

Research Advances on Experimental Biology of Woody Plants of A Tamaulipan Thorn Scrub, Northeastern Mexico and Research Needs

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Abstract

The present review makes a synthesis of various aspects of applied biology of more than 30 woody plant species of a Tamaulipan Thorn scrub, Northeastern Mexico. This deals with the biodiversity of leaf traits, leaf anatomy, plant characteristics, wood anatomy, wood density, phenology and few aspects of physiology and biochemistry viz., leaf pigments, leaf epicuticular wax, trees with high nutritional values, carbon fixation, nitrogen and protein contents. The results show a large variability of all the morpho-physiological traits of the woody species related to the co-existence and adaptation of the woody species in semiarid environments. Special emphasis has been given to discuss the role of various morpho-anatomical and ecophysiological traits for adaptation to xeric environments such leaf anatomical traits (leaf surface, leaf lamina, petiole, venation system) and wood anatomical traits and few ecophysiological traits such as pigments, epicuticular wax, leaf nutrients, carbon fixation etc., which could be related to the adaptation of the species in xeric environment. Different woody species possess specific adaptive mechanisms in a forest ecosystem. This also suggests research needs and put forward few hypotheses for efficient management of forest system. No such inter-disciplinary studies are available on Tamaulipan Thorn scrub.

1. Introduction

Forests play a great role in offering great service to mankind in reducing carbon dioxide from the atmosphere and converting it to carbon in wood as source of energy through the process of photosynthesis and supply domestic and industrial products and function as source of nutrients to grazing animals. Therefore, forests are saviors of our lives, thereby urging the need of conservation of trees and shrubs in forests. In a forest ecosystem different species of woody plants grow together in a harmony in sharing solar radiation through the process of photosynthesis and exchange of gases in the above ground atmosphere and absorbing water and nutrients through roots distributed at soil depths. There is a great necessity of research inputs on woody plant species.

During few years we have made reasonable progress on various aspects of experimental biology of more than 30 woody species in a Tamaulipan Thorn Scrub, at Linares, Northeastern Mexico. We give here a synopsis of research results. Different species

possess various adaptative mechanisms for co-existence in a forest ecosystem (Maiti and Rodriguez, 2015c; Maiti et al., 2016a). Intensive literatures on various aspects of woody trees and shrubs are well documented in two books (Maiti et al. 2016 ed). This makes a brief synthesis of papers published, few in press and few unpublished ones. Research needs and few hypotheses are put forward.

2. Tree Species under Study

We adopted standard protocol for studying different aspects of applied biology.

Data were taken on the following species (Table 1).

3. Leaf Traits

Leaves play an important role in the capture of carbon dioxide through the photosynthetic process and exchange gases for plant metabolism. There exists great diversity in leaf shape, size among woody species for co-existence. The



Table 1: Woody plants used for research.

