Phytochemistry 98 (2014) 9–26

Contents lists available at ScienceDirect 

Phytochemistry

journal homepage: www.elsevier.com/locate/phytochem

Review

North American Artemisia species from the subgenus Tridentatae (Sagebrush): A phytochemical, botanical and pharmacological review 

Christina E. Turi a, Paul R. Shipley b, Susan J. Murch b,⇑

aDepartment of Biology, University of British Columbia, Kelowna, British Columbia, Canada

bDepartment of Chemistry, University of British Columbia, Kelowna, British Columbia, Canada

article info

Article history:

Received 27 September 2013

Received in revised form 7 November 2013 Available online 17 December 2013

Keywords:

Artemisia tridentata

Tridentatae

Asteraceae

Sagebrush

Spiritual botany

Contents

abstract

The genus Artemisia consists of between 350 and 500 species with most of the North American endemic Artemisia species contained within the subgenus Tridentatae (Sagebrush). The reported uses of these spe cies by Native American and First Nations peoples include analgesic, antiinflammatory, antiseptic, immu nostimulation activity, as well as the treatment of afflictions from spiritual origins. Taxonomic revision for North American Sagebrush has created a number of synonyms that confuse the literature. The phyto chemical diversity of the Tridentatae includes at least 220 distinct and important specialized metabolites. This manuscript reviews the current phytochemical, botanical and pharmacological understanding for the subgenus Tridentatae, and provides a foundation for future studies of the metabolomes of the Tridentatae. Modern approaches to phytochemical analysis and drug discovery are likely to provide inter esting lead compounds in the near future.

2013 Elsevier Ltd. All rights reserved.

Introduction. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 10 Evolution, botany and taxonomy . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 10 Phytochemistry . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 12

Phenolics . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 12 Monoterpenes . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 12 Sesquiterpenes. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 12 Diterpenes . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 13 Other phytochemicals . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 15

Bioassay . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 15 Antimicrobial. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 15 Antimycobacterium. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 15 Antioxidant activity. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 15 Antiviral activity . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 18 Cytotoxicity . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 18 Fumigant and insecticidal activity . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 18

Concluding remarks . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 21 Appendix A. Supplementary data. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 24 References . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 24

⇑ Corresponding author. Address: Department of Chemistry, University of British

Columbia, 3247 University Way, Kelowna, British Columbia V1V 1V7, Canada. Tel.:

+1 250 807 9566.

E-mail address: susan.murch@ubc.ca (S.J. Murch).

0031-9422/$ - see front matter 2013 Elsevier Ltd. All rights reserved.

http://dx.doi.org/10.1016/j.phytochem.2013.11.016

10 C.E. Turi et al. / Phytochemistry 98 (2014) 9–26

Introduction

The genus Artemisia consists of 350–500 species, with the majority of individuals residing in temperate zones of the Northern hemisphere (Bora and Sharma, 2011; Riggins and Seigler, 2012; Shultz, 2006) (Fig. 1). Recent estimates suggest there are 50 species of Artemisia (native and introduced) found in North America and which are distributed across the following subgenera: Artemisia (Miller) Less, Absinthium (Miller) Less, Dracunculus Besser, and Tri dentatae (Rydb.) (Shultz, 2009, 2006; Garcia et al., 2011b). Among these, the subgenus Tridentatae (Sagebrush) is endemic to North America (Garcia et al., 2011b; Shultz, 2009) (Fig. 2) and has been subject to numerous taxonomic revisions over the years (Garcia et al., 2011a, 2011b) (Table 1). It is believed there are between 10 and 13 species of Sagebrush in North America (Garcia et al., 2011a, 2011b; Shultz, 2009).

Phytochemical and pharmacological investigations of Artemisia species have led to the discovery of novel biologically active com pounds, most notably artemisinin from Artemisia annua L. (Asian sweet wormwood) (Bora and Sharma, 2011; Jose Abad et al., 2012; Tan et al., 1998). Traditionally, Native American or First Na tions peoples used indigenous Artemisia species as an analgesic, antiinflammatory, antiseptic, gastrointestinal or immunostimula tory aid or to treat afflictions from spiritual or unknown origins (Kelley et al., 1992; Moerman, 2009; Turner et al., 1980; Turner, 2009). A search in Web of Science on December 4, 2012 identified 891 articles referring to members of the subgenus Tridentatae. Of

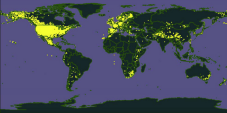


Fig. 1. Global distribution of Artemisia species. (Biodiversity occurrence data accessed through the GBIF Data Portal, www.gbif.net, 2012-12-04). Note: GPS data were only available for 308 out of 500 Artemisia species.

