The Pharma Innovation Journal 2022; 11(8): 977-981

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; 11(8): 977-981

www.thepharmajournal.com
Received: 16-06-2022
Accepted: 26-07-2022

Dr. S Katyaayani
PV Narsimha Rao Telangana Veterinary University, Rajendranagar, Hyderabad, Telangana, India

Dr. A Sarat Chandra
PV Narsimha Rao Telangana Veterinary University, Rajendranagar, Hyderabad, Telangana, India

Dr. DBV Ramana
PV Narsimha Rao Telangana Veterinary University, Rajendranagar, Hyderabad, Telangana, India

Dr. RMV Prasad
PV Narsimha Rao Telangana Veterinary University, Rajendranagar, Hyderabad, Telangana, India

Dr. D Sreenivas
PV Narsimha Rao Telangana Veterinary University, Rajendranagar, Hyderabad, Telangana, India

Corresponding Author:
Dr. S Katyaayani
PV Narsimha Rao Telangana Veterinary University, Rajendranagar, Hyderabad, Telangana, India

A study to predict impact of atmospheric temperature and carbon dioxide increase on proximate, fibre fractions and mineral (Cu, Fe, Zn, Mn) composition of maize fodder

Dr. S Katyaayani, Dr. A Sarat Chandra, Dr. DBV Ramana, Dr. RMV Prasad and Dr. D Sreenivas

Abstract
A study was conducted to assess the impact of increasing temperature and carbon dioxide on the quality of maize fodder (stems and leaves) grown as livestock feed with recommended package of practices in the CTGC chambers under four set of environmental conditions (a) Reference (ambient temperature and carbon dioxide i.e., 27±0.5 ºC and 380±25ppm CO_2), (b) Chamber with temperature gradient of 5±0.5 °C Over reference and referred as elevated temperature (e-Temp), (c) Chamber with elevated CO_2 concentration of 550±50ppm with temperature gradient 5±0.5 °C Over reference referred as elevated carbon dioxide and temperature (eCO_2+eTemp) and (d) Chamber with elevated CO_2 concentration of 550±50ppm referred as elevated carbon dioxide (eCO_2). Leaf and stem portion of maize fodder at milking stage were screened by proximate, Vansoest, energy content, minerals were estimated by ICP method. Higher ($p < 0.05$) dry matter, Ash, ADL, ADF and cellulose per cent were found both in leaves and stem of the maize fodder grown under elevated temperature (e-Temp) environmental conditions. Organic matter and Crude protein content were found highest ($p < 0.05$) at the ambient temperature. Growing maize under elevated carbon dioxide and temperature (eCO_2+e-Temp) environmental conditions increased ($p < 0.05$) NDF and Hemicellulose contents both in leaves and stem. Significantly ($p < 0.05$) higher Crude fibre content in stem was found in the maize grown under elevated temperature, whereas in leaves under elevated carbon dioxide and temperature (eCO_{2+}e-Temp). A non-significant increase in Ether extract was observed in stem of maize fodder grown under elevated temperature, but it was highest ($p < 0.05$) at ambient temperature conditions in leaves. NFE in stem was highest ($p < 0.05$) at elevated carbon dioxide, whereas in the leaves highest ($p <0.05$) was found at ambient temperature. Leaf portion of the maize fodder grown in carbon dioxide and temperature gradient chambers (CTGC) differed significantly ($p < 0.05$) in Iron (Fe) and Copper (Cu) content (ppm), whereas comparable in zinc (Zn) and Manganese (Mn) content. However, in stem portion of the maize fodder grown in carbon dioxide and temperature gradient chambers (CTGC) differed significantly ($p <0.05$) in Iron (Fe) and Manganese (Mn) content and comparable in zinc (Zn) and Copper (Cu) content.