Sl. No.	Scientific name	Family	Type	Sl. No.	Scientific name	Family	Type
1.	<i>Acacia berlandieri</i> Benth.	Fabaceae	tree	21.	<i>Forestiera angustifolia</i> Torr.	Oleaceae	shrub
2.	<i>Acacia farnesiana</i> (L) Willd	Fabaceae	tree	22.	<i>Fraxinus greggii</i> A. Gray	Oleaceae	tree
3.	<i>Acacia rigidula</i> Benth.	Fabaceae	tree	23.	<i>Guaiacum angustifolium</i> Engelm	Zygophyllaceae	shrub
4.	<i>Acacia schaffneri</i> (S. Watson) F.J. Herm	Fabaceae	shrub	24.	<i>Gymnosperma glutinosum</i> (Spreng.) Less	Asteraceae	shrub
5.	<i>Acacia wrightii</i> Benth.	Fabaceae	tree	25.	<i>Havardia pallens</i> (Benth.) Britton & Rose	Fabaceae	tree
6.	<i>Amyris texana</i> (Buckley) P. Wilson	Rutaceae	shrub	26.	<i>Helietta parvifolia</i> (A. Gray) Benth	Rutaceae	tree
7.	<i>Berberis chococo</i> Schlecht	Berberidaceae	tree	27.	<i>Karwinskia humboldtiana</i> (Schult.) Zucc.	Rhamnaceae	shrub
8.	<i>Bernardia myricifolia</i> (Scheele) Benth. & Hook. F.	Euphorbiaceae	shrub	28.	<i>Lantana macropoda</i> Torr.	Verbenaceae	shrub
9.	<i>Caesalpinia mexicana</i> A. Gray	Fabaceae	tree	29.	<i>Leucaena leucocephala</i> (J. de Lamarck) H. C. de Wit	Fabaceae	tree
10.	<i>Celtis laevigata</i> Willd	Ulmaceae	tree	30.	<i>Leucophyllum frutescens</i> (Berland) I.M. Johnst	Scrophulariaceae	shrub
11.	<i>Celtis pallida</i> Torr	Ulmaceae	shrub	31.	<i>Prosopis laevigata</i> (H. & B.) Jonhst	Fabaceae	tree
12.	<i>Cercidium macrum</i> I.M. Johnst	Fabaceae	tree	32.	<i>Quercus virginiana</i> Mitl.	Fabaceae	tree
13.	<i>Condalia hookeri</i> M. C. Johnst	Rhamnaceae	shrub	33.	<i>Retama sphaerocarpa</i> (L.) Boiss	Fabaceae	shrub
14.	<i>Cordia boissieri</i> A. DC.	Boraginaceae	tree	34.	<i>Salix lasiolepis</i> Benth.	Salicaceae	tree
15.	<i>Croton suaveolens</i> Presl.	Euphorbiaceae	shrub	35.	<i>Sargentia greggii</i> S. Wats	Rutaceae	tree
16.	<i>Diospyros palmeri</i> Eastw	Ebenaceae	tree	36.	<i>Sideroxylon celastrinum</i> (Kunth) T.D. Penn	Sapotaceae	tree
17.	<i>Diospyros texana</i> Scheele	Ebenaceae	tree	37.	<i>Zanthoxylum fagara</i> (L.) Sarg.	Rutaceae	shrub
18.	<i>Ebenopsis ebano</i> (Berland.) Barneby & J.W. Grimes	Fabaceae	tree				
19.	<i>Ehretia anacua</i> (Teran & Berland.) I.M. Johnst	Boraginaceae	tree				
20.	<i>Eysenhardtia polystachya</i> Ortega, Sarg.	Fabaceae	shrub				

native species *Cordia boissieri*, *Condalia hookeri*, *Sargentia greggii*, *Diospyros texana*, *Zanthoxylum fagara*, *Sideroxylon celastrinum*, *Karwinskia humboldtiana*, *Celtis pallida*, *Guaiacum angustifolium*, *Prosopis laevigata*, *Celtis laevigata*, *Parkinsonia texana*, *Forestiera angustifolia* and *Havardia pallens* were chosen due to their ecological and economic importance to the rural villages as well as large variability in morphological characteristics between them (Maiti et al., 2014a).

A study was undertaken in variation in leaf traits of 34 Trees and Shrubs in Summer Season in Linares, North-Eastern Mexico. The results revealed that there exists large variations in leaf area (cm²), specific leaf area (cm² g⁻¹) and leaf dry mass (g), petiole length and moisture content both in Winter

and Summer seasons. Leaf area (cm²) ranged from 0.733 to 215.926 (cm²), leaf dry mass from 0.006 to 1.463 (g), specific leaf area from 11.833 to 1982.780 (cm² g⁻¹), leaf length from 0.700 to 51.00 (cm), leaf breadth from 0.400 to 22.400 (cm) and petiole length from 0.100 to 13.00 (cm). Leaf area showed highly significant positive correlations with leaf dry weight (g) (r=0.94), leaf length (r=0.88), leaf breadth (r=0.807), and petiole length (r=0.71) while the leaf dry weight showed highly significant correlation with leaf length (r=0.88), leaf breadth (r=0.775), and petiole length (r=0.734). Specific leaf area did not show any significant correlations with any of the variables studied. Therefore, leaf area, leaf length, petiole length has significant roles in plant productivity and reveals that there exists interspecific diversity among distinct leaf characteristics



which in turn determine distinct functional trends among the community studied (Rodriquez et al., 2015c).

Woody plants possess two types of leaves, open canopy (all leaves exposed to sunlight), others close canopy where all leaves are not exposed to sunlight for capture of solar radiation. It is hypothesized that variability in Leaf Canopy Architecture may be Related to Photosynthetic Efficiency and Carbon Fixation (which needs to be confirmed in future study (Maiti et al., 2014b).

Maiti et al. (2016d) made a synthesis of biodiversity of leaf traits of native woody species of a Tamaulipan Thorn Scrub.

3.1. Leaf anatomy

Leaf anatomical structures such as leaf surface, leaf lamina, petiole venation pattern play important roles in the taxonomic delimitation and adaptation of the woody plants to xeric habitats in Northeastern Mexico.