*A. arbuscula* 

*A. bigelovii*

*A. cana*

*A. nova*

*A. pygmaea*

*A. rigida*

*A. rothrockii*

*A. spiciformis*

*A. tridentata*

*A. tripar ta*

Fig. 2. Distribution of Artemisia species, subgenus Tridentatae in North America A. arbuscula (white) A. bigelovii (black), A. cana (green), A. nova (lavender), A. pygmaea (red), A. rigida (yellow), A. rothrockii (dark blue) A. spiciformis (pink) A. tridentata (light blue) A. tripartita (orange). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

these publications, 64% pertained to research areas in environmen tal sciences and ecology, while less than 5% encompassed research areas in chemistry and pharmacology (Table 2). The objectives of this review were: (1) to summarize current phytochemical and pharmacological understanding for Sagebrush species and (2) to reconcile previous taxonomic classifications within these works with current understanding of plant systematics for the Tridentatae.

Evolution, botany and taxonomy

The exact origin of the subgenus Tridentatae remains un known. Research suggests that Asian relatives belonging to the genus Artemisia subgenus Artemisia are ancestors to North Amer ican species of Sagebrush (Garcia et al., 2011a, 2011b). It was hypothesized that the subgenus Tridentatae emerged in North America during the Pleistocene via herbaceous ancestral members (Garcia et al., 2011b; Shultz, 2009), which would make these spe cies endemic to Western parts of North America (Shultz, 2009). Climatic fluctuations during this time may have facilitated the diversification of the Tridentatae by providing new territory for colonization and barriers which limit gene flow (Garcia et al., 2011b; Riggins and Seigler, 2012; Shultz, 2009; Valles et al., 2011).

The evolutionary history of the Tridentatae is reticulate, which in turn has led to multiple taxonomic re-arrangements within the Tridentatae (Garcia et al., 2008; Stanton et al., 2002) and a plethora of nomenclatural synonyms (Table 1). Tremendous effort has been put forth to effectively group Sagebrush species (Garcia et al., 2011a, 2011b; Garcia et al., 2008; Shultz, 2009). According to the Flora of North America, the subgenus Tridentatae is com prised of the following species: Artemisia arbuscula Nutt, Artemisia bigelovii A. Gray, Artemisia cana Pursh, Artemisia nova A. Nelson, Artemisia pygmaea (A. Gray) W.A. Weber, Artemisia rigida (Nutt) A. Gray, Artemisia rothrockii A. Gray, Artemisia spiciformis Osterhout, Artemisia tridentata Nutt, and Artemisia tripartita Rydb (Shultz, 2006; Table 1). It should be noted that recent molecular works sug gest further redefinition of this subgenus by splitting the Tridenta tae into two or more of the following sections: Tridentatae, Nebulosae and Filifoliae in hopes of concentrating the ‘true Sage brushes’ within section Tridentatae (Garcia et al., 2011b; Shultz, 2009; Valles et al., 2011). Identification of species within the Tri dentatae is challenging due to overlap of key morphological fea tures (Shultz, 2009). Sub-species can be identified by the unique environments they inhabit (Shultz, 2009). Members of the Astera ceae are often identified by weakly ornamented pollen grains, alternate or sparsely distributed leaves, and by close examination of flower heads or capitula (Valles et al., 2011). All members of the Tridentatae are shrubs (Shultz, 2009). The presence of interxy lary cork and bisexual flora heads is helpful to identify the subge nus (Shultz, 2009, 2006; Valles et al., 2011), while plant size, shape and size of flowering heads or pollen, leaf lobbing, and shape of lat eral shoots are helpful determinants at the species level (Shultz, 2009, 2006).

The ability of taxa in the Tridentatae to readily adapt to new ter ritories has led to their broad distribution over tens of millions of hectares in North America (Garcia et al., 2011b; Stanton et al., 2002) (Fig. 2). Sagebrush can thrive in diverse habitats such as canyons, meadows and slopes ranging from steppe to subalpine zones, dry shrublands, foothills, rocky outcrops, scabelands, and valleys (Douglas et al., 1998; Stanton et al., 2002). A. tridentata, A. arbuscula, A. cana, and A. nova are all considered landscape domi nant species, while A. arbuscula, A. bigelovii, A. pygmaea, A. rigida, A. rothrockii, A. spiciformis possess more restricted distributions (Garcia et al., 2008; Stanton et al., 2002) (Fig. 2). Distribution of

r

o

f

b

o

l

tt

u

.