Keywords: Temperature, carbon dioxide, ambient, elevated

1. Introduction

The projected increase of atmospheric carbon dioxide (CO_2) and climate change will have significant impacts on future fodder productivity. Further, the animal feed market, which currently absorbs approximately 45%, 58% and 80% of the world cereal, maize, and soya, respectively (IGC, 2018) [7], is likely to be effected by climate change. Atmospheric CO_2 has steadily increased from preindustrial concentrations of 280mmol is predicted to double by the end of the 21st century (Keeling and Whorf, 1994) [8] Plants of the C4 pathway have a built in mechanism in the bundle sheath cells which allows them to maintain a higher CO_2 concentration around ribulose-1, 5 phosphate carboxylase/Oxygenase (RuBisCo), enabling to fix more CO_2 at ambient levels than does a C3 plant. Therefore, an enriched CO_2 atmosphere represents less change in CO_2 concentrations at the RuBisCo binding sites for C4, resulting in a smaller response for the C4 compared with the C3 plant. High temperature also generally increases accumulation of plant DM (Denium and Dirven, 1974) [3], but the literature in this regard, and particularly tropical forages, is not abundant (Newton, 1991) [12]. Dry matter production and quality of grassland species determines herbivore carrying capacity and thus is a key factor effecting productivity of forage-livestock systems. As CO_2 is a primary raw material in the process of photosynthesis, increase in atmospheric CO_2 concentration has been reported to cause fertilization effect particularly in C4 plants. However, the CO_2 fertilization effect may be modified under increased surface temperature conditions. Maize being a C4 plant how this increase in CO_2 and temperature results change in proximate and mineral composition is not known. Hence, a study was conducted. Determine the effects of increasing CO_2 and the temperature on the quality (proximate fibre fractions and mineral composition) of maize fodder.

2. Materials and methods

The work was carried out at Hayathnagar Research Farm (HRF), CRIDA, Hyderabad, situated at an altitude of 542 meters above mean sea level on 78.476ºE longitude and 17.366ºN latitude. African tall variety of maize was grown from June 2019 to September 2019, with recommended package of practices in Carbon dioxide and Temperature Gradient Chamber (CTGC) at four set conditions. 1. Chamber with ambient temperature and carbon dioxide referred as reference. 2. Chamber with temperature gradient of 5±0.5 °C Over reference and referred as elevated temperature (eTemp). 3. Chamber with elevated CO_2 concentration of 550±50ppm with temperature gradient of 5±0.5 °C (eCO_2+eTemp) and 4. Chamber with elevated CO_2 concentration of 550±50ppm (eCO_2). At each gradient four plants with 2 replications in each chamber were used for the study. At milking stage, the crop was harvested and leaf, stem and cobs were separated. Samples (Leaf and stem) were initially air dried and then oven dried at 60±5 °C. Dried samples were ground to pass a 2mm sieve mill in a Wiley mill. Further analysis of samples i.e. organic matter (OM), crude protein (CP), ether extract (EE), minerals estimation and fibre fractions, were estimated at ICAR-CRIDA (Central Research Institute for Dryland Agriculture), Santoshnagar, Hyderabad.

The proximate analysis of maize samples were performed as per the procedures described by (AOAC, 1995) [2]. Fibre fractions in feed samples were performed as per the method described by Van Soest *et al.* (1995). Minerals like copper (Cu), iron (Fe), Zinc (Zn), Manganese (Mn), Potassium (K), Selenium (Se) were estimated using Di-acid digestion and ICP method.

3. Results and discussion

3.1 Proximate Composition

3.1.1 Dry matter (DM)

The dry matter per cent was significantly (p <0.05) different in stem portion of the maize fodder grown in carbon dioxide and temperature gradient chambers (CTGC). A similar trend was observed in leaf portion of the maize fodder grown in CTGC. Higher dry matter per cent both in leaf and stem portions of the maize fodder grown under elevated temperature (e-Temp) and elevated carbon dioxide and temperature (e-Temp +eCO_2) treatment could be due to the increase in photosynthesis, carbohydrate fixation, respiration and transpiration in the plants (Rosenzweig *et al*., 1996) [14]. Increased photosynthesis and carbohydrate fixation results in the increase of growth rate and plant biomass (Xie Z *et al.*, 2004) [24], which would lead to the increase of dry matter in the plants. Increased respiration and transpiration would also lead to the increase of total leaf area, which could increase the evaporation of water, decrease the water content, and thus relatively increase the dry matter content in plants.

The present study results were in agreement with the finding of Denium and Dirven (1974) [3] in which they observed higher DM accumulation in plants under increased temperature. Similarly, Xiang He *et al.* (2015) [23] observed increased (p < 0.05) dry matter in the wheat straw under elevated CO_2 (eCO_2), elevated temperature (e Temp), and combination of (eCO_2 + e-Temp) treatments.

3.1.2 Ash

The ash content was significantly (p < 0.05) higher in both stem and leaf portion of the maize fodder under elevated temperature, elevated carbon dioxide and elevated temperature + elevated carbon dioxide chambers compared to ambient temperature.