3.1.1. Leaf surface anatomy

A comparative study has been undertaken on leaf surface (dermal) anatomy of 28 species of trees and shrubs of Tamaulipan Thorn Scrub, Northeastern Mexico and its possible relation with drought resistance (unpublished). The species have been classified on the basis of various traits which can be used in species delimitation and adaptation to the semiarid condition such as waxy leaf surface, absence or sparse stomata on the leaf surface, sunken stomata. The species identified as better adapters to semi arid environments on the basis of the presence and absence of stomata on both adaxial and abaxial surface such as., *Berberis chococo*, *Celtis laevigata*, *Condalia hookeri*, *Diospyros palmeri*, *Diospyros texana*, *Ebenopsis ebana*, *Ehretia anacua*, *Forestiera angustifolia*, *Havardia pallens*, *Helietta parviflora*, *Karwinskia humboldtiana*, *Sargantia gregii*, *Sideroxylon celastriana*, *Zanthoxylum fagara*. The water relations and drought resistance of the species mentioned should be confirmed in future study.

3.1.2. Anatomy of leaf lamina

A study was undertaken to determine the variability in leaf anatomical traits and its relation to taxonomic delimitation and adaptation of the woody species in xeric environments in semiarid conditions in Northeastern Mexico. The results show large variability in anatomical traits with respect to cuticle thickness, presence and absence of trichomes, length of palisade cells and thickness of spongy tissue. Species have been classified on the basis of the length and compactness of palisade cells to determine its relation to the taxonomic delimitation and the adaptation of the species to drought condition. The species viz., *Karwinskia humboldtiana*, *Lantana macropoda*, *Prosopis laevigata*, *Zanthoxylum fagara*, *Helietta*

parvifolia, *Acacia berlandieri* and *Acacia wrightii* having long and compact palisade cells are expected to be efficient in photosynthetic function and adaptation to drought. Future research needs to be directed in this direction (Maiti et al., unpublished).

3.2. Petiole anatomy

Petiole plays an important role in holding and exposing leaf lamina to solar radiation, in the transport of water and nutrients and offering mechanical strength against environmental stresses.

A comparative study on petiole anatomy of 36 woody species has revealed the presence of a large variability among species in various anatomical traits which can be used in taxonomic delimitation. Species were grouped on the basis of various petiole anatomical traits. In addition several species are selected for few desirable traits. Only five species are mentioned for each desirable trait such as those having large vascular bundle are efficient in the transport of nutrients and water viz., *Acacia berlandieri*, *Acacia rigidula*, *Diospyros palmeri*, *Fraxinus greggii*, *Guaiacum angustifolia*, thick petiole (*Acacia berlandieri*, *Acacia farnesiana*, *Berberis chococo*, *Bernardia myricifolia*, *Eysenhardtia texana*) and mechanical tissues such as thick cuticle (*Acacia berlandieri*, *Celtis pallida*, *Condalia hookeri*, *Eysenhardtia texana*, *Gymnosperma glutinosum*, a thick collenchyma (*Acacia farnesiana*, *Berberis chococo*, *Bernardia myricifolia*, *Celtis pallida*, *Havardia pallens*) and extra sclerenchyma bands that offer mechanical strength (*Acacia berlandieri*, *Ebenopsis ebano*, *Eysenhardtia texana*, *Lantana macropoda*, *Prosopis laevigata*, *Xanthoxylum fagara*). The species having the combination of various desirable traits are expected to be more efficient in the physiological function and mechanical support. In this respect we can mention *Acacia berlandieri* as an ideal species.

3.3. Venation pattern and venation system

Venation patterns in leaves represent typical vascular skeleton in a leaf lamina offering mechanical function and transport of water, carbohydrates in plants. A study was undertaken on venation pattern and venation density of few trees and shrubs. At first the venation pattern of 30 species has been classified according to the system of Hickey (1971). Among the 30 species studied 28 species belong to Brochidodromous: while only two species belong to Craspedodromous. In the second stage, the venation architecture and venation density of only 20 species were undertaken following the clearing technique by keeping the leaves in test tubes in solutions of H_2O_2 : NH_4OH 50 for time necessary to achieve whitening leaf rib and observed in the microscope at 5X. The species showed large variations in venation architectures in orientation,



size, shape depicting the characteristics of each species. The species also showed variation in density of vein. Islets in few species are bounded by thin veins but traversed by thicker vein to give mechanical strength to the leaf lamina against stress showing, adaptive characteristics. Among the species studied *Eysenhardtia texana* had maximum vein islet density, *Ebenopsis ebano*, *Caesalpinia mexicana*, *Karwinskia humboldtiana*, etc. possessed medium density, while *Guaiacum officinale*, *Amyris madrensis*, *Sargentia greggii*, had low density. There is a necessity to characterize venation system of more trees and shrubs and relate it to the productivity of the species (Maiti et al., 2015h).

