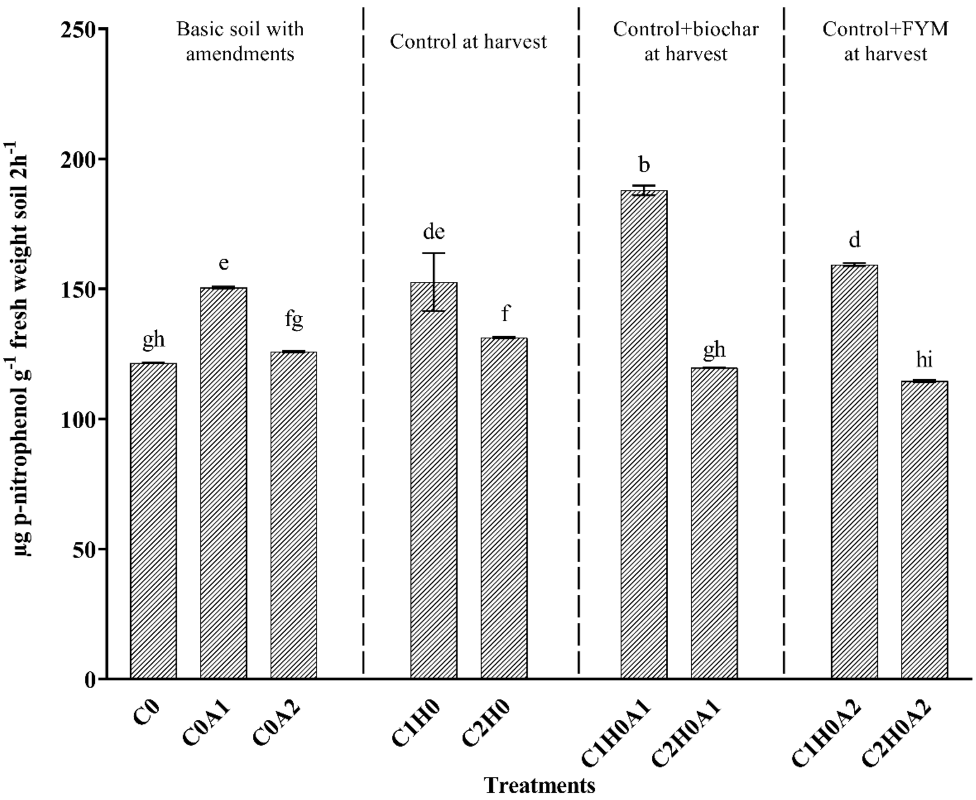


(a)

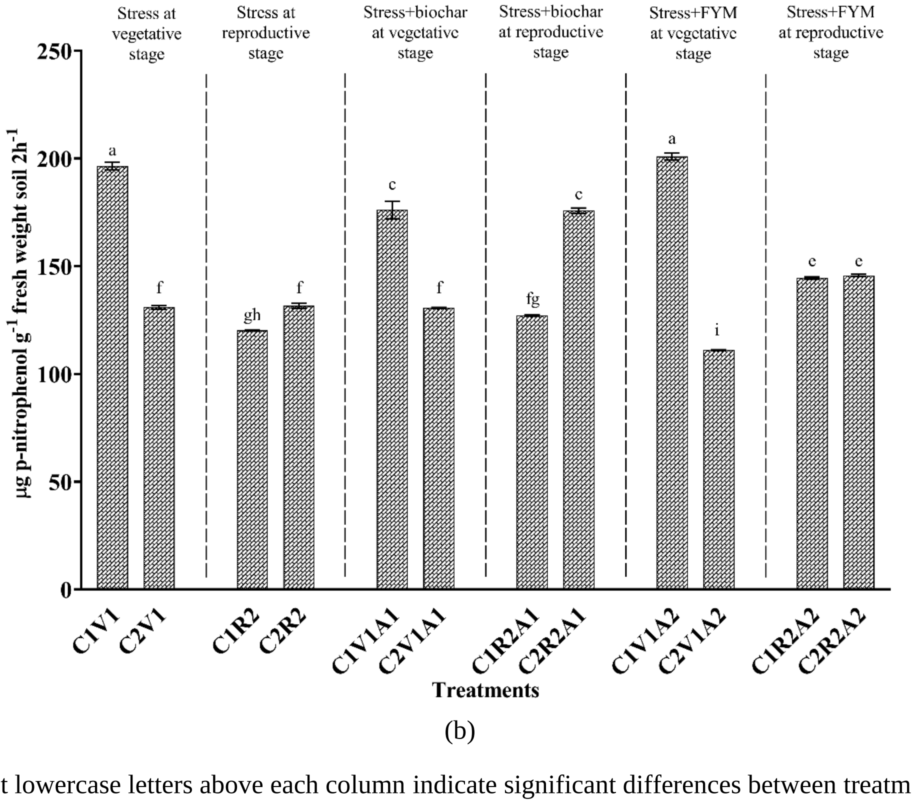
(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance ($P \leq 0.05$) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.17: Acid phosphomonoestrase activity at stress completion as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage



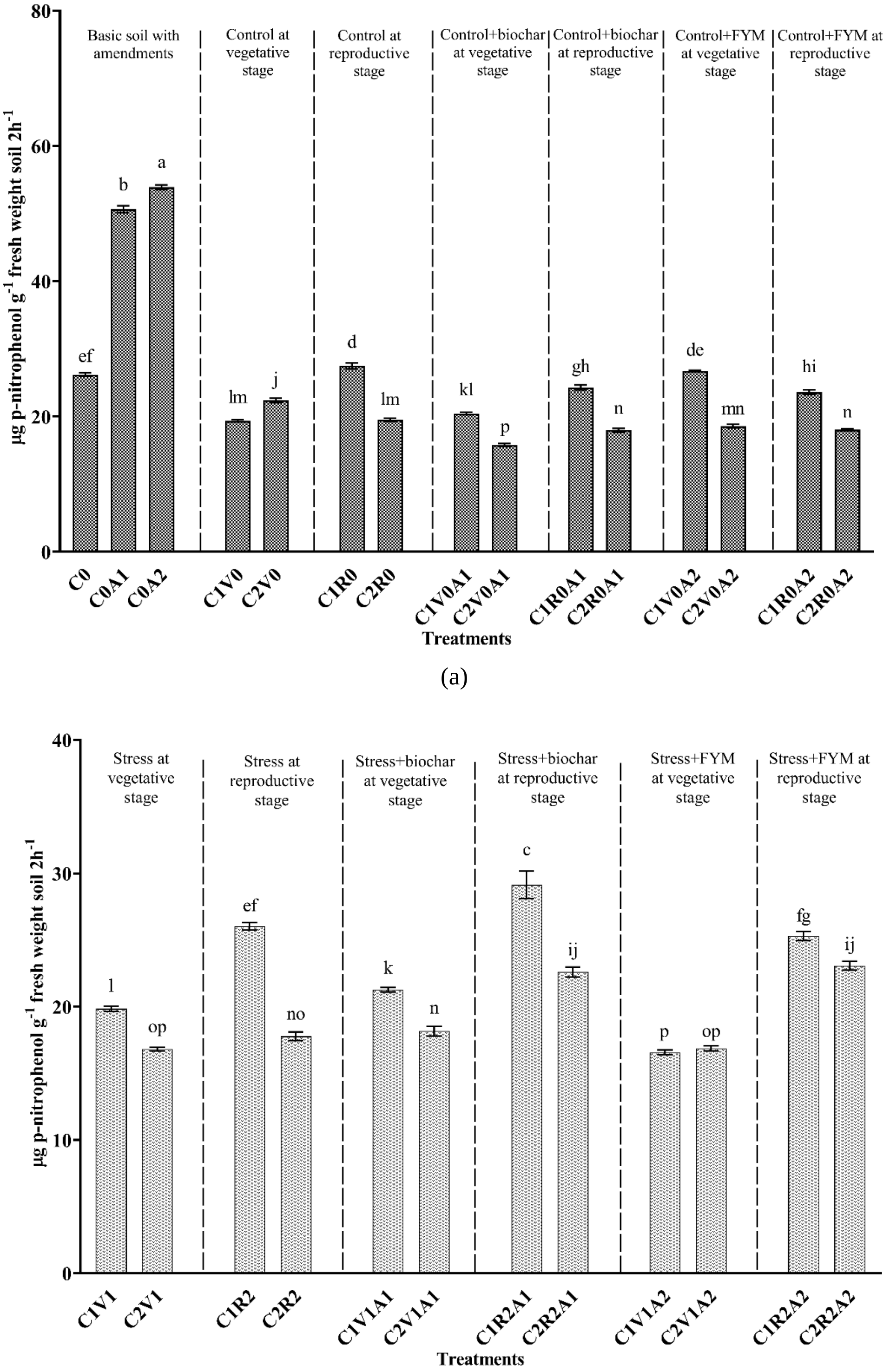
(a)



(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance ($P \leq 0.05$) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.18: Acid phosphomonoestrase activity at harvest as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage

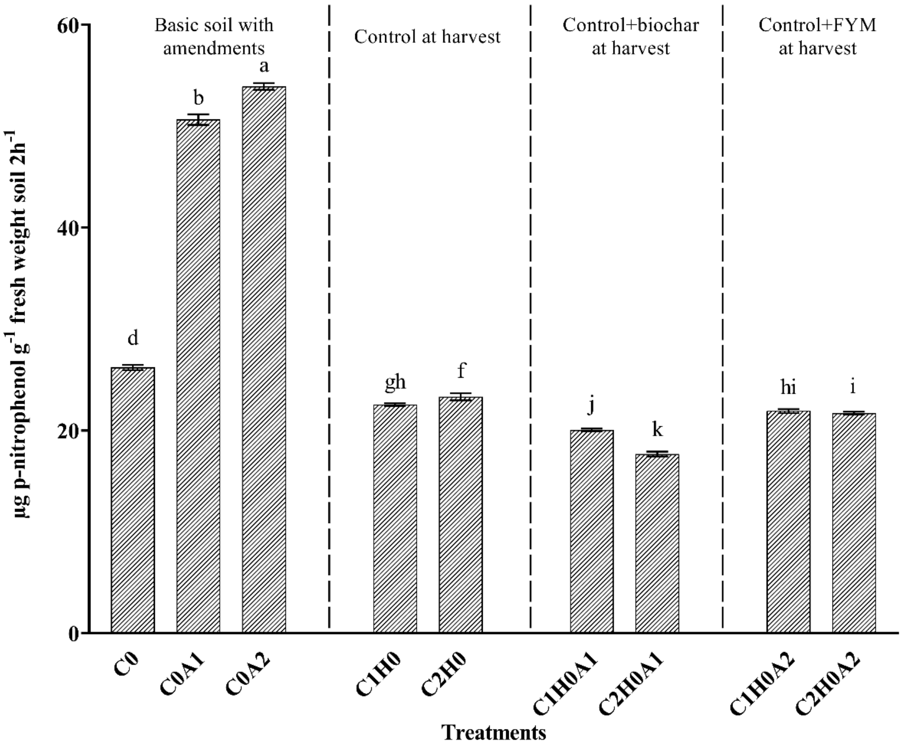


(a)

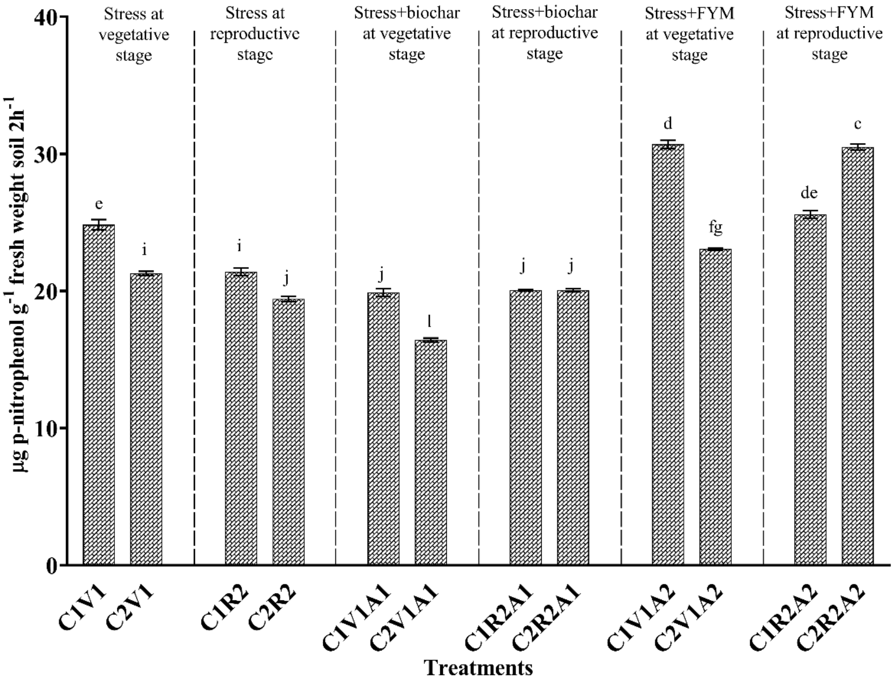
(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance (P≤ 0.05) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.19: Alkaline phosphomonoestrase activity at stress completion as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage



(a)



(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance ($P \leq 0.05$) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.20: Alkaline phosphomonoestrase activity at harvest as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage

b. Alkaline phosphomonoesterase activity

Drought at the vegetative stage of *Vigna radiata* cultivation significantly increased alkaline phosphomonoesterase activity of soil by 2%, but drought at the reproductive stage reduced it by 5%. Regardless of the drought treatments, amending biochar to the soil increased its alkaline phosphomonoesterase activity (up to 11%), but FYM application reduced it by up to 16%.

Exposure to drought at either growth stages of *Lathyrus sativus* reduced alkaline phosphomonoesterase activity (up to 24%). Amending soil with FYM followed by drought at either stage significantly increased it by 29% as compared to biochar (27% increase).