A.

s

u

b

eB

ib

e

d

(

i r

n

a

l

W

av

a

is

it

s

.

p

i i

h

; n

a

p

na

aw

)b

at

n

s

le

yw

1

e

l

ba

T

.

)

6

0

0 2

,

z

t

lu

h

S (

a

c

ir

e

m

A

ht

r

o

N

f o

a

r

o

fl

e

h t

o

t

g

n

i

dr

o

c

c

a

e

a

t

a

t

n

e

di

r

T

s

u

n

e

gb

u

s

e

h t

n

i

s

e

ic

e

ps

b

u

s

d

n

a

s

e

ic

e

p

s

m

y

n

o

n

y S

s

e

ic

e

ps

b

u

S

s

e

m

a

n

n

o

m

m

o

C

s

m

y

n

o

n

y S

s

e

ic

e

pS

.

ps

b

u

s

t

t

u

N

a

l

u

c

s

u

b

r

a

a

i

s

i

m

e

t

r

A

,

hs

u

r

be

g

a

S

kr

a

D

,

e

g

a

S

w

o

L

a

l

u

c

s

u

br

a

.

ps

b

u

s

t

t

u

N

a

t

a

t

n

e

di

r

t

a

i

s

i

m

e

t

r

A

t

t

u

N

a

l

u

c

s

u

b

r

a

a

i

s

i

m

e

t

r

A

a

l

u

c

s

u

br

a

h s

u

r

be

g

a

S

d

n

a

l

b

a

c

S

a

i

s

i

m

e

t

r

A

;

s

t

n

e

m

e

l C

&

ll

a

H

.

M

.

H

)

t

t

u

N

(

i

c

i

p s

a

i

s

i

m

e

t

r

A

.

ps

b

u

s

t

t

u

N

a

l

u

c

s

u

b

r

a

a

i

s

i

m

e

t

r

A

;

n

n

i

M

c

M

)

t

t

u

N

(

a

l

u

c

s

u

br

a

.

r

a

v

a

t

a

t

n

e

di

r

t

ig

n

o

l

a

i

s

i

m

e

t

r

A

z

t

l

u

h S

.

M

.

L

)t

u

o

hr

e

t

s

O(

a

b

o

li

g

n

o

l

r

e

be

W

.

A.

W

)

t

t

u

N

(

m

u

l

u

c

s

u

b

r

a

m

u

i

di

h

pi

r

e

S

N

(

m

u

l

u

c

s

u

br

a

W

)t

u

o

hr

e

t

s

O(

r

a

m

u

i

di

h

pi

r

e

S

.

ps

b

u

s

t

t

u

N

a

l

u

c

s

u

b

r

a

a

i

s

i

m

e

t

r

A

(

m

u

lo

po

m

r

e

ht

e

lt

e

e

B

a

lo

po

m

r

e

ht

h s

u

r

be

g

a

S

w

o

le

gi

B

n

o

t

o

o

W

a

li

h

p

o

r

t

e

p

a

i

s

i

m

e

t

r

A

:

ii

v

o

le

gi

b

a

i

s

i

m

e

t

r

A

y

a

r

G.

A

i i

v

o

le

gi

b

a

i

s

i

m

e

t

r

A

.

K

)

y

a

r

g.

A(

i i

v

o

le

gi

b

m

u

i

di

h

pi

r

e

S;

y

e

ld

n

a

t

S&

s

e

ir

hp

m

u

H

&

r

e

m

e

r

B

m

u

l

o

c

a

i

s

i

m

e

t

r

A

a

n

a

c

.

ps

b

u

s

h

s

r

u

P

a

n

a

c

a

i

s

i

m

e

t

r

A

,

hs

u

r

be

g

a

S

y

k

c

i

t

S,

hs

u

r

be

g

a

S

r

e

v

li

S

r

e

be

W

.

A.

W

)

h

s

r

u

P

(

m

u

n

a

c

m

u

i

di

h

pi

r

e

S

h

s

r

u

P

a

n

a

c

a

i

s

i

m

e

t

r

A

n

a

l

o

b

a

i

s

i

m

e

t

r

A

i r

e

d

n

a

lo

b.

ps

b

u

s

h

s

r

u

P

a

n

a

c

a

i

s

i

m

e

t

r

A

f r

a

w

D

,

d

o

o

w

m

r

o

W

r

e

v

li

S

e

d

n

a

lo

b.

ps

b

u

s

d r

a

W

.

H

.

G

)

y

a

r

G.

A(

h s

u

r

be

g

a

S

yr

e

v

li

S,

hs

u

r

be

ga

S

o

b

m

u

i

di

h

pi

r

e

S

)

h

s

r

u

P

(

m

u

n

a

c

r

e

be

W.