4. Plant Characteristics and Relationship

Woody plant species possess various plant characteristics such as type of leaf canopy, tree crown architecture, plant height, canopy cover, basal diameter, branching patterns and branching density and there exists relationships among these parameters. There exists significant variations in plant parameters and their correlations among species (Maiti et al., 2015d).

4.1. Tree crown

Every tree species possesses a typical tree top crown architecture such as globose, round, irregular architecture with the association of branches and leaves which help in the capture of solar radiation. Few studies have been undertaken in these aspects.

4.1.1. Branching pattern and branching density

Branching pattern and crown architecture are the important component of plant growth and development of any plant species. The leaf area and photosynthesis efficiency mainly depended on the crown architecture. Here, the research findings in this respect pertaining to the shrubs and tree species of the North East Mexico has been reviewed. The branching habit has been classified as monopodial, sympodial and pseudomonopodial, while the crown architecture as globose and irregular (Maiti et al., 2015e).

A study has been undertaken on the perspectives of branching pattern and branching density in 30 woody trees and shrubs in Tamulipan Thornscrub, Northeast of Mexico. The branching pattern functions as solar panel in the capture of solar radiation for the production of biomass and timber. A study was undertaken with the objective of determining the density of branching and types of branching of 30 tree species (trees and shrubs of Tamaulipan thorn scrub such; *Helietta parvifolia*, *Sargentia greggii*, *Guaiacum angustifolium*, *Ebenopsis ebano*, *Harvardia pallens*, *Condalia hookeri*, *Xanthoxylum fagara*, *Cordia boissieri*, *Acacia berlandieri*, *Diospyros texana*, *Celtis pallida*, *Forestiera angustifolia*, *Diospyros*

palmeri, *Parkinsonia texana*, *Acacia farnesiana*, *Sideroxylon celastrina*, *Caesalpinia mexicana*, *Karwinskia humboldtiana*, *Croton suaveolens*, *Amyris texana*, *Leucaena leucocephala*, *Ehretia anacua*, *Gymnosperma glutinosum*, *Celtis laevigata*, *Acacia rigidula*, *Acacia shaffneri*, *Eysenhardtia polystachya*, *Prosopis laevigata*, *Bernardia myricifolia* and *Leucophyllum frutescens*. The types of branching observed are; monopodial, pseudomonopodial, and sympodial. The branching density observed through animation photography in the field has revealed the presence of three types branching density i.e., high, medium and low density. There existed differences in height, biomass, basal trunk, the angle of the primary and secondary branches. With respect to branching density, a higher number of species were high density (15 species), followed by low density (9) and medium density (5 species). The architecture of the tree is the result of the activity of the apical and axial meristems. This model is a strategy for occupying the space and capture of solar radiation (Maiti et al., 2015d).

4.2. Wood anatomy

Wood is an industrial product of great economic importance derived from cambial activity in a tree. Wood is composed of secondary xylem vessels, wood fibres, wood parenchyma and other products. Significant research inputs have been documented on wood anatomy.

A study has been undertaken on wood anatomy of 20 woody species in northeast Mexico. There exists large variation among species in wood anatomical traits such as porosity, vessel diameter, its distribution, parenchyma, compactness of ground tissues and fibre cell characteristics. Most of the species have narrow vessels which help protection against cavitation. Most of the species are ring to semiring porous viz. *Acacia amentacea*, *Acacia berlandieri*, *Acacia shaffneri*, *Acacia wrightii*, *Cordia boissieri*, *Helietta parviflora*, *Condalia hookeri*, *Xanthoxylum fagara*, *Celtis pallida*, *Celtis laevigata*, *Caesalpinia mexicana*, *Eysenhardtia polystachya*; only few of them are diffuse porous viz. *Diospyros palmeri*, *Diospyros texana*. Fibre cell characteristics also showed large variations in morphology, size, lumen breadth and in compactness, these species were soft and hard wood. Most of the species have narrow vessels, viz., *Acacia berlandieri*, *Acacia shaffneri*, *Acacia wrightii*, *Helietta parviflora*, *Cordia boissieri*, *Diospyros palmeri*, *Celtis laevigata*, *Eysenhardtia polystachya*, *Xanthoxylum fagara*. *Celtis pallida* contained medium sized vessels, while *Celtis laevigata* and *Caesalpinia mexicana* possessed big sized vessels. Many of the species possess narrow vessels which although impose transport of water but protect the vessels against cavitation during drought and freezing the species with small narrow vessels mentioned have