Significant reduction (up to 16%) in soil alkaline phosphomonoesterase activity was documented at harvest due to drought treatments in both the crops. However, drought at vegetative stage of *Vigna radiata* cultivation increased the same (10%). Biochar as soil amendment reduced alkaline phosphomonoesterase activity (up to 19%) in *Vigna radiata* cultivation under drought treatments. Whereas, FYM increased the enzyme activity (up to 23%) under the same situation.

At harvest, *Lathyrus sativus* cultivation with FYM as soil amendment significantly increased the activity of alkaline phosphomonoesterase under drought (up to 57%) followed by biochar (up to 3%).

Urease Activity

Increased urease activity (up to 79%) in *Vigna radiata* cultivated soils was noted irrespective of the drought treatments. Contrastingly, decrease of the same was recorded (up to 44%) in *Lathyrus sativus* cultivated soils. Irrespective of the drought treatments, biochar amended soils under *Vigna radiata* cultivation significantly increased urease activity (up to 14%) as compared to FYM (6%). However, when exposed to drought during the vegetative stage of *Lathyrus sativus*, biochar or FYM amended soils recorded a decrease (up to 8%), while an increase (up to 51%) was observed when the stress was imposed during the reproductive stage.

At harvest, the *Vigna radiata* cultivated soils receiving drought at either stages of crop growth documented a reduction (up to 20%) in soil urease activity. Contrastingly, an enhancement was noted under *Lathyrus sativus* cultivation (up to 27%). Biochar or FYM amended soils when exposed to drought at either stages of *Vigna radiata* cultivation documented a reduction in urease activity (up to 35%) except FYM amended soil exposed to drought at reproductive stage (18% increase). Similarly, under *Lathyrus sativus* cultivation, amending the soils with biochar and FYM resulted a reduction (up to 6%) in urease activity regardless of the drought treatments, except for biochar amended soil exposed to drought at reproductive stage (12% increase).

Bacterial, fungal and actinobacterial count

a. Bacterial CFU

Drought during the vegetative stage of *Vigna radiata* significantly decreased bacterial CFU (by 1.7%). However, it increased by 11% when drought appeared during the reproductive stage. When exposed to drought at the either stage, biochar led to a higher reduction in bacterial CFU (up to 15%) as compared to FYM.

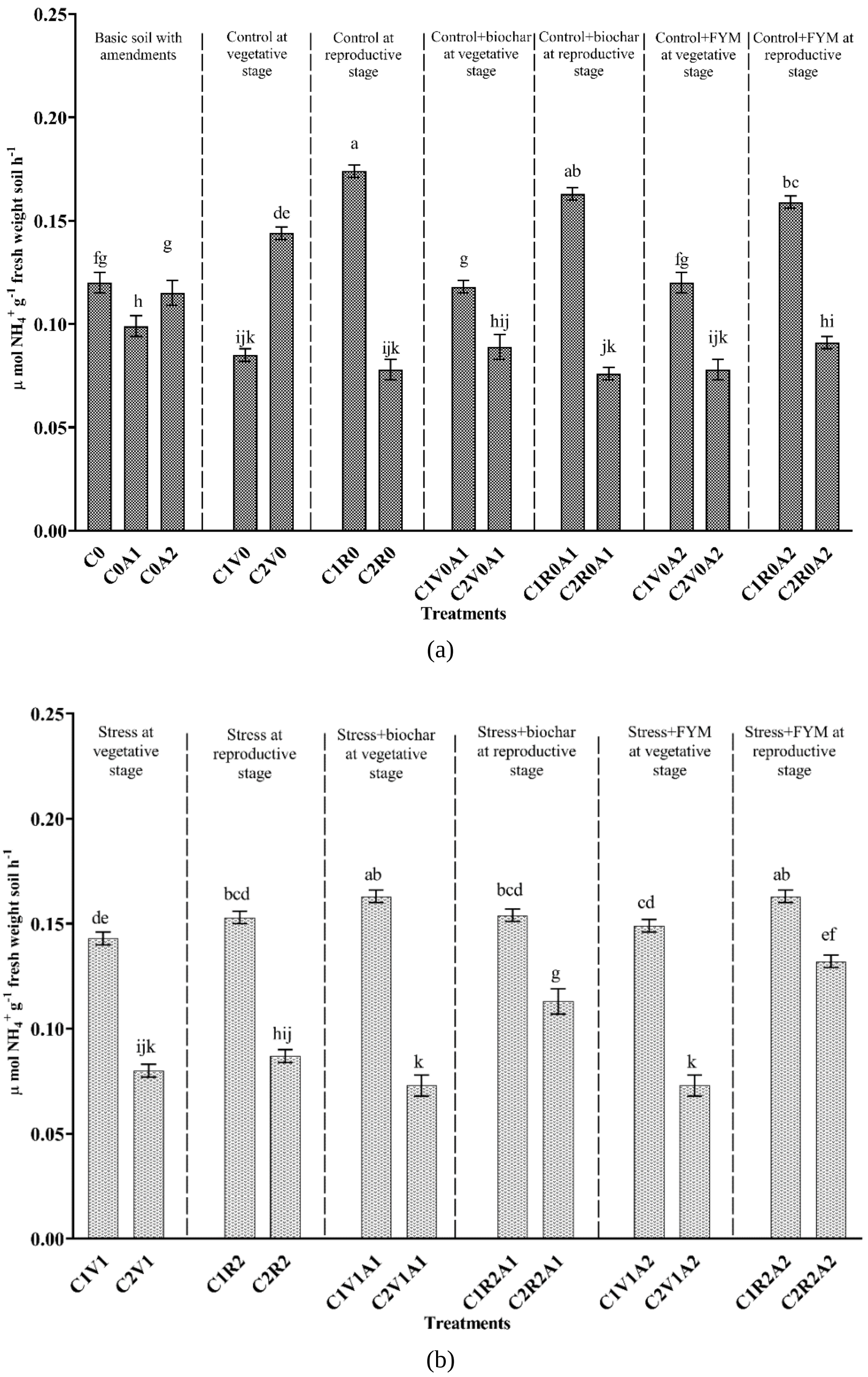
Drought significantly reduced bacterial CFU (by 5%) under *Lathyrus sativus* cultivation. Use of biochar or FYM as soil amendment increased bacterial CFU (up to 0.37%) regardless of drought treatments, with higher increment under biochar application.

Drought at either stage of *Vigna radiata* or *Lathyrus sativus* significantly enhanced soil bacterial CFU at harvest (up to 40%). However, significant reduction in soil bacterial CFU in both the crops were documented under FYM (up to 23%) addition compared to biochar. Increased bacterial CFU (up to 8%) was documented under cultivation of *Vigna radiata* crops when exposed to drought at the reproductive stage regardless of the tested soil amendments.

Fungal CFU

Except in *Vigna radiata* cultivated soils exposed to drought at the vegetative stage (7% reduction), drought at either stage resulted an increment in soil fungal CFU (up to 7%) under cultivation of both the crops. In *Vigna radiata* cultivated soils, amending the soil with biochar or FYM reduced fungal CFU by up to 25% with higher reduction under FYM application. However, no significant change of fungal CFU was noted in *Lathyrus sativus* cultivated soils amended with biochar or FYM under both the drought treatments.

Vigna radiata cultivated soils exposed to drought at either growth stage documented a decrease (up to 28%) in fungal CFU at harvest. Meanwhile, an increment (up to 19%) of the same was noted at harvest in *Lathyrus sativus* cultivated soil. Regardless of drought treatments, FYM application resulted in a higher increase in fungal CFU (up to 72%) as compared to biochar. However, an exception in *Vigna radiata* cultivated soils amended with FYM and exposed to drought at vegetative stage reduced it (3.8% reduction). Similarly, in *lathyrus sativus* cultivated soils with biochar amendment subjected to drought at reproductive stage 12% reduction was recorded.

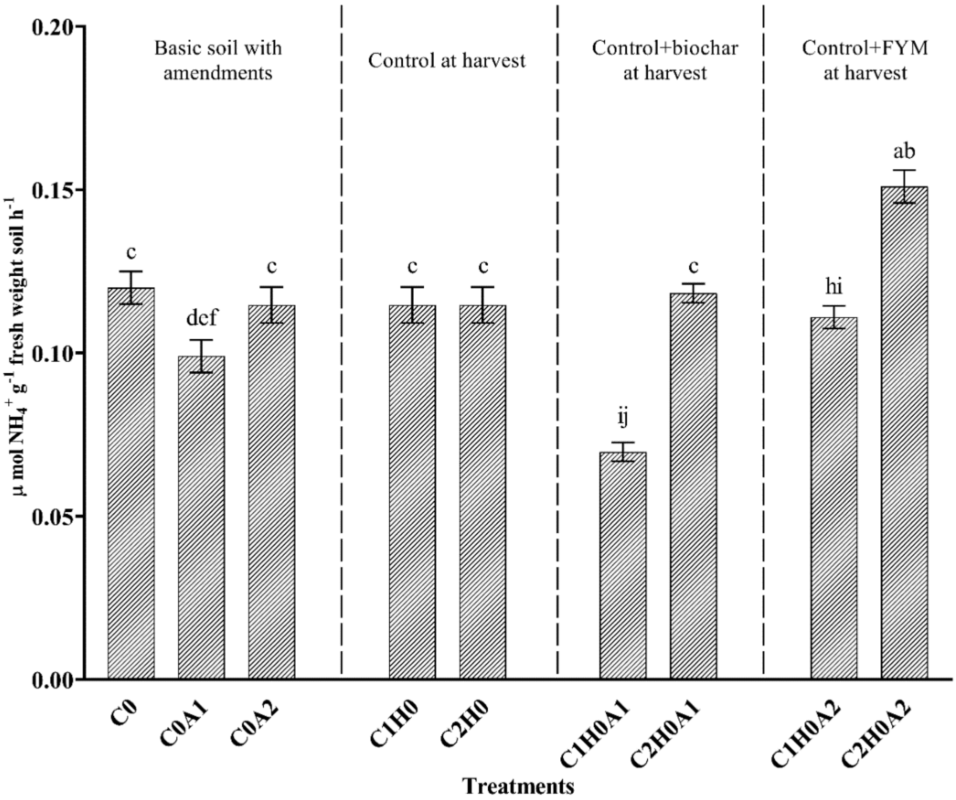


(a)

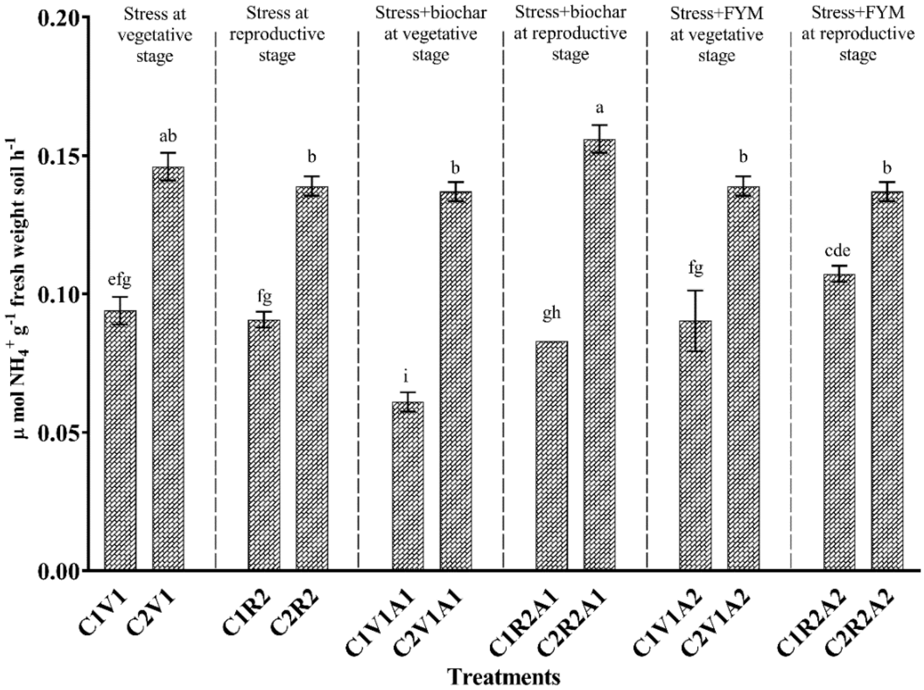
(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance (P≤ 0.05) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.21: Urease activity at stress completion as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage



(a)



(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance ($P \leq 0.05$) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.22: Urease activity at harvest as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage

Table 4.3: Bacterial, fungal, and actinobacterial CFU (Mean ± SD) as affected by drought and application of soil amendments at stress completion