A.

W

a

n

a

c

a

i

s

i

m

e

t

r

A

a

l

u

di

c

s

i

v

.

ps

b

u

s

h

s

r

u

P

a

n

a

c

a

i

s

i

m

e

t

r

A

i

m

e

t

r

A;

e

lt

e

e

B

e

lt

e

e

B

)t

u

o

hr

e

t

s

O(

h s

u

r

be

g

a

S

kc

a

l B

,

e

g

a

s

kc

a

lB

.

A(

a

v

o

n

.

ps

b

u

s

t

t

u

N

a

l

u

c

s

u

b

r

a

a

i

s

i

m

e

t

r

A

n

o

s

le

N

.

A

a

v

o

n

a

i

s

i

m

e

t

r

A

.

r

a

v

a

l

u

c

s

u

b

r

a

a

i

s

i

m

e

t

r

A;

dr

a

W

.

H

.

G

)

n

o

s

le

N

a

t

a

t

n

e

di

r

t

a

i

s

i

m

e

t

r

A

;

t

s

i

u

q

n

o

r

C

)

n

o

s

le

N

.

A(

a

v

o

n

&

ll

a

H

.

M

.

H

)

n

o

s

le

N

.

A(

a

v

o

n

.

ps

b

u

s

t

t

u

N

.

A.

W

)

n

o

s

le

N

.

A(

m

u

v

o

n

m

u

i

di

h

pi

r

e

S

;

s

t

n

e

m

e

lC

r

e

be

W

e

g

a

Sy

m

g

y P

r

e

be

W

.

A.

W

)

y

a

r

G.

A(

m

u

e

a

m

g

y p

m

u

i

di

h

pi

r

e

S

.

A.

W

)

y

a

r

G.

A(

a

e

a

m

g

y p

a

i

s

i

m

e

t

r

A

r

e

be

W

h s

u

r

be

g

a

S

d

n

a

l

b

a

c

S

;

t

t

u

N

a

di

gi

r

.

r

a

v

t

t

u

N

a

d

fii

r

t

a

i

s

i

m

e

t

r

A

y

a

r

G

.

A

)t

t

u

N

(

a

di

g

i r

a

i

s

i

m

e

t

r

A

r

e

be

W

.

A.

W

)

t

t

u

N

(

m

u

di

g

i r

m

u

i

di

h

pi

r

e

S

h s

u

r

be

g

a

S

y

k

c

i

t

S

,

kc

o

r

ht

o

R

.

A(

i i

kc

o

r

ht

o

r

.

ps

b

u

s

t

t

u

N

a

t

a

t

n

e

di

r

t

a

i

s

i

m

e

t

r

A

y

a

r

G.

A

i i

kc

o

r

ht

o

r

a

i

s

i

m

e

t

r

A

m

u

i

di

h

pi

r

e

S

;

s

t

n

e

m

e

l C

&

ll

a

H

.

M

.

H

)

y

a

r

G

r

e

be

W

.

A.

W

)

y

a

r

G.

A(

i i

kc

o

r

ht

o

r

h s

u

r

be

g

a

S

dl

e

fi

w

o

n

S

;

s

i

m

r

o

fi

c

i

ps

.

ps

b

u

s

t

t

u

N

a

t

a

t

n

e

di

r

t

a

i

s

i

m

e

t

r

A

t

u

o

hr

e

t

s

O

s

i

m

r

o

fi

c

i

p s

a

i

s

i

m

e

t

r

A

g

n

i L

.

R

.

Y

)t

u

o

hr

e

t

s

O(

e

m

r

o

fi

c

i

ps

m

u

i

di

h

pi

r

e

S

u

g

n

a

a

i

s

i

m

e

t

r

A

.

ps

b

u

s

t

t

u

N

a

t

a

t

n

e

di

r

t

a

i

s

i

m

e

t

r

A

,

hs

u

r

be

g

a

S

gi

B

,

hs

u

r

be

g

a

S

n

is

a

B

r

e

be

W

.

A.

W

)t

t

u

N

(

m

u

t

a

t

n

e

di

r

t

m

u

i

di

h

pi

r

e

S

t

t

u

N

a

t

a

t

n

e

di

r

t

a

i

s

i

m

e

t

r

A

s

b

u

s

a

t

a

t

n

e

di

r

t

a

t

a

t

n

e

di

r

t

,

hs

u

r

be

g

a

S

n

o

m

m

o

C

,

e

g

a

S-

gi

B

y ll

e

K

.

G.