strategy to adapt both to hot and cold climate against cavitation. The species having big vessel diameter may be susceptible to drought such as *Celtis pallida*, *Caesalpinia mexicana* or they may have deep root system for adaptation to semiarid climates in northeast Mexico. All these wood anatomical traits could be utilized to distinguish species as well as quality determinations of species. The variation in hydraulic systems determine the capacity of water transport among species. Statistically significant differences are observed in all wood anatomical parameters among species studied. In addition a study has been made on wood anatomy of 33 woody trees and shrubs showing a large variability in wood anatomical traits which may be used in the taxonomic delimitation and adaptation of the species to xeric environments. It has been documented in the literatures that the species having narrow vessels acts against cavitation and embolism during hot summer, in which direction research needs to be directed to confirm it further in semiarid regions of Northeastern Mexico.

In addition, a comparative study has been undertaken on wood anatomy of 12 woody species at Linares, northeast Mexico. The results show large variation among species in wood anatomical traits such as porosity, vessel diameter, its distribution, parenchyma, compactness of ground tissues and fibre cell characteristics. Most of the species are ring to semiring porous viz., *Acacia shaffneri*, *Acacia wrightii*, and *Eysenhardtia polystachya*. Fibre cell characteristics also showed large variations in morphology, size, lumen breadth and in compactness, these species were soft and hard wood. Most of the species have narrow vessels, viz., *Acacia shaffneri*, *Acacia wrightii*, *Helietta parvifolia*, contained medium sized vessels. Many of the species possess narrow vessels which although impose transport of water but protect the vessels against cavitation during drought and freezing the species with small narrow vessels mentioned have strategy to adapt both to hot and cold climate against cavitation. All these wood anatomical traits could be utilized to distinguish species as well as quality determinations of species. The variation in hydraulic systems determine the capacity of water transport among species (Gonzalez Rodriguez et al., not published).

A study was undertaken to determine the variability in fiber cell morphology and its length among wood species of the Tamaulipan thornscrub, northeastern Mexico, used for various uses such as timber for furniture, fence, post, firewood and sources of forage. The results show large variability in fiber cell morphology and fiber cell length. The species have been classified on the basis of its fiber cell morphology and fiber cell length and recommended for their possible utilization for different purposes. This technique can be used in preliminary screening of woody species for its utilization for different

purposes. Further studies are needed to confirm (Maiti et al., 2015f).

It has been observed that the species having high value of length/breadth ratio of fibre cells are expected to produce strong wood fibres were: *Ehretia anacua* (55.77 μm), *Quercus polymorpha* (51.71 μm), *Helietta parvifolia* (41.85 μm), *Prosopis laevigata* (38.31 μm), *Celtis laevigata* (37.28 μm), *Acacia farnesiana* (33.95 μm), *Celtis pallida* (33.45 μm), *Gochnatia hypoleuca* (32.67 μm), *Karwinskia humboldtiana* (32.36 μm) and *Cordia boissieri* (31/47 μm). These could be recommended for paper pulp manufacture also. Species having broad breadth are expected to be desirable for paper pulp production. Species having high wall thickness are expected to produce strong fibre for high lignification. The results on fibre dimensions in the present study coincide with the findings by several authors mentioned before for its possible utility with respect to variability in fibre cell dimensions and lignin content.

It has been hypothesized that wood Anatomy could predict the adaptation of woody plants to environmental stresses and quality of timbers (Maiti and Rodriguez, 2015d).

4.3. Wood density

A preliminary study has been undertaken for wood density and its utilization in northeastern Mexico for different purposes and to find possible relationship of density with wood fibre characteristics. The results reveal large variability in wood density and in fibre cell morphology. The species have been classified on the basis of wood density and its fiber cell morphology and has been recommended for their possible utilization for different purposes.

Species desirable for strong furniture making, paper pulp, soft furniture, fence etc. can be selected on the basis of fibre length to breadth ratios as strong fibres for furniture and fibre cells with broad lumen and thin cell wall use for fabrication of paper pulp and other utilities.

Subsequently a study has been undertaken by Maiti et al. (2016c) on variability of Wood density and its possible relation to few wood chemical composition and wood fiber cell structure anatomy. The results revealed that among 10 species studied, there exist a large variation in wood density (0.51 to 1.09), and few wood chemical composition such % carbon (37.14 to 44.07), nitrogen (9.18 to 19.22), sulphur (31.45 to 33.82), lignin (15.28 to 24.35), hemicellulose (19.94 to 27.36%), and % cellulose (33.69 to 45.92). In general, though there was no clear relationship between wood density and other chemical composition of wood. It was observed that the species having moderate to high wood density contained >40% carbon, >30% sulphur and >40% cellulose and more or less 20% lignin. It seems that carbon, sulphur, cellulose and



lignin contents contribute to greater density. The wood fiber cell with wall lignification seemsto be related to higher wood density (Maiti et al., 2016d).