Treatments	Bacteria (Log CFU g^{-1} soil) ±SD	Fungi (Log CFU g^{-1} soil) ±SD	Actinobacteria (Log CFU g^{-1} soil) ±SD	MBC (mg kg^{-1}) ± SD	Gmean of the total enzymes ± SD	Relative Gmean change of the enzymes ± SD
Basic Soil						
C0	5.32 ^{def}±0.27	5.04 ^{ab}±0.73	3.68 ^{fgh}±0.33	129.00 ^{mn}±16.84	41.02 ^{g}±0.24	
C0A1	6.06 ^{ab}±0.31	5.33 ^{a}±0.12	3.81 ^{ef}±0.20	221.60 ^{c}±9.84	43.67 ^{de}±0.57	
C0A2	6.10 ^{a}±0.46	5.18 ^{a}±0.15	3.66 ^{fgh}±0.05	567.53 ^{a}±22.64	40.30 ^{gh}±0.31	
Control						
C1V0	5.34 ^{def}±0.03	4.16 $^{b-f}$±1.21	3.55 ^{ghi}±0.04	148.83 ^{k}±1.14	32.14 ^{o}±0.13	
C2V0	5.49 $^{c-f}$±0.07	3.56 ^{ef}±0.04	3.55 ^{ghi}±0.04	166.34 $^{h-k}$±2.76	44.42 ^{d}±0.11	
C1R0	5.68 $^{b-e}$±0.03	3.71 ^{def}±0.03	3.37 ^{ij}±0.02	125.63 ^{mn}±0.69	40.29 ^{gh}±0.15	
C2R0	5.35 ^{def}±0.02	4.23 $^{b-e}$±0.03	4.55 ^{a}±0.04	135.41 ^{m}±0.90	36.14 ^{m}±0.21	
Control with biochar						
C1V0A1	5.27 ^{fg}±0.02	3.30 ^{f}±0.04	3.96 ^{cde}±0.04	172.05 $^{f-i}$±1.30	37.96 ^{jk}±0.07	
C2V0A1	5.52 $^{c-f}$±0.04	3.60 ^{def}±0.02	3.67 ^{fgh}±0.05	169.11 ^{ghi}±0.99	34.28 ^{n}±0.26	
C1R0A1	5.69 ^{bcd}±0.02	3.77 $^{c-f}$±0.02	3.45 ^{hij}±0.03	156.18 ^{ijk}±1.30	45.45 ^{c}±0.14	
C2R0A1	5.23 ^{fg}±0.02	3.61 ^{def}±0.03	4.35 ^{ab}±0.02	161.65 $^{h-k}$±1.52	37.53 ^{kl}±0.13	
Control with FYM						
C1V0A2	5.80 ^{abc}±0.06	3.95 $^{c-f}$±0.04	4.14 ^{bc}±0.05	150.09 ^{jk}±1.75	46.56 ^{b}±0.08	
C2V0A2	5.27 ^{fg}±0.04	3.61 ^{def}±0.02	3.67 ^{fgh}±0.02	173.89 $^{f-i}$±1.21	36.65 ^{lk}±0.61	
C1R0A2	5.23 ^{fg}±0.03	4.60 ^{abc}±0.03	3.22 ^{j}±0.02	227.85 ^{c}±1.93	43.18 ^{e}±0.10	
C2R0A2	5.22 ^{fg}±0.02	3.47 ^{ef}±0.02	3.77 ^{efg}±0.03	120.93 ^{mn}±1.52	38.56 ^{ij}±0.21	
Stress at vegetative stage						
C1V1	5.25 ^{fg}±0.04	3.85 $^{c-f}$±0.04	4.36 ^{ab}±0.04	190.00 ^{ef}±2.11	35.91 ^{m}±0.31	0.12 ^{c}±0.01
C2V1	5.20 ^{fg}±0.03	3.67 ^{def}±0.06	3.68 ^{fgh}±0.01	175.29 ^{fgh}±1.65	34.78 ^{n}±0.22	-0.22 ^{h}±0.01
Stress at reproductive stage						
C1R2	5.98 ^{ab}±0.07	4.46 $^{a-d}$±0.05	3.78 ^{efg}±0.03	190.73 ^{ef}±1.09	44.41 ^{n}±0.12	-0.14 ^{g}±0.01
C2R2	5.29 ^{efg}±0.02	3.77 $^{c-f}$±0.03	4.12 ^{bcd}±0.04	116.16 ^{n}±1.23	38.01 ^{hi}±0.34	0.09 ^{cd}±0.02
Stress at vegetative stage with biochar						
C1V1A1	5.17 ^{fg}±0.04	3.47 ^{ef}±0.05	3.66 ^{fgh}±0.05	210.79 ^{cd}±2.58	48.55 ^{d}±0.01	0.17 ^{b}±0.00
C2V1A1	5.26 ^{fg}±0.02	3.70 ^{def}±0.08	3.76 ^{efg}±0.04	186.43 ^{efg}±2.07	38.48 ^{jk}±0.64	0.11 ^{c}±0.02
Stress at reproductive stage with biochar						
C1R2A1	5.07 ^{g}±0.06	3.31 ^{f}±0.03	4.21 ^{bc}±0.04	219.71 ^{c}±1.03	44.51 ^{a}±0.28	0.07 ^{d}±0.01
C2R2A1	5.31 ^{def}±0.03	3.80 $^{c-f}$±0.03	4.12 ^{bcd}±0.03	168.66 $^{g-j}$±1.17	30.87 ^{ijk}±0.53	0.03 ^{e}±0.02
Stress at vegetative stage with FYM						
C1V1A2	5.41 $^{c-g}$±0.05	3.61 ^{def}±0.04	3.65 ^{bc}±0.04	125.62 ^{mn}±0.89	44.51 ^{cd}±0.36	-0.04 ^{f}±0.01
C2V1A2	5.26 ^{fg}±0.03	3.70 ^{def}±0.04	3.87 ^{bcd}±0.04	196.39 ^{de}±1.10	30.87 ^{p}±0.43	-0.16 ^{g}±0.03
Stress at reproductive stage with FYM						
C1R2A2	5.08 ^{g}±0.06	3.30 ^{f}±0.04	4.35 ^{ab}±0.03	247.74 ^{b}±1.41	42.04 ^{f}±0.23	-0.03 ^{f}±0.01
C2R2A2	5.30 ^{efg}±0.03	3.77 $^{c-f}$±0.02	4.11 ^{bcd}±0.04	174.59 $^{f-i}$±1.15	47.78 ^{a}**±0.19**	0.24 ^{a}±0.01

Data presented as mean ±SE; Different superscript lower case letters within each column indicate significant differences between treatments at 5% level of significance (at P≤ 0.05) according to Tukey's honestly significant difference (HSD) test.

Table 4.4: Bacterial, fungal, and actinobacterial CFU (Mean ± SD) as affected by drought and application of soil amendments at harvest

Treatments	**Bacteria (Log CFU g^{-1} soil) ±SD**	**Fungi (Log CFU g^{-1} soil) ±SD**	**Actinobacteria (Log CFU g^{-1} soil) ±SD**	**MBC (mg kg^{-1}) ± SD**	**Gmean of the total enzymes ± SD**	**Relative Gmean change of the enzymes ± SD**
Basic Soil						
C0	5.32 $^{f-i}$±0.27	5.04 ^{bc}±0.73	3.68 ^{f}±0.03	129.00 ^{m}±16.84	41.02 ^{ef}±0.24	--
C0A1	6.06 ^{bcd}±0.31	5.33 ^{ab}±0.12	3.81 ^{ef}±0.20	221.60 ^{ef}±9.84	43.67 ^{bc}±0.57	
C0A2	6.10 ^{bc}±0.46	5.18 ^{ab}±0.15	3.66 ^{fg}±0.05	567.53 ^{a}±22.64	40.30 ^{f}±0.31	
Control						
C1H0	4.26 ^{l}±0.05	4.61 ^{cd}±0.06	3.25 ^{ij}±0.01	195.62 ^{gh}±1.71	33.48 ^{m}±0.45	
C2H0	4.42 ^{kl}±0.05	3.31 ^{h}±0.06	4.43 ^{b}±0.02	173.53 ^{ijk}±1.75	39.11 ^{hi}±0.27	
Stress at vegetative stage						
C1V1	5.97 ^{cde}±0.03	3.61 ^{fgh}±0.04	3.67 ^{fg}±0.02	192.29 ^{ghi}±1.75	46.20 ^{a}±0.47	0.39 ^{a}±0.01
C2V1	5.69 $^{c-f}$±0.05	3.95 ^{efg}±0.04	4.46 ^{b}±0.02	173.28 ^{ijk}±3.12	37.84 ^{i}±0.32	-0.03 ^{de}±0.01
Stress at reproductive stage						
C1R2	5.58 $^{e-h}$±0.06	3.31 ^{h}±0.03	3.38 $^{g-j}$±0.05	206.50 ^{fg}±1.61	31.35 ^{n}±0.24	-0.06 ^{ef}±0.01
C2R2	5.25 ^{ghi}±0.08	3.74 ^{fgh}±0.08	4.37 ^{bc}±0.02	167.48 ^{kl}±2.73	36.59 ^{kl}±0.28	-0.06 ^{ef}±0.01
Control with biochar						
C1H0A1	6.46 ^{ab}±0.05	3.31 ^{h}±0.04	3.99 ^{de}±0.07	305.72 ^{c}±2.81	38.20 ^{ij}±0.18	
C2H0A1	5.23 ^{ghi}±0.07	3.46 ^{gh}±0.04	3.36 ^{hij}±0.05	177.17 $^{h-k}$±1.19	39.48 ^{h}±0.16	
Control with FYM						
C1H0A2	5.06 ^{ij}±0.04	4.45 ^{de}±0.04	4.11 ^{cd}±0.07	188.85 $^{g-j}$±1.24	38.12 ^{ij}±0.18	
C2H0A2	6.69 ^{a}±0.06	3.47 ^{gh}±0.05	2.38 ^{k}±0.05	326.36 ^{c}±1.93	42.49 ^{d}±0.33	
Stress at vegetative stage with biochar						
C1V1A1	5.25 ^{ghi}±0.04	3.72 ^{fgh}±0.03	4.25 ^{bcd}±0.04	206.50 ^{fg}±1.63	35.56 ^{l}±0.30	-0.07 ^{f}±0.00
C2V1A1	5.18 ^{hij}±0.04	4.05 ^{ef}±0.04	4.39 ^{bc}±0.06	168.15 ^{jk}±2.56	33.76 ^{m}±0.04	-0.14 ^{g}±0.00
Stress at reproductive stage with biochar						
C1R2A1	5.83 ^{l}±0.05	3.47 ^{gh}±0.05	4.76 ^{a}±0.05	229.17 ^{e}±1.36	43.97 ^{bc}±1.02	-0.01 ^{d}±0.00
C2R2A1	4.28 ^{cde}±0.03	3.96 ^{efg}±0.16	4.36 ^{bc}±0.01	257.32 ^{d}±1.87	37.43 ^{jk}±0.15	0.06 ^{c}±0.00
Stress at vegetative stage with FYM						
C1V1A2	5.64 $^{d-g}$±0.04	3.72 ^{fgh}±0.03	3.77 ^{ef}±0.06	206.44 ^{fg}±1.74	37.87 ^{i}±0.19	0.15 ^{b}±0.03
C2V1A2	4.34 ^{kl}±0.03	4.05 ^{ef}±0.04	3.54 $^{f-i}$±0.02	253.04 ^{d}±3.44	42.08 ^{de}±0.16	-0.12 ^{g}±0.01
Stress at reproductive stage with FYM						
C1R2A2	6.06 ^{bcd}±0.06	5.70 ^{a}±0.01	3.21 ^{j}±0.05	394.41 ^{c}±2.07	43.11 ^{cd}±0.40	0.13 ^{b}±0.01
C2R2A2	4.77 ^{jk}±0.06	4.14 ^{def}±0.06	3.57 ^{fgh}±0.04	146.71 ^{lm}±1.93	44.37 ^{b}±0.32	0.04 ^{c}±0.01

Data presented as mean ±SE; Different superscript lower case letters within each column indicate significant differences between treatments at 5% level of significance (at $P \leq 0.05$) according to Tukey's honestly significant difference (HSD) test.

Table 4.5: Table showing correlation matrix amongst soil biological properties as affected by drought and application of soil amendments at stress completion.

Parameters	**Bacterial CFU**	**Fungal CFU**	**Actinobacterial CFU**	**MBC**	**Arylsulphatase activity**	***ß*-Glucosidase activity**	**Dehydrogenase activity**	**FDA hydrolysis activity**	**Acidic PME activity**	**Alkaline PME activity**	**Urease activity**
Bacterial CFU	1										
Fungal CFU	0.637**	1									
Actinobacterial CFU	-0.280	-0.222	1								
MBC	0.390*	0.425*	-0.073	1							
Arylsulphatase activity	0.483*	0.643**	-0.333	0.311	1						
***ß*-Glucosidase activity**	-0.145	-0.070	0.393*	-0.313	-0.149	1					
Dehydrogenase activity	0.017	-0.149	-0.166	0.035	0.187	-0.158	1				
FDA hydrolysis activity	-0.247	-.407*	0.100	-0.055	-0.244	-0.106	0.113	1			
Acidic PME activity	-0.133	-0.226	0.274	0.003	-0.283	0.134	0.119	.401*	1		
Alkaline PME activity	0.706**	0.704**	-0.101	0.720**	0.575**	0.000	0.116	-0.277	0.107	1	
Urease activity	0.123	-0.064	-0.225	0.094	-0.113	-0.050	0.300	0.252	0.267	0.207	1

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

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

Table 4.6: Table showing correlation matrix amongst soil biological properties as affected by drought and application of soil amendments at harvest.

Parameters	**Bacterial CFU**	**Fungal CFU**	**Actinobacterial CFU**	**MBC**	**Arylsulphatase activity**	***ß*-Glucosidase activity**	**Dehydrogenase activity**	**FDA hydrolysis activity**	**Acidic PME activity**	**Alkaline PME activity**	**Urease activity**
Bacterial CFU	1										
Fungal CFU	0.129	1									
Actinobacterial CFU	-0.270	-0.251	1								
MBC	.455*	.436*	-0.305	1							
Arylsulphatase activity	0.184	0.304	0.165	0.070	1						
***ß*-Glucosidase activity**	0.361	0.212	-.477*	0.021	0.323	1					
Dehydrogenase activity	0.327	-0.011	-0.315	0.039	0.205	.471*	1				
FDA hydrolysis activity	0.359	0.139	-0.121	0.369	-0.265	0.321	0.368	1			
Acidic PME activity	0.077	-0.101	0.190	-0.065	-0.036	0.211	0.282	.498*	1		
Alkaline PME activity	0.287	.603**	-0.165	.522*	.646**	0.203	0.094	-0.018	0.017	1	
Urease activity	-0.343	0.010	-0.138	-0.060	0.124	-0.057	-0.040	-.555**	-.476*	-0.097	1

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

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

b. Actinobacterial CFU

Drought at either stage of *Vigna radiata* or *Lathyrus sativus* resulted a significantly higher actinobacterial CFU (up to 22%). Amending the soil with biochar or FYM in *Vigna radiata* followed by drought at vegetative stage reduced the actinobacterial CFU up to 16%. However, an enhancement of the same was noted under cultivation of *Lathyrus sativus* (up to 5%). Drought at reproductive stage of *Vigna radiata* significantly increased actinobacterial CFU in the cultivated soils under addition of biochar or FYM as amendment. However, no significant change was documented under *Lathyrus sativus* cultivation under the similar conditions.

Regardless of the drought treatments, *Vigna radiata* cultivated soils documented an increase in actinobacterial CFU at harvest (up to 12%). Biochar amended soil revealed higher increment in soil actinobacterial CFU (up to 40%) as compared to FYM, when exposed to drought at either stage of crop growth.