R

e

v

a

jo

M

,

hs

u

r

be

g

a

S

n

is

a

B

t

a

e

r

G

s

ir

a

p

a

i

s

i

m

e

t

r

A

i i

h

s

ir

a

p.

ps

b

u

s

t

t

u

N

a

t

a

t

n

e

di

r

t

a

i

s

i

m

e

t

r

A

,

hs

u

r

be

g

a

S

n

i

a

t

n

u

o

M

,

hs

u

r

be

ga

S

o

s

p

e

J

)

y

a

r

g.

A(

s

t

n

e

m

e

l C

&

ll

a

H

.

M

.

H

)

y

a

r

G.

A(

,

hs

u

r

be

g

a

S

s

’

y

e

s

a

V

,

hs

u

r

be

ga

S

.

ps

b

u

s

r

e

be

W

h s

u

r

be

g

a

S

g

n

i

m

o

yW

y

e

s

a

v

a

i

s

i

m

e

t

r

A

.

ps

b

u

s

t

t

u

N

a

t

a

t

n

e

di

r

t

a

i

s

i

m

e

t

r

A

n

i

W

a

r

o

fli

c

u

a

p

e

lt

e

e

B

)b

dy

R

(

a

n

a

y

e

s

a

v

dy

R

(

a

n

a

y

e

s

a

v

r

e

be

W.

A.

W

e

di

r

t

a

i

s

i

m

e

t

r

A

.

ps

b

u

s

t

t

u

N

a

t

a

t

n

e

di

r

t

a

i

s

i

m

e

t

r

A

W

.

L

.

S

)g

n

u

o

Y

) g

n

u

o

Y

.

M

.

A &

e

lt

e

e

B

(

s

is

n

e

g

n

i

m

o

yw

.

ps

b

u

s

r

e

be

W

.

ps

b

u

s

b

dy

R

a

t

it

r

a

pi

r

t

a

i

s

i

m

e

t

r

A

h s

u

r

be

g

a

S

de

p

pi

T

-

e

e

r

hT

t

t

u

N

a

t

a

t

n

e

di

r

t

a

i

s

i

m

e

t

r

A

;

t

t

u

N

a

d

fii

r

t

a

i

s

i

m

e

t

r

A

b

dy

R

a

t

it

r

a

pi

r

t

a

i

s

i

m

e

t

r

A

a

t

it

r

a

pi

r

t

) b

dy

R

(

m

u

t

it

r

a

pi

r

t

m

u

i

di

h

pi

r

e

S,

a

d

fii

r

t

.

ps

b

u

s

a

l

o

c

ip

u

r

.

ps

b

u

s

b

dy

R

a

t

it

r

a

pi

r

t

a

i

s

i

m

e

t

r

A

r

e

be

W

.

A.

W

e

lt

e

e

B

S

12 C.E. Turi et al. / Phytochemistry 98 (2014) 9–26

Table 2

Distribution of articles across specific research areas according to web of science search engine analysis function.

me of these species, but the total metabolome has not been de scribed. The following sections highlight the characteristic compounds of the Tridentatae subgenus. Additional structures are

Total number of articles identified pertaining to species found within the subgenus Tridentatae

891

found in the supplementary information.

Research areas Counts Percent

Agriculture 181 20 Biochemistry Molecular Biology 57 6 Biodiversity Conservation 67 8 Biotechnology Applied Microbiology 8 1 Chemistry 24 3 Entomology 15 2 Environmental Sciences Ecology 567 64 Evolutionary Biology 30 3 Forestry 77 9 Genetics Heredity 13 1 Geochemistry Geophysics 5 1 Geology 17 2 Marine Freshwater Biology 5 1 Meteorology Atmospheric Sciences 10 1 Pharmacology Pharmacy 7 1 Physical Geography 7 1 Plant Sciences 191 21 Remote Sensing 6 1 Water Resources 15 2 Zoology 48 5

Research areas encompassing at least 1% of publications are only shown above.

35

**y**

**r**

**t**

**s**

**i**

Phenolics

A total of 29 plant phenolics were described in the literature for the Tridentatae in A. arbuscula, A. cana, A. nova, A. pygmaea, A. roth rockii, A. spiciformis, A. tridentata, A. tripartita (Fig. 3B). All are phe nylpropanoids, with the majority being flavonoids and glycosylated flavonoids (Table 3). The majority of the studies de scribe the identification of phenolics by high performance liquid chromatography (HPLC) with diode array detection (DAD) or ultra violet (UV) detection and quantification by comparison to refer ence standards. A small number of novel phenylpropanoids were also isolated and characterized from the Tridentatae including dihydroquercetin 7,30-dimethyl ether (1), artelin (2), methylesculin (3) and some coumarin sequiterpene ethers that will be described along with the sesquiterpenes. Esculin (4), scopoletin (5), axillarin (6), esculetin (7), isoscopoletin (8), and 6-b-D-glucosyl-7-methoxy coumarin (9) were most widely detected (>30% of species) (Figs. 3B and 4).