5. Reproductive Biology

In a forest ecosystem trees and shrubs start flowering, fruitification and finally disperse seeds for maintenance of their life cycles. It is necessary to know these phenomenon for the foresters for effective management of the forest. A study has been made by Rodriguez and Maiti (2015b) to determine flowering and fruiting phenology of 12 woody species in Linares, Northeast of Mexico during the period from March to December 2013. The most representative species are: *Prosopis laevigata* (Humb. and Bonpl ex Willd.), M.C Johnst, *Ebenopsis ebano* (Berland.) Barneby and J.W Grimes, *Acacia amentacea* D.C., *Castela erecta* Turpin sub sp *texana* (Torr. and A. Gray) Cronquist, *Celtis pallida* Torr., *Parkinsonia texana* var. *Macra* (IM Johnst.) Isely, *Forestiera angustifolia* Torr., *Cordia boissieri* A.DC., *Leucophyllum frutescens* (Berland.) IM Johnst., *Guaiacum angustifolium* Engelm., *Cylindropuntia leptocaulis* (DC.) F.M Knuth, *Opuntia* spp, *Zanthoxylum fagara* Sarg., *Sideroxylon celastrinum* (Kunth) T.D. Penn, *Heliotta parvifolia* (A. Gray ex Hemsl) Benth., among others. The species were selected on the basis of ecological and nutritional value for livestock and wild ruminant animals and multiple uses of shrubs. There exists a large variability in the phenological stages among species. The first study was concentrated on the basis of the percentage of different phenological stages. The second study was mainly concentrated on the time of appearance of each phenological stage in individual species. The results clearly demonstrate about the variation in phenological time schedule among different species. Very little studies have been undertaken in this aspect in the literature. Therefore, there is a need to evaluate the phenology of each individual species. This knowledge will help forest managers for efficient management of the forest as well as the time of seed production of the species of seeds.

A study has been made on phenology and pollen viability of four woody species revealing that temperature play an important role on pollen viability (Maiti and Rodriguez, 2015a).

6. Physiology and Biochemistry

6.1. Leaf pigments

Woody plant species possess different pigments such as chlorophyll a, chlorophyll b, carotenoids and other pigments among which chlorophyll helps in the absorption of solar energy during the process of photosynthesis.

A study has been made on pigment contents (Chlorophyll and Carotenoid) in 37 species of Trees and Shrubs in Northeast of Mexico during summer season. Large variations were observed in the contents of chlorophyll (a, and b and total) and also carotenoids among species. Chlorophyll a was minimum in *Leucophyllum frutescens*, *Acacia berlandieri* contained (around 0.6 mg), maximum was observed in *Leucaena leucocephala* (nearing 1.8 mg). Chlorophyll b was minimum in *Foresteria angustifolia*, *Acacia berlandieri*, *Acacia palmeri*, *Leucophyllum frutescens* (0.1 to 0.2 mg), while *Leucaena leucocephala* contained maximum (0.4 mg). Carotenoid content was minimum (around 0.2 mg) were in *Eysenhardtia polystachya*, *Guaiacum angustifolia*, *Leucophyllum frutescens* and others but maximum value was observed in *Croton suaveolens*. Total chlorophyll was minimum values (around 0.5 mg) in *Leucophyllum frutescens*, *Heliotta parviflora*, *Lantana macropoda*, *Foresteria angustifolia*, *Croton suaveolens*, while maximum value (around 2 mg) was obtained in *Leucaena leucocephala*. Chlorophyll (a, b) ratio *Foresteria angustifolia*, *Parkinsonia aculeata* showed maximum value (around 7) followed by *Diospyros texana* (around 6). Chlorophyll total/ carotenoids a showed maximum value (nearing 8), while minimum value was obtained in *E. trifoliata* (around 1). There is a necessity to study photosynthetic efficiency and productivity of the woody species with high pigment contents.

In a study there exists seasonal variation of leaf pigments in trees and shrubs in summer and Winter seasons, the species contained lower pigments during Winter seasons (Maiti et al., 2016d-American Academic press).