At harvest, *Lathyrus sativus* cultivated soil showed no significant change in actinobacterial CFU when drought appeared at its vegetative stage. However, a significant reduction of the same was noted when exposed to drought at reproductive stage. Amending the soils with FYM followed by drought at either stage resulted in higher (up to 20%) reduction in actinobacterial CFU, as compared to biochar (up to 1.6%).

Microbial Biomass Carbon (MBC)

Significant increase in soil MBC was documented (up to 28%) under cultivation of both the crops irrespective of the drought treatments. Whereas, *Lathyrus sativus* cultivated soils exposed to drought at reproductive stage noted a reduction of the same (30%). FYM amended soil revealed significant increase in soil MBC (up to 50% increase) over biochar amended soils (up to 45% increase) when subjected to drought at either growth stages of both the crops. FYM amended soils exposed to drought at the reproductive stage of *Vigna radiata* decrease it (33% decrease).

At harvest, no significant change in soil MBC was noted in the both the crops when subjected to drought treatments. Amending the soils with FYM (up to 91% increase) delineated an edge over biochar (up to 10% increase) in enhancing soil MBC under drought exposure in *Vigna radiata* cultivation. However, in *Lathyrus sativus* cultivated soils, an increment of soil MBC was noted in the soils amended with biochar or FYM and exposed to drought.

Interactive effects

During the drought period, a strong positive correlation (P≤0.01) was documented between Alkaline PME activity and bacterial CFU (R=0.706), Fungal CFU (R=0.704), MBC (R=0.720), and arylsulphatase (R=0.575). FDA hydrolysis was positively correlated with Acidic PME (P≤0.05; R=0.401) and negatively correlated with fungal CFU (P≤0.05; R=-0.407). Fungal CFU was documented to be positively correlated with arylsulphatase activity (P≤0.01; R=0.643) and MBC (P≤0.05; R=0.425).

At harvest, a negative correlation of urease was documented with FDA hydrolysis activity (P≤0.01; R=-0.555) and acidic PME (P≤0.05; R=-0.476). A positive correlation of alkaline PME was noted with fungal CFU (P≤0.01; R=0.603), arylsulphatase (P≤0.01; R=0.401) and MBC (P≤0.05; R=0.522). MBC showed a positive correlation (P≤0.05) with bacterial and fungal CFU (R=0.455 and R=0.436, respectively).

Objective 3

To assess the impact of management induced responses on grain quality of legumes.

Biomass

a. Shoot biomass

Drought significantly increased (up to 78%) the shoot biomass of both the crops. Addition of soil amendments (biochar or FYM) further improved it (up to 101%), except in *Lathyrus sativus* crop under FYM addition when exposed to drought at reproductive stage (19% reduction). However, both the tested amendments significantly increased shoot biomass in *Vigna radiata* and *Lathyrus sativus* crops by up to 231% and 175%, respectively.

b. Root Biomass

Drought exposure during either stage of *Vigna radiata* crop reduced root biomass by up to 14%. However, applying FYM under the same situation significantly mitigated the loss by up to 128% compared to biochar (99%). Positive impact of drought was observed on root biomass of *Lathyrus sativus* (up to 57%). Biochar or FYM addition to the soil increased root biomass (up to 79%) regardless of the drought treatments. However, FYM amended soil under exposure to drought at the reproductive stage noted a 17% reduction of root biomass. Under well-watered conditions, biochar and FYM increased root biomass by up to 95% and 271%, respectively in both crops.

c. Pod biomass

Drought significantly reduced pod biomass (up to 27%), except drought during the vegetative stage in *Lathyrus sativus*. Amending the soils with biochar had an edge in enhancing pod biomass (204% increase) over FYM (152%) in both the crops. Furthermore, under well-watered conditions, biochar and FYM application improved pod biomass of both crops by 117% and 161%, respectively.

Grain carbohydrates

Drought exposure at either stage reduced the carbohydrates content of *Vigna radiata* grains (up to 29%). Amending the soils with FYM under drought at either stage of growth led to higher increment in grain carbohydrates (up to 96%) followed by biochar (32%). Drought at vegetative or reproductive stages of *Lathyrus sativus* increased grain carbohydrates (up to 36% and 29%, respectively). Under well-watered conditions, amending the soil with biochar or FYM increased grain carbohydrates by up to 35%. However, adding biochar as soil amendment under drought significantly reduced grain carbohydrate levels (up to 20%) as compared to FYM (15%).

Grain total Protein

Exposure to drought at vegetative or reproductive stages of *Vigna radiata* reduced grain total protein (up to 3%) content in first year of cultivation but enhanced it (up to 1.7%) in the second year. Amending the soil with biochar or FYM improved grain total protein up to 16% in the first year but a reduction of the same was noted in the second year of cultivation (up to 14%) with higher reduction under biochar application. Drought at vegetative stage of *Lathyrus sativus* recorded a decrease in grain total protein (up to 13%); whereas, an increase was noted when drought appeared at reproductive stage (13%). Amending the soil with biochar or FYM recorded a decline in total protein when crop experienced drought at either stage of growth (up to 12%).

Application of biochar or FYM under well-watered condition recorded a decline in grain total protein content of *Vigna radiata* (up to 9%) but in *Lathyrus sativus* the same was found to enhance by up to 5%.

Grain Phytic Acid Content

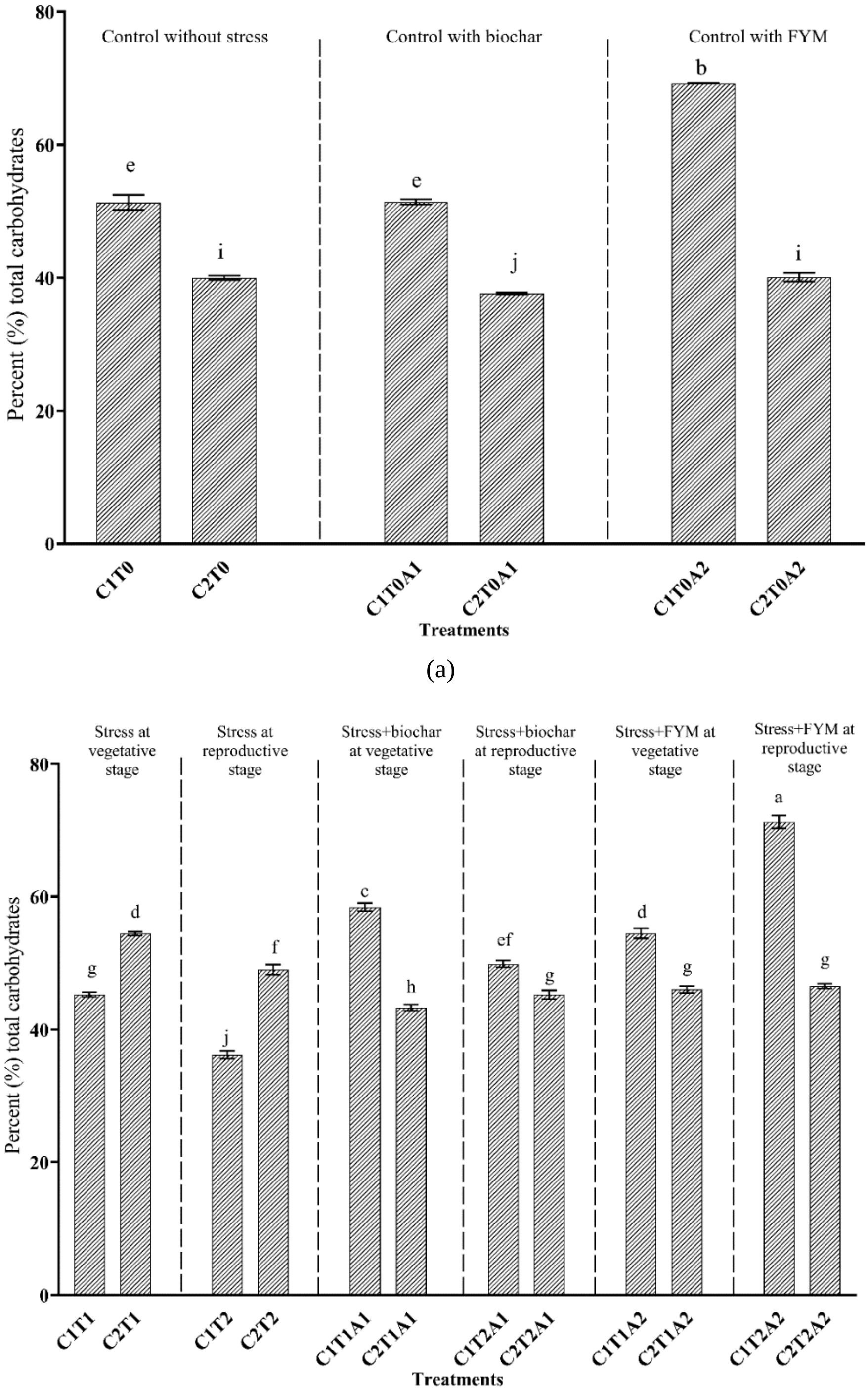
Under *Vigna radiata* cultivation, exposure to drought at vegetative or reproductive stage enhanced the content of grain phytic acid up to 40% and 60% respectively. Amending the soil with biochar under followed by drought at the vegetative stage enhanced grain phytic acid content. However, FYM as soil amendment decreased phytic acid content under the tested drought treatments.

Drought at either stage of *Lathyrus sativus* led to a reduction in grain phytic acid content (up to 37%). Amending the soil with biochar or FYM led to an increase in grain phytic acid content up to 22% and 40% respectively. Under well-watered conditions, both the soil amendments (biochar or FYM) increased grain phytic acid content in *Vigna radiata* (18% and 19% respectively). However, a decline was noted for the same for *Lathyrus sativus* grains (up to 19% and 13% respectively).

Table 4.7: Root, shoot, pod and total biomass of the crops (Mean ± SD) as affected by drought and application of soil amendments

Treatments	Root g^{-1} Plant	Shoot g^{-1} Plant	Pod g^{-1} Plant	Total g^{-1} Plant
Control				
C1T0	3.505^{m} ±0.37	0.288^{fg} ±0.02	1.469^{f} ±0.34	5.262
C2T0	3.895^{m} ±0.29	0.654^{def} ±0.02	2.439^{ef} ±0.41	6.988
Stress at vegetative stage				
C1T1	5.842^{ijk} ±0.31	0.246^{g} ±0.01	1.863^{ef} ±0.27	7.952
C2T1	5.108^{kl} ±0.43	0.773^{cde} ±0.13	2.049^{ef} ±0.19	7.930
Stress at reproductive stage				
C1T2	4.355^{lm} ±0.60	0.284^{fg} ±0.02	1.525^{f} ±0.18	6.165
C2T1	5.108^{kl} ±0.43	0.773^{cde} ±0.13	2.049^{ef} ±0.19	7.930
Control with biochar				
C1T0A1	6.717^{hi} ±0.27	0.409^{efg} ±0.01	2.207^{ef} ±0.17	9.333
C2T0A1	10.721^{ab} ±0.31	1.277^{b} ±0.13	5.304^{ab} ±0.24	17.301
Control with FYM				
C1T0A2	11.605^{a} ±0.21	1.069^{bc} ±0.07	4.879^{b} ±0.26	17.553
C2T0A2	8.158^{ef} ±0.22	2.359^{a} ±0.22	5.159^{b} ±0.18	15.676
Stress at vegetative stage with biochar				
C1T1A1	8.956^{de} ±0.25	0.492^{defg} ±0.10	5.590^{ab} ±0.33	15.038
C2T1A1	10.199^{bc} ±0.33	1.389^{b} ±0.15	5.816^{ab} ±0.10	17.404
Stress at reproductive stage with biochar				
C1T2A1	8.783^{def} ±0.31	0.414^{efg} ±0.02	2.762^{de} ±0.34	11.959
C2T2A1	9.357^{cd} ±0.44	1.298^{b} ±0.09	6.231^{a} ±0.25	16.886
Stress at vegetative stage with FYM				
C1T1A2	7.899^{fg} ±0.23	0.562^{defg} ±0.03	3.713^{c} ±0.62	12.173
C2T1A2	6.542^{hij} ±0.22	1.212^{b} ±0.18	2.683^{de} ±0.32	10.437
Stress at reproductive stage with FYM				
C1T2A2	5.623^{jk} ±0.19	0.437^{efg} ±0.03	2.344^{ef} ±0.24	8.404
C2T2A2	5.593^{jk} ±0.33	0.846^{cd} ±0.18	3.394^{cd} ±0.26	9.833

Data presented as mean ±SE; Different superscript lower case letters within each column indicate significant differences between treatments at 5% level of significance (at P≤ 0.05) according to to Tukey’s honestly significant difference (HSD) test.