Monoterpenes

Monoterpenes belong to a class of specialized metabolites called terpenes, which are formed by the linking of two 5 carbon isoprene units (Guimarães et al., 2013). Anti-microbial, anti

**m**

**e**

**hc**

**o**

**t**

**yh**

**P**

**g**

**n**

**i**

**bi**

**r**

**c**

**s**

**e**

**D**

**s**

**r**

**e**

**pa**

**P**

**f**

**o**

**r**

**e**

**b**

**m**

**u**

**N**

***e***

***a***

***t***

***a***

***t***

***n***

***e***

***di***

***r***

**T**

**e**

**h**

**t**

**r**

**o**

**f**

30

inflammatory, hypotensive and analgesic activity has been re

25

ported for a wide range of monoterpene compounds (Guimarães

et al., 2013) including menthol and borneol which are sold as neu

20

traceuticals in Canada (Basu et al., 2007). Overall, 89 monoterpenes

15

have been reported in A. arbuscula, A. bigelovii, A. cana, A. nova, A.

pygmaea, A. spiciformis, A. tridentata (Fig. 3B, Table 4).

10

The overwhelming majority of monoterpenes were identified

5

by GC analysis with detection and tentative identification by either

EI-MS (electron impact mass spectrometry) followed by database

0

matching of the mass spectra, or by flame ionization detection,

where the compounds were either identified by comparison with

standards, or tentatively identified by relative retention using the

Kovacs retention index.

Fig. 3a. Number of publications describing phytochemistry of the Tridentatae (1930–2013).

subspecies is primarily dictated by moisture-elevation gradients and/or characteristics specific to soils and substrates (Stanton et al., 2002).

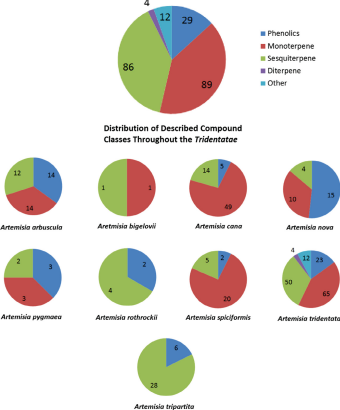
Phytochemistry

Research interest for the phytochemical complexity of Sage brush has been under investigation for many decades but declining since the 1970s (Fig. 3A). The reported phytochemistry of the Tri dentatae spans the major classes of plant secondary metabolism – phenolics (13.2%), monoterpenes (40.5%), sesquiterpenes (39.1%), diterpenes (1.8%) and others (5.5%) (Fig. 3B). This phyto chemistry is not a comprehensive representation of the metabolo me, but rather the result of several decades of targeted phytochemical discovery using primarily gas chromatography with flame ionization detection (GC/FID) and gas chromatography with mass spectrometry (GC/MS) for profiles of the essential oils. Con siderable effort has also been made to characterize more complex terpenes, plant phenolics, and other constituents of the metabolo

A number of novel monoterpenes were identified and fully characterized from the Tridentatae, of which most are irregular monoterpenes. These include chrysanthemol (10) and its oxidized derivative chrysanthemal (11), methyl santolinate (12), santolina triene (13), oxido santolina triene (14), artemesia triene (15), santolinolide A (16) and B (17), artemiseole (also spelled artemese ole, and artemisol) (18), rothrockene (19), neolyratol (20), (1,6,6- trimethyl-4-ethenyl-exo-2-oxabicyclo[3.1.0]hexane (21), lavandu lol (22), arbusculone (23), 2,2-dimethyl-6-isopropenyl-2H-pyran (24), 2,3-dimethyl-6-isopropyl-4H-pyran (25), and 2-isopropyl-5- methylhexa-trans-3,5-diene-1-ol (26) (Fig. 5). Compounds most commonly described in these species (>40% of Tridentatae mem bers) include: a-pinene (27), santolina triene (13), artemiseole (18), camphor (28), methacroleine (29) p-cymene (30), camphene (31) and eucalyptol (32) (Table 4, Fig. 5).