This could be due to higher C/N ratio, increased carbon influence of more photosynthetic activity along with more deposition of minerals like calcium and magnesium (Meena Kumari *et al*., 2017) [10].

Ash per cent in maize stem also increased (p < 0.01) from G1 to G5 with increase in temperature both in the eTemp and eCO_2+e Temp chambers. Sreedevi *et al.* (2015) [17] observed similar results in maize genotypes, viz. DHM117, Harsha and Varun. Contrary to Erbs *et al.* (2010) [5] and Xiang He *et al.* (2015) [23] reported significantly decreased ash content in wheat straw at elevated temperature. This variations in different studies may be due to the fact that ash content varies with the plant species either C_3 or C_4.

3.1.3 Organic Matter (OM)

Stem portion of the maize fodder grown in carbon dioxide and temperature gradient chambers (CTGC) differed significantly (p < 0.05) in organic matter per cent. A similar trend was also observed in leaf portion of the maize fodder. Highest OM was found at ambient conditions in both stem and leaf portions and decreases in all other chambers compared to ambient. The results of the present study contradicts the findings reported by Abdalla *et al*. (2019) [1] that the whole forage, leaf, stem of the C_4 grass (*Brachiaria decumbens*) was unaffected under elevated CO_2.

3.1.4 Ether Extract (EE)

The ether extract percentage was relatively higher in stem portion of the maize fodder grown under eTemp and eCO_2+ eTemp chambers, however the differences were non-significant. Significantly (p < 0.05) lower EE content was observed in leaf portion of maize fodder grown under eCO_2 than other chambers and it could be due to early maturation of the leaf under elevated temperature and interference of nutrient and water relations and assimilate partitioning. Little is known about the effects of elevated temperature on the content and distribution of EE in plants, it may be due to the increase of photosynthesis Tao *et al*. (2006) [19].

The results of the present study support the findings of Xiang He *et al.* (2015) [23] where in ether extract content of wheat straw was significantly more in eTemp and eCO_2+ e-Temp conditions.

3.1.5 Crude Fibre (CF)

The crude fibre per cent was significantly (p < 0.01) different in stem portion of the maize fodder grown in carbon dioxide and temperature gradient chambers (CTGC). A similar trend was observed in leaf portion of the maize fodder grown in CTGC. Higher crude fibre per cent both in leaf and stem portions of the maize fodder grown under elevated temperature (e-Temp) and elevated carbon dioxide and temperature (eTemp + eCO_2) treatment could be due to the increase in structural carbohydrates along with more lignification. This study contradicts the results of Hogy *et al.* (2013). Where in it was reported that concentration and yield of a C_3 crop (barley) CF remain unaffected by warming.

3.1.6 Crude Protein (CP)

Stem portion of the maize fodder grown in carbon dioxide and temperature gradient chambers (CTGC) differed significantly ($p < 0.05$) in crude protein per cent. A similar trend was also observed in leaf portion of the maize fodder. Significantly ($p < 0.05$) lower crude protein was observed in both leaf and stem portions of maize fodder grown under eTemp and eCO_2 + eTemp chamber conditions. The significant reduction of the protein content under e-Temp and eCO_2 + e-Temp has been attributed more to a dilution-effect due to an overall increase in total non-structural carbohydrates, rather than an absolute decrease of the protein content in stem and leaves (Dumont *et al.* 2015).

Decrease in CP of stem at elevated CO_2 and elevated temperature treatments both individually and combined treatments are in agreement with the previous studies of Xiang He *et al.* (2015) [23] and Santosh *et al*. (2018) [15].

3.1.7 Nitrogen Free Extract (NFE)

The nitrogen free extract percentage was significantly ($p < 0.05$) higher in stem portion of the maize fodder grown under ambient and eCO_2 chambers than others. A similar trend was observed in leaf portion of the maize fodder grown in CTGC. Significantly ($p < 0.05$) lower CP content in leaf and stem portion of maize fodder grown under e-Temp and eCO_2 + e-Temp chamber conditions could be due to the increase in structural carbohydrate along with more lignification. Further, early maturation of the leaf under elevated temperature and interference of nutrient and water relations and assimilate partitioning could also affect the NFE content.