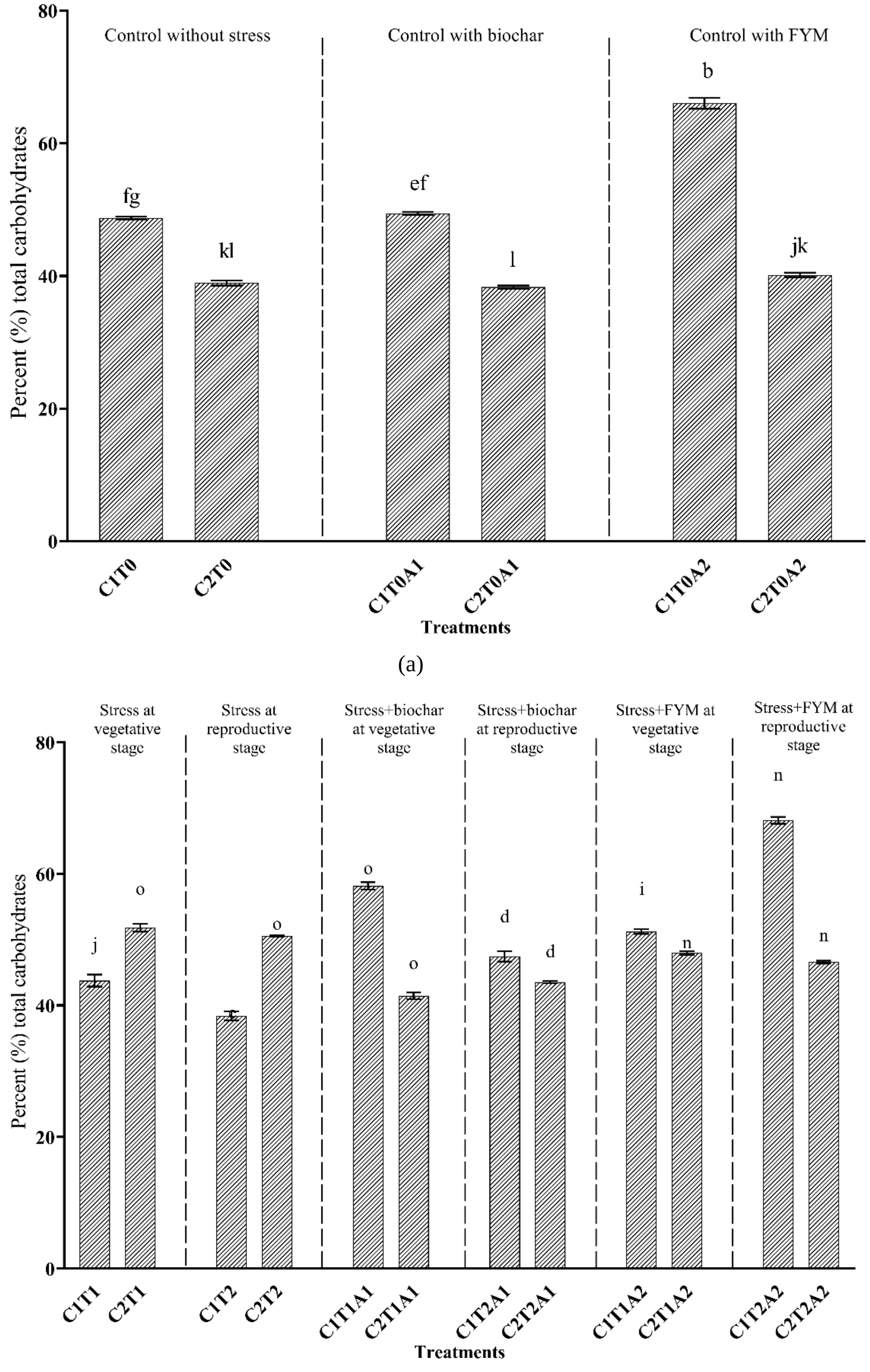


(a)

(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance ($P \leq 0.05$) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.23: Grain total carbohydrates as affected by application of (a) biochar and FYM as soil amendments and (b) under drought at vegetative and reproductive stage and application of biochar and FYM as soil amendments in year 1.

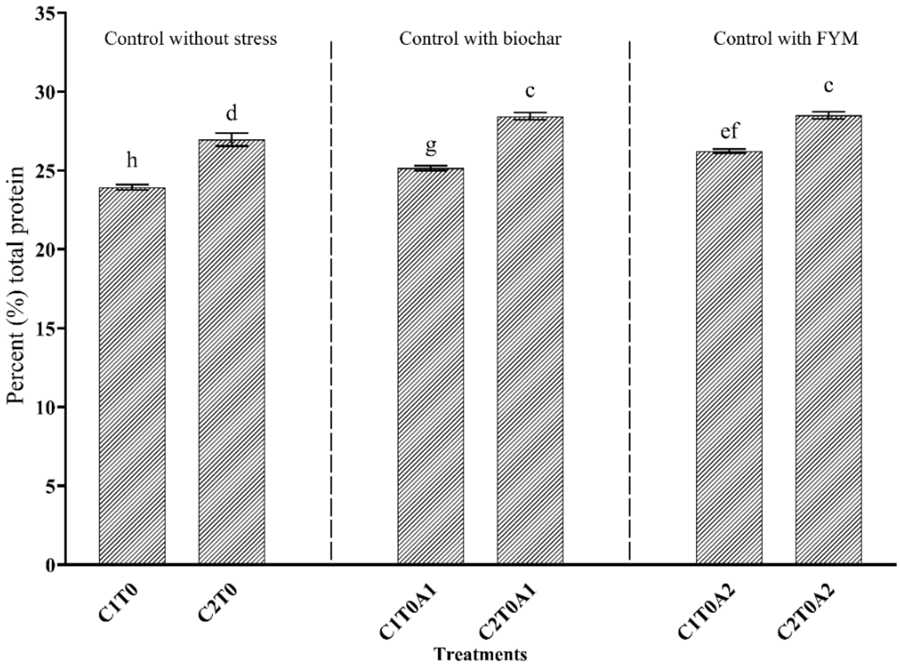


(a)

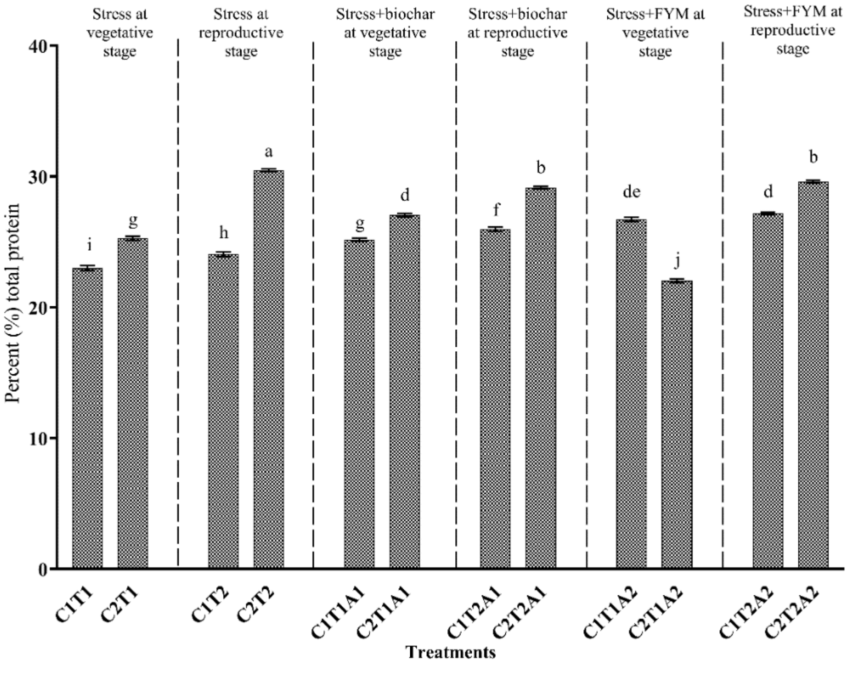
(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance ($P \leq 0.05$) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.24: Grain total carbohydrates as affected by application of (a) biochar and FYM as soil amendments and (b) under drought at vegetative and reproductive stage and application of biochar and FYM as soil amendments in year 2.



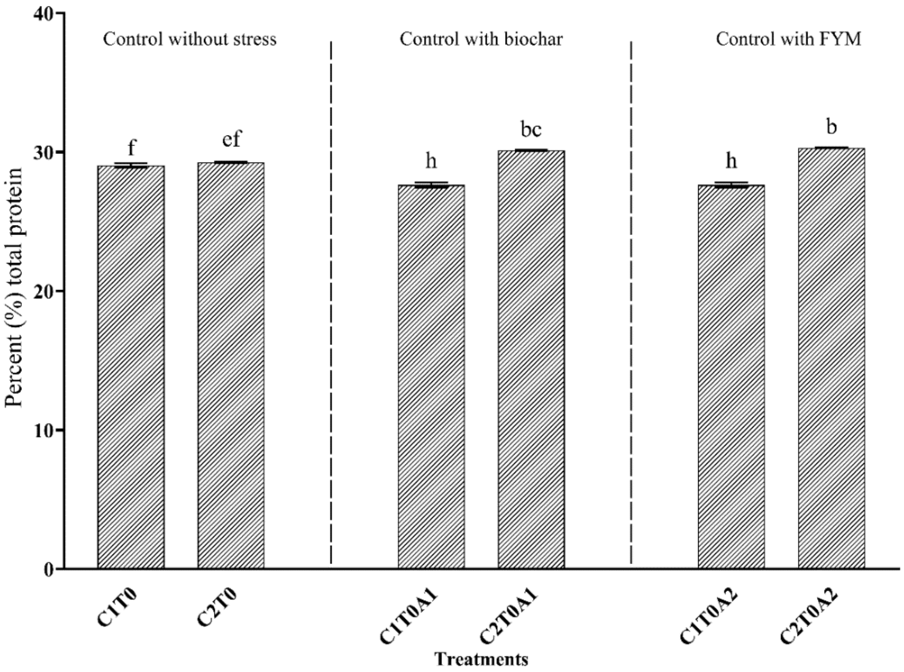
(a)



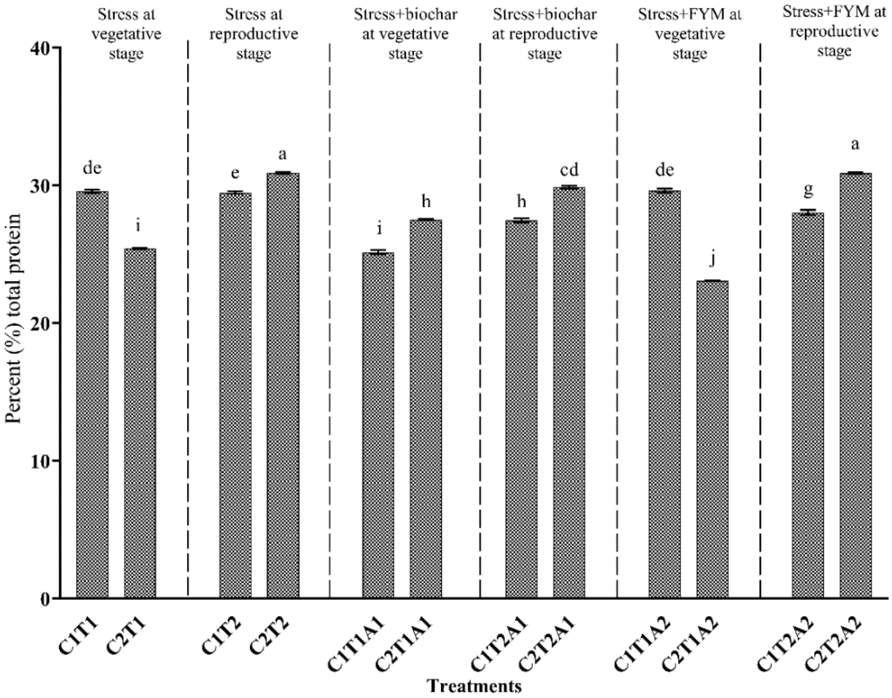
(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance ($P \leq 0.05$) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.25: Grain total protein as affected by application of (a) biochar and FYM as soil amendments and (b) under drought at vegetative and reproductive stage and application of biochar and FYM as soil amendments in year 1.



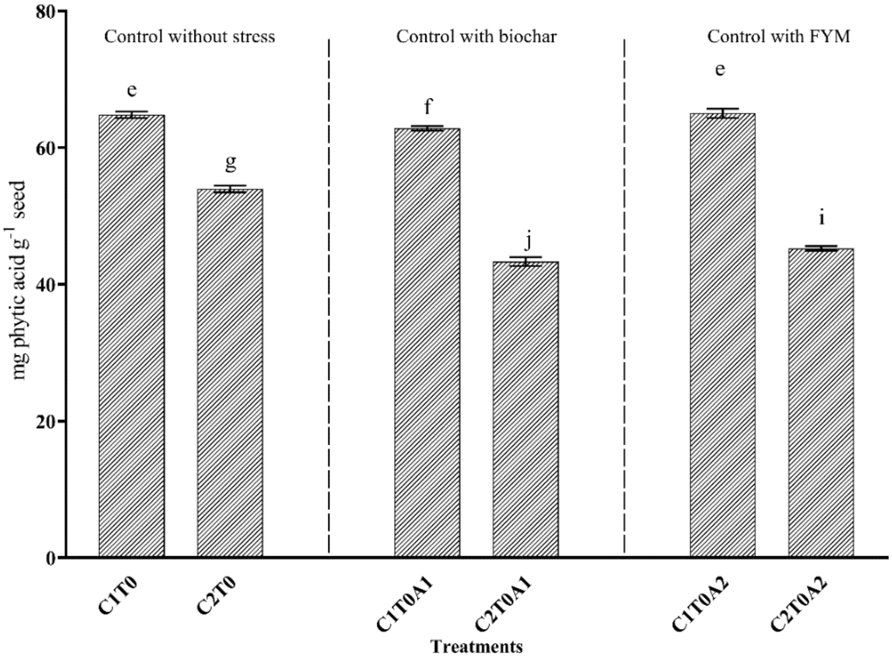
(a)



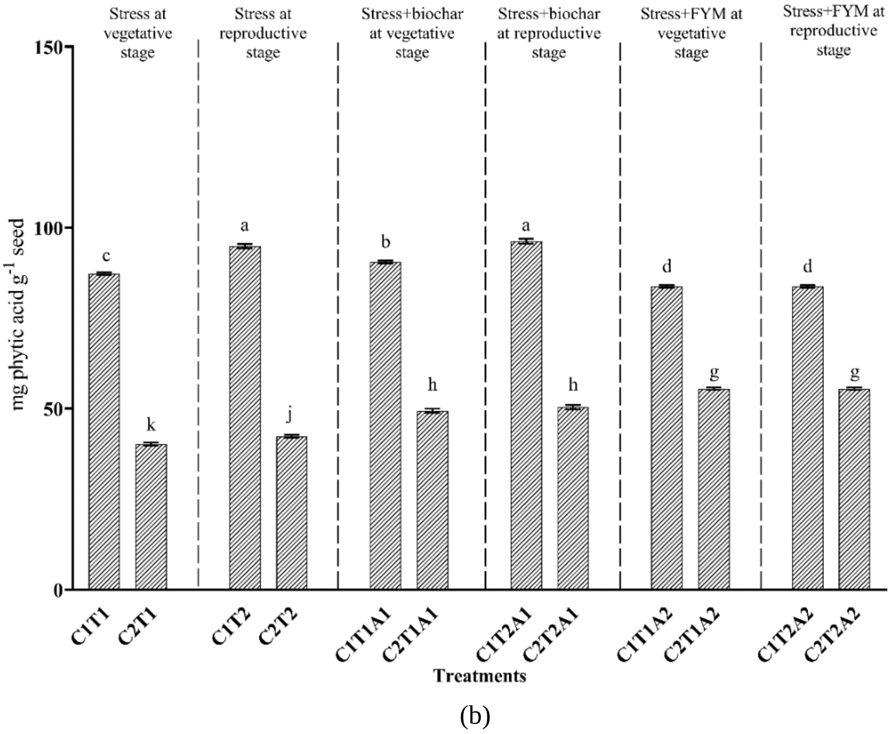
(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance (P≤ 0.05) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.26: Grain total protein as affected by application of (a) biochar and FYM as soil amendments and (b) under drought at vegetative and reproductive stage and application of biochar and FYM as soil amendments in year 2.