In the context of the results it may be interpreted that the species showed variations in various pigment contents in both winter (February, 2015) and Summer, (June 3), few remaining more less stable, others showed decline while few showed increase. These variations in pigment contents could have direct or indirect effect on photosynthetic capacity and the productivity of the species studied which need to be confirmed in future study. It may be mentioned here that at the time of collection of leaf samples in February the temperature ranged from 2 to 3°, but few species did not show decline as mentioned above showing tolerance to cold temperature such as *Sargentia greggii* and *Guaiacum angustifolium* (papers in press, IJBSM). Therefore, the climatic conditions and environments have influence on pigment contents and probable photosynthetic capacity. It may be interpreted that the increase in chl-a in *Ebenopsis ebano* and *Leucaena leucocephala* could be related to higher photosynthetic capacity in summer season. Similarly *Eysenhardtia polystachya* showing an increase in chl b could be related to higher photosynthetic capacity in summer season. Similarly, the increase in total chlorophyll content in *Ebanopsis*



ebano and *Leucaena leucocephala* could be related to higher photosynthetic capacity in summer season. Our observations coincide with the findings of various authors who discussed the role of pigments in plant metabolism and plant productivity.

6.2. Epicuticular wax

Several woody species in the semiarid regions of Northeastern Mexico possess waxy leaf surface owing to the presence of epicuticular wax. It has been documented that epicuticular wax helps in the reflection of sunlight from the leaf surface, thereby reducing radiation load and maintaining lower leaf temperature which impart resistance to drought.

A study on the variability in epicuticular wax in 35 woody species in Linares, Northeast Mexico at the experimental station of Facultad de Ciencias Forestales, Universidad. Considerable variation in wax accumulation was found among species showing prominent interspecific variation. Wax load varied from 11.18 to 702.04 $\mu\text{g cm}^{-2}$ among species studied during summer. Few species selected with high epicuticular wax viz, *Forestiera angustifolia* (702.04 $\mu\text{g cm}^{-2}$), *Diospyros texana* (607.65 $\mu\text{g cm}^{-2}$), *Bernardia myricifolia* (437.53 $\mu\text{g cm}^{-2}$), *Leucophyllum leucocephala* (388.50 $\mu\text{g cm}^{-2}$), during summer which could well be adapted under semi-arid environments for their efficiency in the reflection of radiation load, reduced transpiration, gas exchange and probably impart drought resistance. The large variations in epicuticular wax could be related to their physiological functions such as transpiration, gas exchange, water relations etc (Maiti et al., 2015f).

6.3. Macro and micronutrients

Woody plants possess various leaf nutrients which help in the growth and development of the species and serve as sources of nutrients by the grazing animals.

A study was undertaken to estimate six nutrients in the leaves, three macronutrients (K, Mg, P) and three micronutrients (Cu, Fe, Zn) of twenty five woody species in Linares, Northeastern of Mexico (Maiti et al., 2016d). Macronutrients and micronutrient contents (Cu, Fe, Mn, Zn, Ca, K, Mg, P, C and N) of ten native species exhibit large variations among species in the contents of the nutrients. K values ranged from round about 6.80 to 75.62 mg g^{-1} ; Mg content ranges 0.22 to 5.29 mg g^{-1} , P 0.09 to 2.43 mg g^{-1} Cu from 0.09 to 2.8 to 30.71 $\mu\text{g g}^{-1}$, Fe from 66.32 to 276 $\mu\text{g g}^{-1}$, Zn from 10.23 to 144.86 $\mu\text{g g}^{-1}$. *Croton suaveolens* acquired highest level of P (2.43 mg g^{-1}) and K (75.62 mg g^{-1}), whereas *Parkinsonia aculeata* for Mg (5.29 mg g^{-1}). *Cordia boissieri* for both Cu (30.71 $\mu\text{g g}^{-1}$) and Fe (280.55 $\mu\text{g g}^{-1}$), on the other hand, *Salix lasiolepis* for Zn (144.86 $\mu\text{g g}^{-1}$). These species could serve as excellent sources for ruminants and could adapt and grow well for high nutrient contents. The values of mineral contents were much

higher than required by the grazing ruminants.

Leaf nutrients play an important role for the growth and development of trees and are sources of nutrients for ruminants in forest. The present study was undertaken to estimate six nutrients in the leaves, three macronutrients (P, Mg, K, protein, C, N, C/N and three micronutrients (Cu, Fe, Zn). Among macronutrients P: varied from 0.78 to 243 (mg g^{-1} dw), the species containing high P are *Croton suaveolens* 2.43, *Eysenhardtia polystachya* 1.84, *Prosopis laevigata* 1.65, *Parkinsonia aculeata*, 1.56, *Acacia farnesiana* 1.54, Mg (mg g^{-1} dw) varied from 0.22 to 9.45 (mg g^{-1} dw). The species containing high Mg (mg g^{-1} dw) are *E. anacua* 9.45, *C. hookeri* 6.50, *P. aculeata* 5.29.