3.2 Fibre Fractions

3.2.1 Neutral Detergent Fibre (NDF)

The neutral detergent fibre per cent of stem portion of maize fodder was significantly ($p < 0.05$) different among different chambers in CTGC. A similar trend was observed in leaf portion of the maize fodder grown in CTGC. Significantly ($p < 0.05$) higher NDF content in leaf and stem portion of maize fodder grown under eTemp and eCO_2 + e-Temp chamber conditions could be due to the increase in structural carbohydrate along with more lignification. In general, a rise in temperature increases plant growth, reduces leaf: Stem ratios and increases NDF, ADF and lignin contents. Further, early maturation of the leaf under elevated temperature and interference of nutrient and water relations and assimilate partitioning could also affect the NDF content. Similarly, Xiang He *et al.* (2015) [23] observed increased NDF in wheat straw grown under elevated temperature (eTemp), elevated carbon dioxide (eCO_2) and combination of two treatments (eCO_2 + eTemp).

3.2.2 Acid Detergent Fibre (ADF)

Stem portion of the maize fodder grown in carbon dioxide and temperature gradient chambers (CTGC) differed significantly ($p < 0.05$) in acid detergent fibre per cent. A similar trend was also observed in leaf portion of the maize fodder. Significantly ($p < 0.05$) higher acid detergent fibre was observed in both leaf and stem portions of maize fodder grown under eTemp and eCO_2 + e-Temp chamber conditions.

The significant enhancement of the acid detergent fibre content under eTemp and eCO_2 + e-Temp has been attributed to increase in structural carbohydrate along with more lignification. In general, a rise in temperature increases plant growth, reduces leaf: stem ratios and increases NDF, ADF and lignin contents. Further, early maturation of the leaf under elevated temperature and interference of nutrient and water relations and assimilate partitioning could also affect the NDF content. Similarly, Xiang He *et al.* (2015) [23] observed increased ADF in wheat straw grown under elevated temperature (eTemp), elevated carbon dioxide (eCO_2) and combination of two treatments (eCO_2+ e-Temp).

3.2.3 Hemicellulose

The hemicellulose per cent of stem portion of maize fodder was significantly ($p < 0.05$) different among different chambers in CTGC. A similar trend was observed in leaf portion of the maize fodder grown in CTGC. Significantly ($p < 0.05$) higher hemicellulose content in leaf and stem portion of maize fodder grown under eCO_2+ eTemp chamber conditions could be due to the increase in structural carbohydrate along with more lignification. In general, a rise in temperature increases plant growth, reduces leaf: Stem ratios and increases NDF, ADF and lignin contents.

Further, early maturation of the leaf under elevated temperature and interference of nutrient and water relations and assimilate partitioning could also affect the NDF content. Similarly, Tom-Dery *et al*. (2018) [20] observed increased ADF in Kyasuwa grown under elevated carbon dioxide.

3.2.4 Cellulose

Stem portion of the maize fodder grown in carbon dioxide and temperature gradient chambers (CTGC) differed significantly ($p < 0.05$) in cellulose per cent. A similar trend was also observed in leaf portion of the maize fodder. Significantly ($p < 0.05$) higher cellulose was observed in both leaf and stem portions of maize fodder grown under eTemp chamber conditions. The significant enhancement of the cellulose content under eTemp has been attributed to increase in structural carbohydrates along with more lignification.

In general, a rise in temperature increases structural carbohydrates concentration. Further, early maturation of the leaf under elevated temperature and interference of nutrient and water relations and assimilate partitioning could also affect the cellulose content.

3.2.5 Acid Detergent Lignin (ADL)

The acid detergent lignin percent of stem portion of maize folder was significantly ($p < 0.05$) different among different chambers in CTGC. A similar trend was observed in leaf portion of the maize fodder grown in CTGC. Significantly ($p < 0.05$) higher acid detergent lignin content in leaf and stem portion of maize fodder grown under eTemp and eCO_2+ e-Temp chamber conditions could be due to the increase in structural carbohydrate along with more lignification. Similarly, Xiang He *et al.* (2015) [23] observed increased ADL in wheat straw grown under elevated temperature and carbon dioxide. In general, a rise in temperature increases NDF, ADF and lignin contents. Further, early maturation of the leaf under elevated temperature and interference of nutrient and water relations and assimilate partitioning could also affect the ADL content. It also suggests that the effects of warming on forage quality could mostly be driven by the evolution of plant phenology.