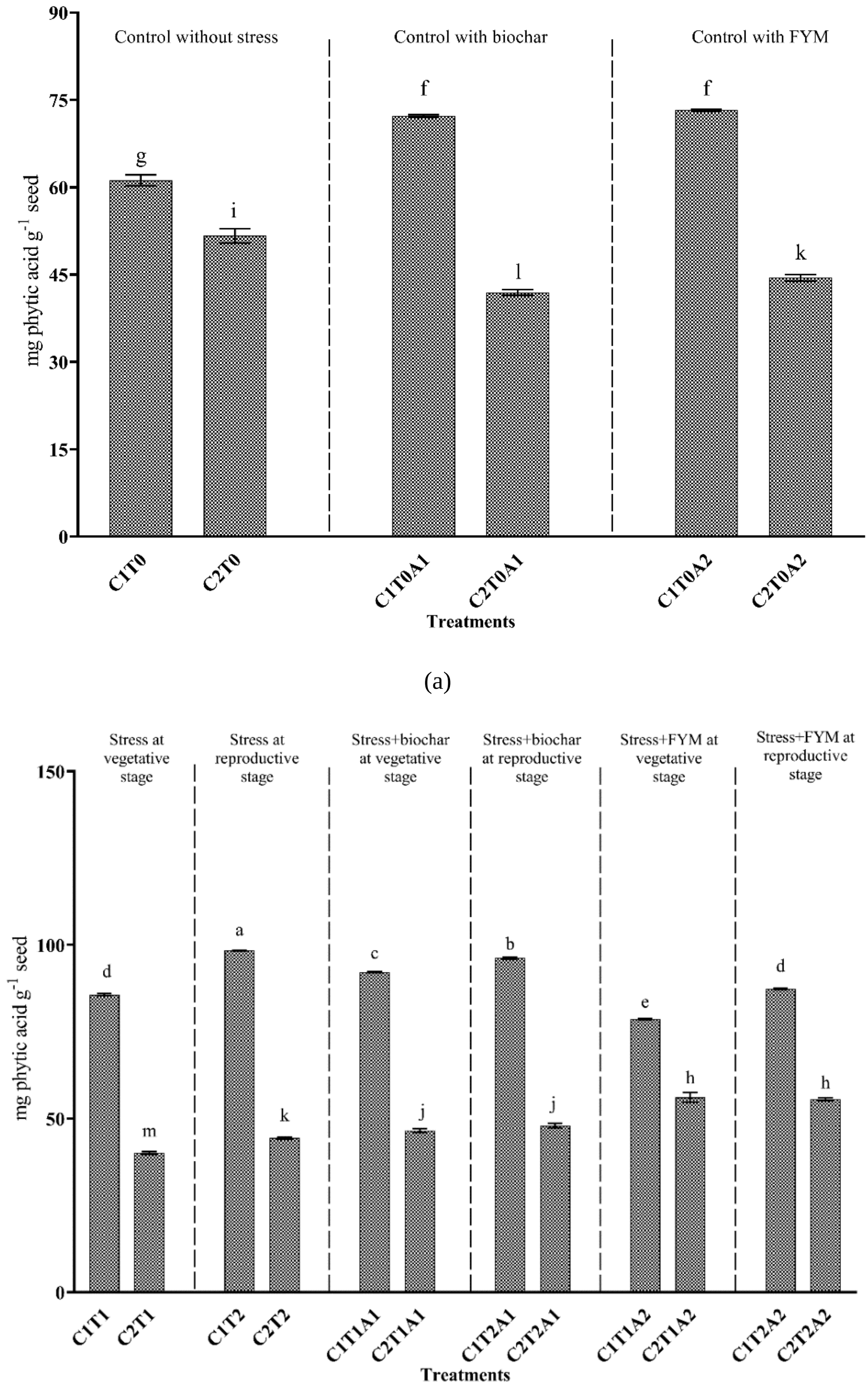
(a)



(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance (P≤ 0.05) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.27: Grain phytic acid as affected by application of (a) biochar and FYM as soil amendments and (b) under drought at vegetative and reproductive stage and application of biochar and FYM as soil amendments in year 1.

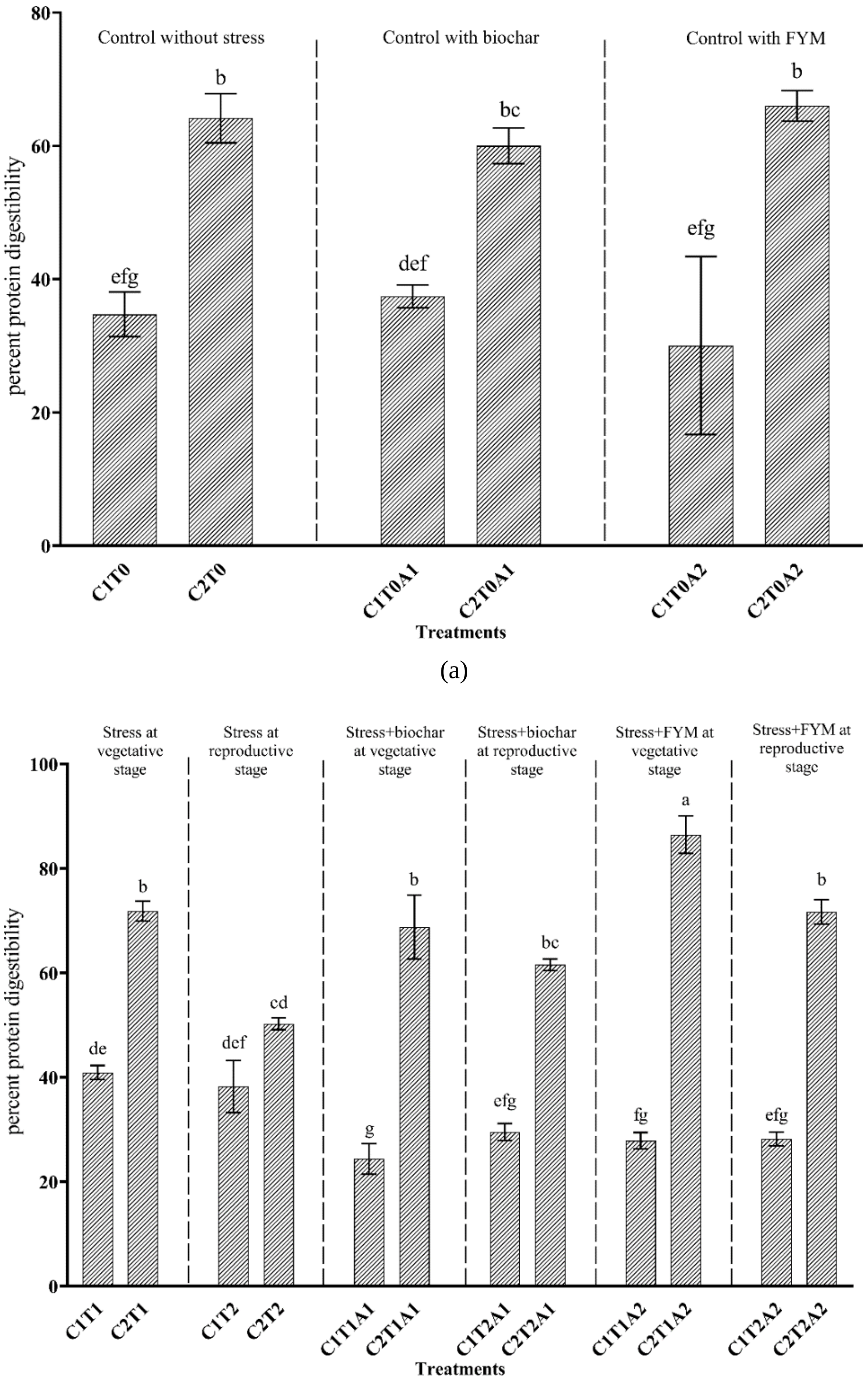


(a)

(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance (P≤ 0.05) according to Tukey’s Honestly Significant Difference (HSD)

Figure 4.28 Grain phytic acid as affected by application of (a) biochar and FYM as soil amendments and (b) under drought at vegetative and reproductive stage and application of biochar and FYM as soil amendments in year 2.

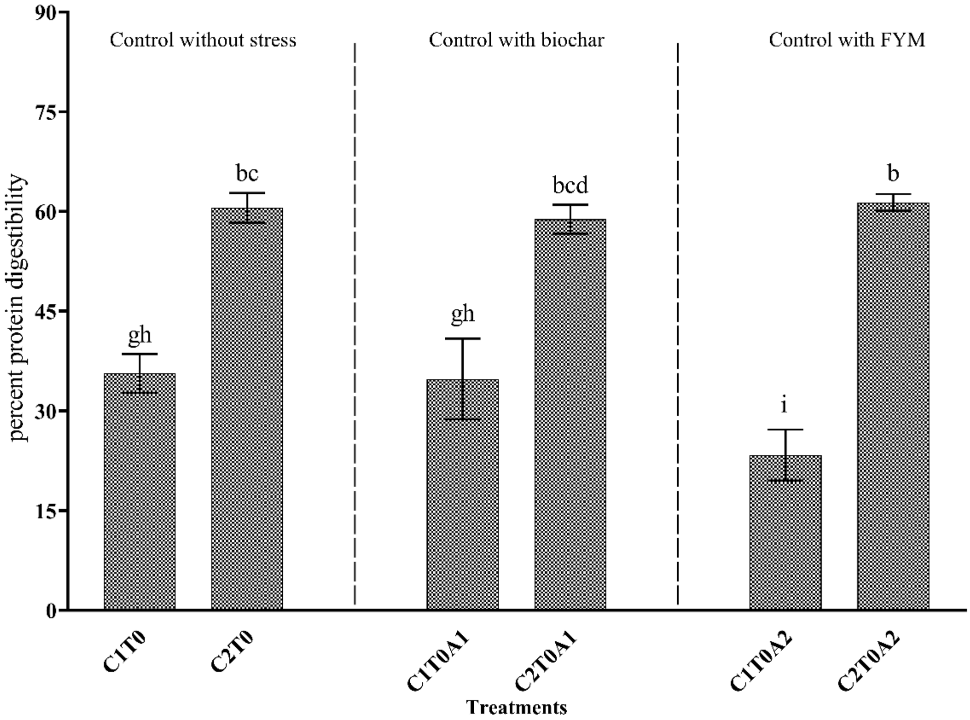


(a)

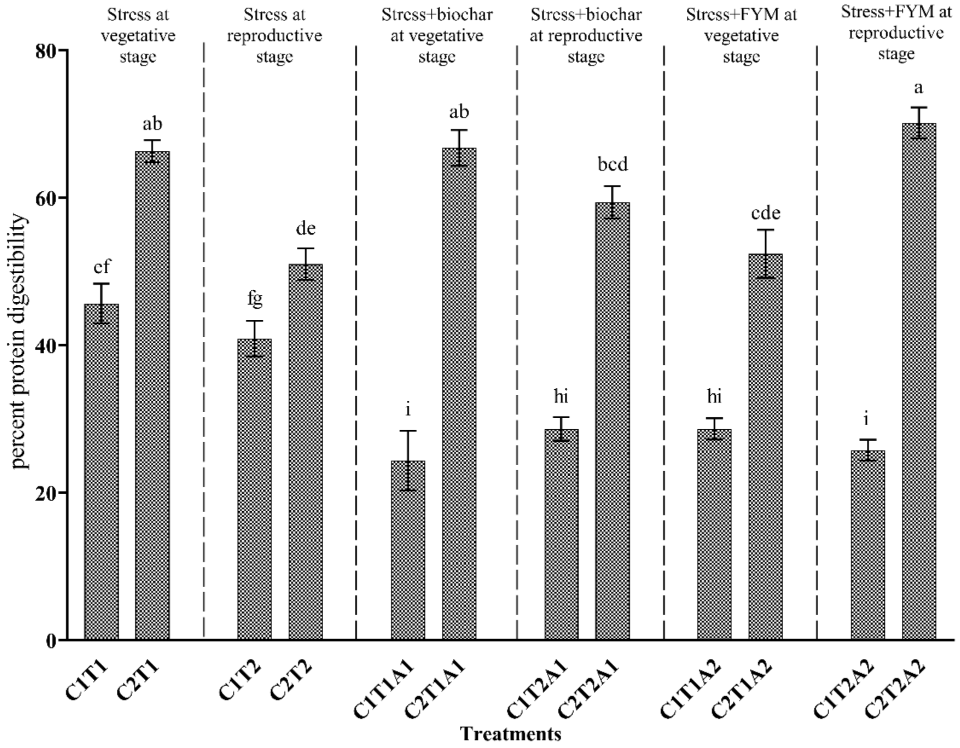
(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance (P≤ 0.05) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.29: Grain *in-vitro* protein digestibility as affected by application of (a) biochar and FYM as soil amendments and (b) under drought at vegetative and reproductive stage and application of biochar and FYM as soil amendments in year 1.