Sesquiterpenes

Sesquiterpenes have provided many interesting biologically active lead compounds including artemisinin (Brown, 2010) and parthenolide (Ghantous et al., 2010). In total, 86 sesquiterpenes and their derivatives were found in A. arbuscula, A. bigelovii, A. cana, A. nova, A. pygmea, A. rothrockii, A. spiciformis, A. tridentata, and A. tridentata (Fig. 3B, Table 5). Most of the sesquiterpenes

C.E. Turi et al. / Phytochemistry 98 (2014) 9–26 13Fig. 3b. Distribution of compound classes in the Tridentatae and its members.

described in the Tridentatae were first isolated and structurally characterized from members of the genus Artemisia, and repre sent a remarkable chemical diversity (Table 5). Sesquiterpenes were identified by a variety of techniques after their original iso lation and characterization, including comparisons to standards by thin layer chromatography (TLC), HPLC/DAD, HPLC/UV, and HPLC/MS.

The majority of sesquiterpenes that were first described in the Tridentatae are sesquiterpene lactones, with structures based on: the lactone fused to a bicyclo[4.4.0]decane framework such as arbusculins A (33), B (34), C (35), D (36), and E (37), colartin (38), ridentin B (39), rothins A (40) and B (41), 1-b-hydroxy sant-3-en-6,12-olide-C (42), 1-b-hydroxysant-4(14)-en-6,12- olide-C (43) (Fig. 6); the lactone fused to the open cyclodecane framework, such as artevasin (44), novanin (45), badgerin (46), deacetyllaurenobiolide (47), spiciformin (48), and tatricidins A (49) and B (50) (Fig. 6); or the lactone fused to the large ring of a bicyclo[5.3.0]decane such as arbiglovin (51), artecanin (also re ferred to in the literature as chrysartemin B) (52), canin (53), cumambrin A (54) and B(55), 8-deoxycumambrin B (56), cumam

brin B oxide (57), matricarin (58), deacetoxymatricarin (also re ferred to as leucodin in the literature) (59), deacetylmatricarin (60), rupicolins A (61) and B (62), rupins A (63) and B (64), and viscidulins A (65), B (66), and C (67) (Fig. 6). Four sesquiterpene coumarin ethers have been isolated and structurally characterized in the Tridentatae including tripartol (68), secondriol (69), second rial (70), and drimachone (71), as well as three other sesquiter penes, longilobol (72), arbusculin E (37), and pygmol (73) (Fig. 7). Arbusculins A (33), B (34), and C (35), artevasin (44), deacetoxymatricarin (59), deacetylmatricarin (60), desacetoxym atricarin (74), ridentin (75), tatridin-A (49) and B (50) were re ported within more than 30% of species in the Tridentatae (Table 5, Figs. 3B and 7).

Diterpenes

Only 4 diterpenes have been characterized in extracts of A. tridentata including: methyl isopimarate (76), methyl levopimarate (77), methyl palustrate (78), and methyl trans-communate (79) (Fig. 8, Table 6).

.

e

a

t

a

t

n

e

di

r

T

e

h t

n

i

s

di

.

A

.

A

.

A

.

A

.

A

.

A

.

A

.

A

a

i

s

i

m

e

t

r

A

a

n

a

c

.

A

a

i

s

i

m

e

t

r

A

a

i

s

i

m

e

t

r

A

.

A

.

A

a

i

s

i

m

e

t

r

A

a

i

s

i

m

e

t

r

A

a

i

s

i

m

e

t

r

A

a

i

s

i

m

e

t

r

A

r

a

l

u

c

e

lo

M

Z /

M

l

a

c

i

m

e

hC

a

t

a

t

n

e

di

r

t

a

t

a

t

n

e

di

r

t

a

t

a

t

n

e

di

r

t

n

e

di

r

t

i

c

i

ps

ht

o

r

a

di

gi

r

gy

p

a

v

o

n

.

ps

b

u

s

a

n

a

c

a

n

a

c

a

n

a

c

le

gi

b

a

l

u

c

s

u

br

a

a

l

u

c

s

u

br

a

a

l

u

c

s

u

br

a

a

l

u

c

s

u

br

a

t

h

gi

e

w

a

lu

m

r

o

f

.

ps

b

u

s

.

ps

b

u

s

.

ps

b

u

s

a

t

a

t

s

i

m

r

o

f

i i

kc

o

r

a

e

a

m

r

e

d

n

a

l

u

o

b

.

ps

b

u

s

.

ps

b

u

s

i i

v

o

.

ps

b

u

s

.

ps

b

u

s

.

ps

b

u

s

a

t

a

t

n

e

di

r

t

g

n

i

m

o

yw

a

n

a

y

e

s

a

v

a

l

u

di

c

s

iv

a

n

a

c

a

lo

po

m

r

e

ht

a

b

o

li

g

n

o

l

a

l

u

c

s

u

br

a

s

is

n

e

8 6

3 .