4. Minerals Concentration

Results of mineral composition (Cu, Fe, Zn, Mn) did not vary significantly between the different chambers in CTGC in both the maize leaves and stems and most of the minerals concentration was relatively higher at ambient temperature conditions. These results are in line with Abdalla *et al*. (2019) [1]. Who reported that the elevated CO_2 did not influence the mineral concentrations except Calcium. Our results also support the findings of Overdieck (1993) and he reported lower Zinc concentration under elevated CO_2 than ambient. Analysis of harvested maize leaves at the heading stage (60 days after sowing) grown at elevated temperature indicated that artificial warming significantly increases leaf C:N ratio and soluble sugar contents (glucose, fructose, and sucrose), but not the mineral nutrients (Zyeng *et al*., 2013).

Table 1: Maize stem proximate, fibber fractions and mineral composition at different gradients

Mean from G1 to G5	Reference	Elevated Temperature (e-Temp)	Elevated CO_2 (eCO_2)	Elevated CO_2 & Temperature (eCO_2+ e-Temp)	*P* Value
Proximate Composition					
Dry matter	33.7^a	35.6^b	33.8^a	34.4^a	<0.05
Ash	4.5^a	5.6^b	4.6^a	6.0^b	<0.05
Organic Matter	95.5^b	94.4^a	95.4^b	94.0^a	<0.05
Crude Fibre	32.6^a	37.5^b	32.5^a	37.4^b	<0.05
Crude Protein	4.6^b	4.4^a	4.6^b	4.4^a	<0.05
Ether Extract	1.51^a	1.52^b	1.48^a	1.52^b	<0.05
NFE					<0.05
Fibre Fractions					
NDF	64.7^a	66.8^b	63.9^a	68.9^c	<0.05
ADF	40.2^a	49.8^c	41.1^a	43.9^b	<0.05
Hemicellulose	24.5^c	17.0^a	22.8^b	25.1^c	<0.05
ADL	12.4^a	13.3^b	12.7^a	13.1^b	<0.05
Cellulose	24.6^a	28.9^c	24.9^a	26.8^b	<0.05
Minerals					
Copper	0.061	0.059	0.054	0.060	-
Iron	2.621^b	1.924^a	2.324^b	2.317^a	<0.05
Zinc	0.421	0.337	0.382	0.372	-
Manganese	0.486^b	0.407^a	0.421^a	0.416^a	<0.05

Table 2: Maize leaf proximate, fibre fractions and mineral composition at different gradient chambers

Mean from G1 to G5	Reference	Elevated Temperature (e-Temp)	Elevated CO_2 (eCO_2)	Elevated CO_2 & Temperature (eCO_2+ e-Temp)	*P* Value
Proximate Composition					
Dry matter	22.6^a	23.9^b	22.5^a	24.5^c	< 0.05
Ash	10.2^a	12.2^b	11.4^a	11.5^b	< 0.05
Organic Matter	89.8^b	87.8^a	88.6^a	88.5^a	< 0.05
Crude Fibre	21.9^a	23.2^b	23.0^b	23.5^c	< 0.05
Crude Protein	8.5^b	7.6^a	8.3^b	7.8^a	< 0.05
Ether Extract	1.68	1.59	1.62	1.61	-
NFE	57.7^b	55.4^a	55.7^a	55.6^a	< 0.05
Fibre Fractions					
NDF	59.4^a	65.4^c	62.2^b	65.3^c	< 0.05
ADF	34.6^a	39.6^c	37.2^b	37.8^b	< 0.05
Hemicellulose	24.8^a	25.8^a	25.0^a	27.4^b	< 0.05
ADL	10.8^a	11.1^b	11.0^a	11.1^b	< 0.05
Cellulose	14.8^a	16.6^b	15.5^a	15.9^b	< 0.05
Minerals					
Copper	0.123^b	0.102^a	0.110^a	0.107^a	< 0.05
Iron	2.461^c	1.905^a	2.260^b	2.103^b	< 0.05
Zinc	0.339	0.313	0.322	0.317	-
Manganese	1.111	1.069	1.087	1.083	-

5. Conclusion

Proximate and Vansoest analysis of both stem and leaf of maize grown in CTGC indicated that elevated temperature could impact nutritive value of maize fodder compared to the elevated carbon dioxide. Nutritive value of maize fodder in terms of CP, The quality of maize fodder is lowered under conditions of elevated carbon dioxide and temperature. Under elevated temperature conditions the ADL percentage is increased which leads to high lignification in fodder making it less palatable. Mineral (Cu, Fe, Zn, Mn) concentrations are not much influenced by the elevated temperature and carbon dioxide concentrations.

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