6.4. Biodiversity in leaf chemistry (Pigments, Epicuticular Wax and Leafmacro and micronutrients

6.4.1. A study has been made on pigments, epicuticular wax and macro and micronutrients of 15 woody species (Maiti et al., 2015 g)

The results of studies undertaken on more than 30 woody species in North-eastern Mexico revealed that there exists large variations in pigments (chlorophyll, carotenoids), epicuticular wax, macro and micro nutrients. Several species have been selected with high values of the pigments, epicuticular wax and various macro and micronutrients. For example, species with high Chlorophyll content were: *Ebenopsis ebano* (1.755), *Croton suaveolens* (0.589), *Amyris texana* (1.66), and those with high chlorophyllb were *Ebenopsis ebano* (0.398), *Amyris texana* (1.66) and species with high Chlorophyll total (Chl a+b) were: *Ebenopsis ebano* (2.253), *Leucaena leucocephala* (1.687). Species with high carotenoids were: *Berberis chococo* (0.585), *Diospyros palmeri* (0.433). The species showing high epicuticular wax load are *Forestiera angustifolia* (702.04 $\mu\text{g cm}^{-2}$), *Diospyros texana* (607.65 $\mu\text{g cm}^{-2}$), *Bernardia myricifolia* (437.53 $\mu\text{g cm}^{-2}$). There is a here aneed to confirm the efficiency of these selected species for productivity and adaptation of the species to environment.

6.4.2. Nutrients in woody plant species in North-eastern Mexico, a synthesis

The present paper makes a synthesis of two earlier studies undertaken on macro and micronutrients of 1) 37 woody species and 2) 44 medicinal plants used traditionally of Northeastern Mexico (Maiti et al., 2016c).

In the both the studies we estimated the contents of six nutrients in the leaves, three macronutrients (P, Mg, K, protein, C, N, C/N and three micronutrients (Cu, Fe, Zn) both for woody species and medicinal plants. A large variability exists in nutrient contents in woody species and medicinal



plants. The species selected for the highest macronutrients and micronutrients may be utilized for confirming their physiological efficiency and probable better growth and productivity as well as good sources of macro and micronutrients for grazing wild animals.

We selected Eco-physiologically Highly Efficient Woody Plant Species in Northeastern Mexico (Maiti and Rodriguez, 2015b).

6.5. Carbon, nitrogen and protein contents

The present study was undertaken by Rodriguez et al. (2015c) to determine carbon and nitrogen content among 40 plant species of diverse growth habit with a view to select species with high carbon fixation (carbon content) and nitrogen content. In this study, few species were selected with high carbon fixation such as *Eugenia caryophyllata* (51.66%), *Litsea glaucescens* (51.54%), *Rhusvirens* (50.35%), *Gochantia hypoleuca* (49.86%), *Pinus arizonica* (49.32%), *Eryobotrya japonica* (47.98%), *Tecoma stans* (47.79%), *Rosamarinus officinalis* (47.77%). Few of these species could be recommended for plantation in CO₂ polluted areas to reduce carbon load. In addition these, high carbon concentration could serve as good source of energy. We selected few species with high nitrogen content such as *Mimosa malacophylla* (8.44%), *Capsicum annum* (6.84%), *Moringa oleifer* (6.25%), *Azadirachta indica* (5.85%), *Eruca sativa* (5.46%), *Rosamarinus officinalis* (5.40%), *Mentha piperita* (5.40%). These species could serve as good sources of nitrogen for health care. We selected few species with high C/N ratio such as *Arbutus xalapensis* (26.94%), *Eryngium heterophyllum* (24.29%), *Rhus virens* (22.52%), *Croton suaveleons* (20.16%), *Cinnamomum verum* (19.89%) which may be related to high production of secondary metabolites and antioxidants (Maiti et al., 2016-American Academic Press in press)

Maiti et al. (2016e) suggested adaptive morpho-physiological traits of woody plants for co-existence in a forest ecosystem.

It is discussed that woody plants being dominant vegetation in a forest ecosystem of semiarid Mexico possess specific morpho-anatomical, ecophysiological and biochemical traits for adaptation in the semi-arid environments with special reference to hot summer and cool winter, similar to the environments prevalent in Mediterranean climates.

The paper put forward few hypothetical concepts for co-existence and adaptation of woody plant species in a Tamaulipan Thorn Scrub, Northeastern Mexico. The hypotheses have been put forward on the basis of our results on various morphological, anatomical and ecophysiological traits of A Tamaulipan Thorn Scrub, Northeastern Mexico. Few future research lines are suggested to confirm the hypotheses.

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