(a)



(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance (P≤ 0.05) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.30: Grain *in-vitro* protein digestibility as affected by application of (a) biochar and FYM as soil amendments and (b) under drought at vegetative and reproductive stage and application of biochar and FYM as soil amendments in year 2.

In-vitro Protein Digestibility of the grains

Drought at either stage increased grain IVPD in *Vigna radiata* (up to 28%) and *Lathyrus sativus* (up to 106%). In both the years of cultivation, amending the soils with FYM under drought revealed a higher reduction in IVPD of *Vigna radiata* grains (up to 46%) as compared to biochar (up to 37%). However, using FYM as a soil amendment in *Lathyrus sativus* increased grain IVPD (up to 42%) over biochar (up to 22% increase).

Protein Fractions of the grains

a. Grain Globulin Content

Drought exposure at either stage reduced the globulin fraction of grain protein in both the crops (up to 45%). Amending the soils with biochar or FYM had no significant effect on globulin fractions of grain protein in *Vigna radiata* when the crop experienced drought during the vegetative stage. However, it increased when the drought was imposed during the reproductive stage of the crop (up to 82% and 70%, respectively).

However, amending the soil with biochar in *Lathyrus sativus* resulted in an increased grain globulin (up to 34%) compared to FYM (up to 15%) when the drought appeared at the vegetative stage.

Albumin Content

Irrespective of the crops, drought increased grain albumin content (up to 143%). Biochar as soil amendment led to a higher increment (up to 51%) in grain albumin content over FYM (up to 30%) under drought at the vegetative stage of *Vigna radiata*. However, a higher reduction of grain albumin was observed when biochar amended soils were exposed to drought at the reproductive stage (up to 38%) compared to FYM (up to 30%).

Under *Lathyrus sativus* cultivation, amending the soils with biochar increased grain albumin content (up to 4%) compared to FYM (21% reduction) when exposed to drought at the vegetative stage. However, when exposed to drought at the reproductive stage, biochar amended *Lathyrus sativus* resulted in reduced grain albumin (up to 11%) compared to FYM (up to 27% increase).

b. Grain prolamin content

In *Vigna radiata*, drought at either stage of growth decreased grain prolamin content by up to 35% in the first year of cultivation. Biochar as soil amendment resulted in a higher reduction in grain prolamin content (up to 41%) compared to FYM (35%).

Under cultivation of *Lathyrus sativus* exposure in either stage increased the grain prolamin content (up to 9%) in the first year. Amending the soil with FYM resulted in higher grain prolamin content (up to 20%) compared to biochar (up to 13%) when exposed to drought at either stage of growth.

Drought during the second year of cultivation (at either stage) of *Vigna radiata* increased the grain prolamin content significantly (up to 22%). Significantly higher grain prolamin content was recorded in FYM amended soils (23%) compared to biochar (11%) when drought appeared in the vegetative stage. However, the same treatments recorded a decline in grain prolamin content (up to 56%) when the drought was imposed at the reproductive stage.

A significant decrease (up to 23%) in grain prolamin content was documented during the second year of *Lathyrus sativus* cultivation when drought appeared at either growth stage. Amending the soil with biochar led to a higher reduction of the same (up to 56%) as compared to FYM (up to 8%).

c. Grain glutelin content

Significant decrease in grain glutelin content (up to 23%) of both the crops was documented when drought appeared at either stage of growth. However, an exception was noted in *Vigna radiata* crops exposed to drought at the vegetative stage (22% increase).

Significant increase of grain glutelin in FYM amended *Vigna radiata* crops was documented as compared to biochar (up to 20%) under drought treatments at either stage of crop growth. However, in *Lathyrus sativus* grains produced with biochar as soil amendment, documented a higher reduction in (up to 54%) grain glutelin as compared to FYM (up to 8%) under drought treatments.

Residual grain protein

Drought at either stage of crop growth increased the residual protein fraction up to 116% in *Vigna radiata*. Amending the soil with FYM under drought significantly lowered the grain residual protein fraction (up to 38%) as compared to biochar (up to 35%) under drought treatments.

Significant reduction (up to 44%) of residual grain protein of *Lathyrus sativus* was found under exposure to drought at either stage of crop growth. Amending the soil with biochar reduced the residual protein (up to 30%) as compared to FYM when drought appeared at the vegetative stage. However, when exposed to drought at reproductive stage both the soil amendments enhanced the grain residual protein in *Lathyrus sativus*, with higher increment under biochar application (up to 56%).

Grain Mineral Contents

Exposure to drought at the vegetative stage of *Vigna radiata* crop enhanced the grain minerals (Fe, Na, and Ca by 54%, 65%, and 24%, respectively) content in both the years of cultivation. However, it reduced Zn, K, and Mg in the grains by 77 %, 1%, and 43%, respectively. Amending the soils with biochar under drought at the vegetative stage of *Vigna radiata* significantly reduced Fe, K, Na, and Ca (up to 25%, 2%, 4%, and 14%, respectively) but enhanced Mg and Zn by 38% and 15% respectively. Similarly, amending the soils with FYM delineated a reduction in Fe, K, Na, and Ca (up to 42%, 1%, 38%, and 14%, respectively), but an increase in Zn and Mg was recorded (up to 181%, and 51%) when drought appeared at vegetative stage.

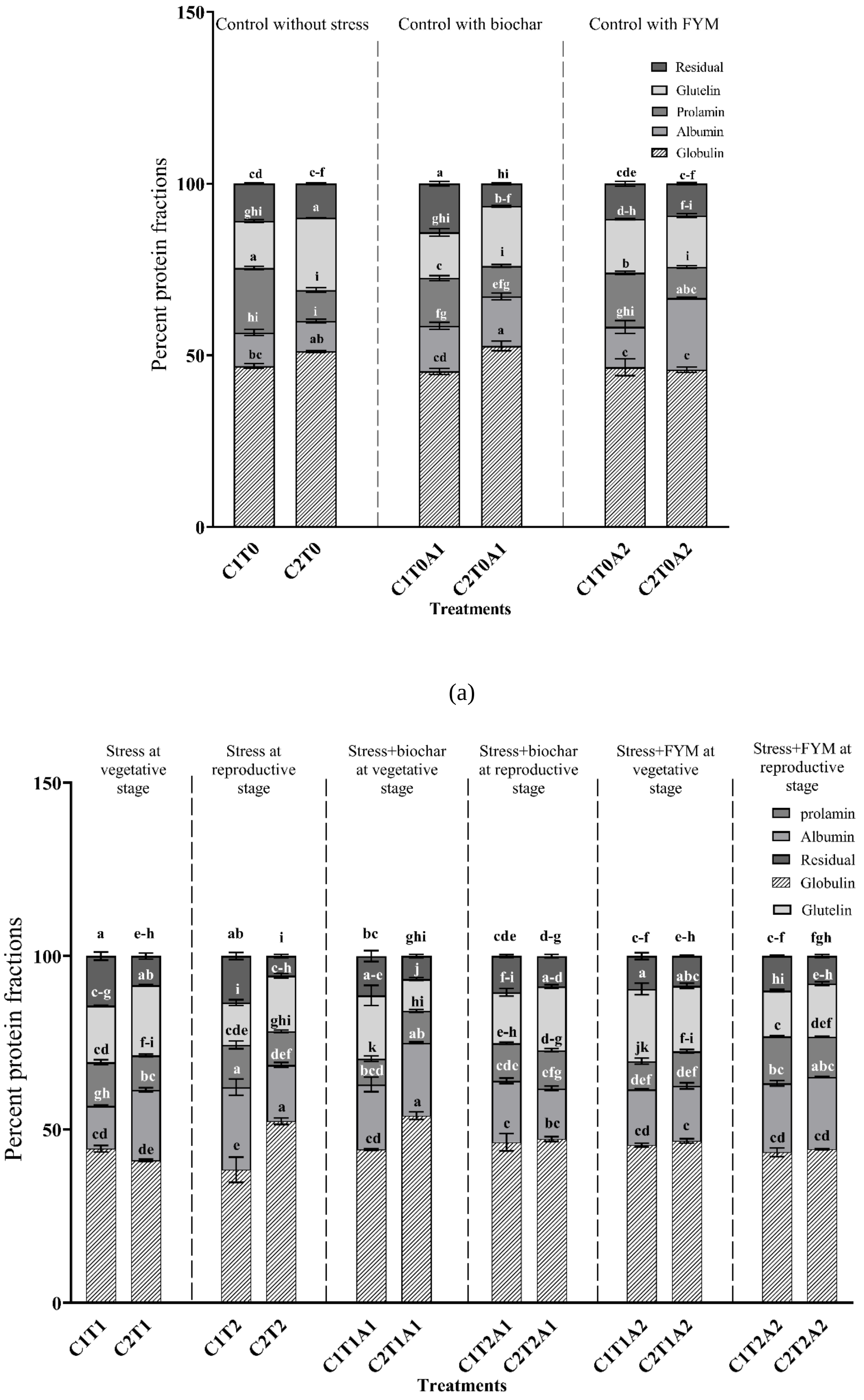
Drought at the reproductive stage of *Vigna radiata* cultivation led to an increase in Fe, Zn, Mg, Na, and Ca up to 50%, 10%, 31%, 18%, and 27%, respectively, but a reduction of K (1%) was also documented. Amending the soil with biochar led to a higher reduction of Fe and Zn (72% and 88%, respectively), compared to FYM, where K, Mg, Na, and Ca (up to 1.5%, 62%, 38%, and 22%, respectively) were lowered when drought appeared at the reproductive stage.

Under *Lathyrus sativus* cultivation, exposure to drought at the vegetative stage significantly enhanced Zn, Mg, Na, and Ca by 22%, 15%, 62%, 90%, and 2%, respectively, along with a decline of Fe content (2%). Amending the soil with biochar under drought at the vegetative stage, significantly increased Zn, Mg, and Na (up to 68%, 106%, and 62%, respectively) with a reduction of Fe and Ca (15% and 2% correspondingly). Meanwhile, FYM as a soil amendment led to an increment of Zn, Mg, and Na (21%, 25%, and 77%, respectively) with a decrease in Fe and Ca content (21% and 9% correspondingly) when drought was imposed at vegetative stage of *Lathyrus sativus*.

When drought appeared at reproductive stage of *Lathyrus sativus*, it showed an increase in K, Mg, Na, and Ca (up to 16%, 33%, 34%, and 14%, respectively) along with a decline of Fe, and Zn (up to 33%, and 58% correspondingly). Biochar as soil amendment enhanced Zn, Mg, and Na (up to 182%, 38%, and 90%) along with reduced Fe, K, and Ca content (up to 16%, 21%, and 24%, respectively). While amending the soil with FYM, significant enhancement of Zn and Mg content (up to 59% and 18%, respectively) was documented when drought appeared at reproductive stage. But a reduction in Fe, Na, and Ca content (up to 17%, 19%, and 24% respectively) was noted under the same treatment.

Interactive effects

In both the years of cultivation, the grain phytic acid showed a strong negative correlation with IVPD (up to R=-0.802, P≤0.01), grain globulin content (up to R=-0.541, P≤0.05) but a strong positive correlation with grain residual protein (R=0.763, P≤0.01). Furthermore, the IVPD of the grains also revealed a strong negative correlation with grain carbohydrates (up to R=-0.655) at P≤0.01 in both the years of cultivation. In the first year of cultivation, the residual protein showed a strong negative correlation with crude protein (R=-0.649, P≤0.01), IVPD (R=-0.545, P≤0.05), and globulin content (R=-0.619, P≤0.01). However, in the second year of cultivation, a strong negative correlation of globulin with residual protein (R=-0.774, P≤0.01) and albumin was documented (R=-0.645, P≤0.01). Moreover, we observed a highly strong positive correlation of glutelin with prolamin fraction (R=0.990, P≤0.01).

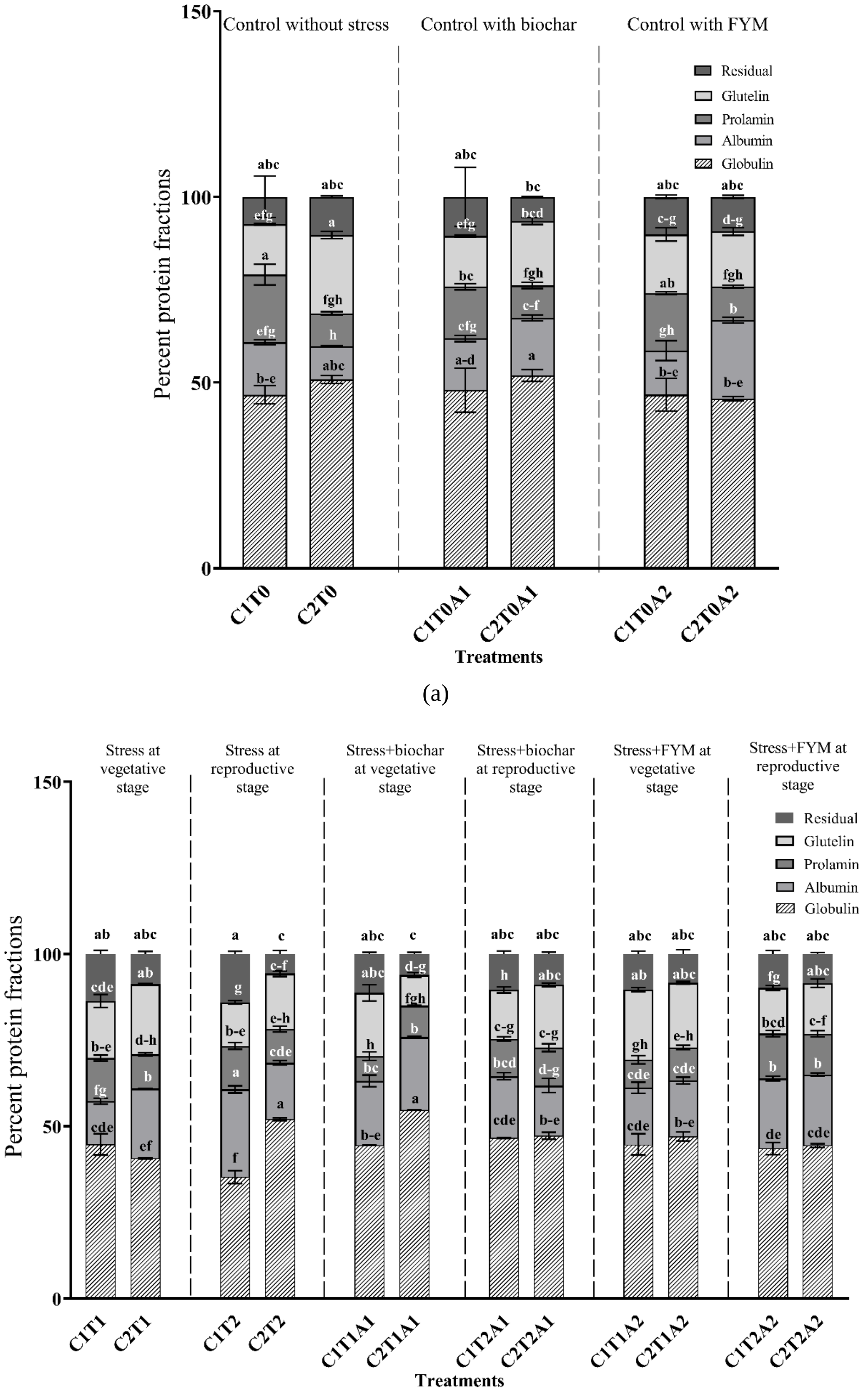


(a)

(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance (P≤ 0.05) according to Tukey’s Honestly Significant Difference (HSD)

Figure 4.31 Grain protein fractions as affected by application of (a) biochar and FYM as soil amendments and (b) under drought at vegetative and reproductive stage and application of biochar and FYM as soil amendments in year 1.



(a)

(b)

*Different lowercase letters above each column indicate significant differences between treatments at 5% level of significance (P≤ 0.05) according to Tukey's Honestly Significant Difference (HSD)

Figure 4.32 Grain protein fractions as affected by application of (a) biochar and FYM as soil amendments and (b) under drought at vegetative and reproductive stage and application of biochar and FYM as soil amendments in year 2.

Table 4.8: Mineral content of the grains (Mean ± SD) as affected by drought and application of soil amendments in year 1

Treatments	Na (µg g^{-1}) ± SD	Mg (µg g^{-1}) ± SD	K (µg g^{-1}) ± SD	Ca (µg g^{-1}) ± SD	Fe (µg g^{-1}) ± SD	Zn (µg g^{-1}) ± SD
Control						
C1T0	4144.08 ^{fg} ±3.39	162.63 ^{i}± 5.16	15809.32 ^{a}± 450.34	563.33 ^{efg}± 19.37	162.63 ^{i}± 5.17	236.77 ^{d}±9.86
C2T0	2826.88 ^{kl} ±7.75	343.37 ^{b}± 3.63	13607.67 ^{d}± 75.68	792.25 ^{ab}± 25.68	343.38 ^{b}± 3.64	155.08 ^{g}±3.30
Drought at vegetative stage						
C1T1	6301.88 ^{a} ±41.82	266.53 ^{cd} ± 13.49	15639.36 ^{a}± 122.50	704.12 ^{bc}± 83.03	266.53 ^{cd}± 13.49	53.19 ^{j}±3.30
C2T1	3298.21 ^{ij} ±110.87	334.0467 ^{b}± 3.01	15773.25 ^{a}± 368.03	809.08 ^{a}± 12.90	334.05 ^{b}± 3.01	186.34 ^{ef}±1.28
Drought at reproductive stage						
C1T2	4894.50 ^{e} ±109.34	242.87 ^{ef}± 9.91	15621.44 ^{ab}± 143.21	646.17 ^{cde}± 14.10	242.88 ^{ef}± 9.91	253.08 ^{c}±7.87
C2T2	3800.71 ^{e}±33.98	227.54 ^{fg}± 8.46	15835.08 ^{d}± 45.17	718.29 ^{bc}± 11.87	227.55 ^{fg}± 8.46	100.00 ^{i}±6.30
Control with biochar						
C1T0A1	4411.71 ^{f} ±35.49	242.56 ^{ef}± 9.48	15387.40 ^{ab}± 281.91	533.41 ^{fg}± 29.78	242.57 ^{ef}± 9.49	132.15 ^{h}±6.08
C2T0A1	2690.63 ^{l} ±18.23	246.29 ^{fg}± 4.07	14128.25 ^{c}± 62.34	661.29 ^{cd}± 17.94	246.30 ^{def}± 4.07	221.96 ^{d}±2.42
Control with FYM						
C1T0A2	5542.08 ^{cd} ± 27.12	583.29 ^{a}± 12.81	15381.85 ^{ab}± 284.49	596.92 ^{defg}± 9.73	583.29 ^{a}± 12.82	290.94 ^{b}±7.62
C2T0A2	3351.75 ^{ij} ±182.84	255.21 ^{de}± 1.77	14849.17 ^{c}± 13.29	547.79 ^{fg}± 40.65	255.21 ^{de}± 1.78	311.96 ^{a}±2.33
Stress at vegetative stage with biochar						
C1T1A1	6266.00 ^{ab} ± 2.29	199.79 ^{h}± 7.55	15288.65 ^{ab}± 200.19	601.21 ^{defg}± 6.36	199.79 ^{h}± 7.56	200.33 ^{e}±4.91
C2T1A1	5364.33 ^{d} ± 86.59	281.87 ^{c}± 1.69	14237.92 ^{d}± 14.66	788.46 ^{ab}± 1.35	281.88 ^{c}± 1.69	313.92 ^{a}±3.75
Stress at reproductive stage with biochar						
C1T2A1	3156.13 ^{ijk} ±25.84	66.62 ^{j}± 2.34	15464.37 ^{ab}± 135.37	604.42 ^{def}± 7.53	66.62 ^{j}± 2.35	29.00 ^{k}±3.96
C2T2A1	4147.50 ^{fg} ± 279.86	190.83 ^{h}± 2.41	12393.75 ^{e}± 262.12	610.13 ^{def}± 13.80	190.84 ^{h}± 2.41	181.63 ^{f}±2.28
Stress at vegetative stage with FYM						
C1T1A2	3461.21^{hi} ± 200.93	152.19 ^{i}± 13.45	15386.42 ^{ab}± 308.59	514.38 ^{g}± 3.24	152.19 ^{i}± 13.46	149.47 ^{g}±4.58
C2T1A2	5841.29 ^{bc} ± 377.08	263.54 ^{cde}± 3.78	15893.00 ^{a}± 92.65	730.38 ^{abc}± 2.56	263.55 ^{cde}± 3.79	225.75 ^{d}±6.48
Stress at reproductive stage with FYM						
C1T2A2	2996.71 ^{jkl} ± 148.28	207.28 ^{gh}± 4.98	15382.99 ^{ab}± 281.72	543.00 ^{fg}± 56.71	207.28 ^{gh}± 4.98	31.13 ^{k}±5.02
C2T2A2	3071.38 ^{ijkl} ±129.44	187.25 ^{h}± 3.72	15778.00 ^{a}± 37.66	613.77 ^{def}± 23.33	187.25 ^{h}± 3.73	115.71 ^{i}±1.15

Data presented as mean ±SE; Different superscript lower case letters within each column indicate significant differences between treatments at 5% level of significance (at P≤ 0.05) according to to Tukey's honestly significant difference (HSD) test.

Table 4.9: Mineral content of the grains (Mean ± SD) as affected by drought and application of soil amendments in year 2

Treatments	**Na (µg g^{-1}) ± SD**	**Mg (µg g^{-1}) ± SD**	**K (µg g^{-1}) ± SD**	**Ca (µg g^{-1}) ± SD**	**Fe (µg g^{-1}) ± SD**	**Zn (µg g^{-1}) ± SD**
Control						
C1T0	4108.92 ^{h}±31.74	15098.96 ^{c}±23.38	15546.04 ^{a}±26.07	519.58 ^{i}±12.01	164.87 ^{i}±1.58	232.94 ^{d}±6.29
C2T0	2944.48 ^{m}±13.37	5264.33 ^{q}±13.34	13739.83 ^{f}±33.97	760.00 ^{ab}±8.75	328.00 ^{b}±3.12	160.42 ^{h}±3.91
Drought at vegetative stage						
C1T1	6775.84 ^{a}±17.72	8589.56 ^{l}±24.75	15558.66 ^{a}±17.70	634.58 ^{e}±6.88	273.06 ^{c}±4.79	53.01 ^{m}±3.30
C2T1	3525.08 ^{jk}±32.10	8560.17 ^{l}±10.13	15534.08 ^{a}±20.98	757.92 ^{ab}±4.73	326.25 ^{b}±3.68	198.34 ^{f}±3.07
Drought at reproductive stage						
C1T2	4667.29 ^{f}±20.87	19785.08 ^{a}±16.43	15538.75 ^{a}±3.57	662.50 ^{d}±4.51	247.38 ^{e}±5.24	257.70 ^{c}±1.89
C2T2	3609.43 ^{j}±18.14	7052.33 ^{p}±13.52	15541.50 ^{a}±7.23	703.33 ^{c}±5.05	221.71 ^{f}±3.67	65.84 ^{l}±2.80
Control with biochar						
C1T0A1	4598.74 ^{f}±37.08	11467.41 ^{h}±20.71	15545.79 ^{a}±28.77	552.92 ^{h}±10.10	248.17 ^{e}±2.56	131.65 ^{j}±5.99
C2T0A1	2619.40 ^{n}±10.88	7382.33 ^{o}±11.61	14266.08 ^{d}±16.06	676.25 ^{d}±10.68	258.25 ^{de}±6.57	218.25 ^{e}±4.19
Control with FYM						
C1T0A2	5821.66 ^{d}±49.12	11749.54 ^{g}±24.48	15542.90 ^{a}±32.71	622.50 ^{ef}±7.50	588.00 ^{a}±7.33	294.88 ^{b}±3.51
C2T0A2	3308.72 ^{l}±57.89	12535.83 ^{e}±10.13	15221.83 ^{c}±19.13	577.50 ^{g}±5.00	276.50 ^{c}±4.24	315.04 ^{a}±2.32
Stress at vegetative stage with biochar						
C1T1A1	6468.41 ^{b}±35.63	11876.61 ^{f}±23.55	15401.01 ^{b}±19.31	605.00 ^{f}±12.31	203.65 ^{gh}±2.95	202.30 ^{f}±2.69
C2T1A1	5653.14 ^{e}±30.19	17700.33 ^{b}±9.47	14113.83 ^{e}±13.99	768.75 ^{a}±8.20	277.42 ^{c}±5.12	318.54 ^{a}±4.50
Stress at reproductive stage with biochar						
C1T2A1	3467.54 ^{k}±30.68	9219.58 ^{k}±43.51	15541.09 ^{a}±10.36	634.58 ^{e}±6.41	67.32 ^{j}±2.09	29.00 ^{g}±3.96
C2T2A1	4303.71 ^{g}±31.77	9737.00 ^{j}±10.51	12269.33 ^{g}±15.71	604.17 ^{f}±5.64	196.71 ^{gh}±3.14	186.04 ^{n}±1.80
Stress at vegetative stage with FYM						
C1T1A2	3766.33 ^{i}±38.06	13015.16 ^{d}±28.69	15555.64 ^{a}±26.56	530.83 ^{hi}±5.05	157.93 ^{i}±8.75	146.45 ^{i}±1.65
C2T1A2	6059.95 ^{c}±26.07	10706.50 ^{i}±13.71	15517.50 ^{a}±17.18	736.67 ^{b}±8.78	265.54 ^{cd}±2.88	231.33 ^{d}±5.78
Stress at reproductive stage with FYM						
C1T2A2	3221.45 ^{l}±26.93	7600.44 ^{n}±75.62	15543.05 ^{a}±20.27	533.33 ^{hi}±7.53	207.43 ^{g}±4.97	31.01 ^{n}±5.22
C2T2A2	3740.36 ^{i}±25.45	8348.92 ^{m}±7.64	15537.92 ^{a}±14.88	631.25 ^{e}±1.25	190.04 ^{h}±4.32	105.21 ^{k}±3.46

Data presented as mean ±SE; Different superscript lower case letters within each column indicate significant differences between treatments at 5% level of significance (at P≤ 0.05) according to to Tukey's honestly significant difference (HSD) test.

Table 4.10: Table showing correlation matrix amongst grain quality of the crops as affected by drought and application of soil amendments in year 1.

Parameters	Grain Carbohydrates	Grain Protein	PhyticAcid	IVPD	Globulin	Albumin	Prolamin	Glutelin	Residual protein
Grain Carbohydrates	1								
Grain Protein	-0.064	1							
PhyticAcid	0.284	-0.461	1						
IVPD	-.542*	0.162	-0.769**	1					
Globulin	-0.245	0.440	-0.527*	0.289	1				
Albumin	-0.080	0.162	0.112	0.144	-0.400	1			
Prolamin	0.358	-0.302	0.151	-0.353	-0.243	-0.374	1		
Glutelin	0.009	0.007	-0.144	0.187	-0.025	-0.349	-0.433	1	
Residual protein	0.102	-0.649**	0.672**	-0.545*	-0.619**	-0.181	0.425	-0.141	1

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

Table 4.11: Table showing correlation matrix amongst grain quality of the crops as affected by drought and application of soil amendments in year 2.

Parameters	Grain Carbohydrates	Grain Protein	PhyticAcid	IVPD	Globulin	Albumin	Prolamin	Glutelin	Residual protein
Grain Carbohydrates	1								
Grain Protein	-0.364	1							
PhyticAcid	0.356	-0.156	1						
IVPD	-.655**	0.219	-.802**	1					
Globulin	-0.014	0.034	-.541*	0.225	1				
Albumin	-0.107	-0.016	0.207	0.104	-.645**	1			
Prolamin	-0.023	-0.150	-0.137	0.064	-0.072	-0.374	1		
Glutelin	0.018	-0.164	-0.191	0.074	0.046	-0.455	.990**	1	
Residual protein	-0.015	-0.032	.763**	-0.409	-.774**	0.235	0.137	0.043	1

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