2

3 3

9

0.

2

3 3

7

O61

H

7

1C

n

it

e

c

r

e

u

q

o

r

r

e

h

t

e

ly

ht

e

m

i

3

92

5

2.

6

6 2

8

0.

6

6 2

6

O41

H3

1 C

n

6 4

6

4,

5

4,

9 3

6

4,

3,

5 3

9

3,

64

1

3.

4

5 3

0

1.

4

5 3

9

O81

H61

C

-

7n

r

e

ht

e

l

)

n

il

u

c

s

e

ly

6

3,

6

4,

2

3,

9 3

6

4,

5

4,

9 3

6

4,

2

3,

3,

5 3

5

3,

9

3,

6 4

5 3

5 3

5

3,

6 4

5

3,

6 4

8

2.

0

4 3

8

0.

0

4 3

9

O61

H5

1 C

n

5

3,

6

4

,

9 3

5

4

,

6

4

,

9 3

6

4

,

3,

5

3

9 2

9 3

5

3

5

3,

6 4

6 4

7

1

.

2

9 1

4

0.

2

9 1

4

O8

H

01

C

-

7

(

n

it

e

l

-

6-

yx

)

n

ir

a

m

u

o

c

yx

9 3

5 4

,

9 3

8

6.

3

8 6

8 6

9

3,

64

6 4

9

2.

6

4 3

7

0.

6

4 3

8

O41

H7

1 C

n

ir

5

3,

9 3

5

4,

9 3

9

2,

6

4,

5

3,

3

9

3,

6 4

5 3

6 4

5

3,

6 4

4

1.

8

7 1

3

0.

8

7 1

4

O6

H

9 C

n

it

6

4

,

5

3,

2

3,

9 3

6

4

,

5

4

6

4

,

2

3,

3,

5

3

9 2

6

4

,

9 3

6 4

5

3,

6 4

7

1

.

2

9 1

4

0.

2

9 1

4

O8

H

0

1

C

n

it

e

lo

p

5

3

5

3

5

3

5

3

1

3.

8

3 3

0

1

.

8

3 3

8

O81

H

61

C

-

7

-

l

ys

o

c

u

l

g-

D

-

a

n

ir

a

m

u

o

c

yx

4 2

4

3.

4

7

3

0

1

.

4

7

3

8

O81

H

91

C

yx

o

r

dy

h

0

-

e

n

o

v

a

flyx

o

ht

e

9 3

93

4

2.

0

7 2

5

0.

0

7 2

5

O0

1

H5

1 C

n

in

8 6

6

2

.

4

8 2

7

0.

4

8 2

5

O2

1

H

61

C

l y

ht

e

m

-

0

4

n

in

)

n

it

e

c

a

c

a

(

6 4

6

4,

5 4

6 4

6 4

6 4

6 4

8

3.

2

3 4

1

1.

2

3 4

01

O0

2

H1

2C

O

-

7

n

in

e

di

s

3

92

8

2

.

0

4

3

8

0.

0

4

3

9

O61

H

5

1

C

n

it

e

l

u

c

s

e

(

n

ii

r

) e

di

s

o

c

u

l

3

6

2.

6

1 3

6

0.

6

1 3

7

O21

H6

1 C

n

il

o

9

1

.

2

2

2

5

0.

2

2

2

5

O0

1

H

1

1

C

-

7

(

n

i

di

x

-

8,

6-

yx

)

n

ir

a

m

u

o

c

yx

o

h

6

4

,

9 3

6

4

,

9 3

6 4

0 7

9

3,

6 4

6 4

6 4

4

2

.

6

8 2

5

0.

6

8 2

6

O0

1

H

5

1

C

l

o

r

e

fp

8 6

6

2

.

6

1

3

6

0.

6

1

3

7

O2

1

H

61

C

-

6

l

o

r

e

fp

r

e

h

t e

l

6

4,

2 3

6

4,

5 4

,

2

3,

3

0 7

64

6 4

4

2.

6

8 2

5

0.

6

8 2

6

O0

1

H5

1 C

n

il

3

8

3.

8

4 4

0

1.

8

4 4

11

O0

2

H1

2C

O-

7-

n

il

e

di

s

9 2

1

6.

2

2 6

3

2.

2

2 6

41

O83

H0

3 C

e

di

s

o

lo

6 4

8

6,

6

4,

3

6 4

8 6

8

6.

6 4

2

3.

4

4 3

9

0.

4

4 3

7

O61

H8

1 C

n

it

e

l

6 4

9

4,

6 4

6 4

9

3,

6 4

6 4

6 4

4

2.

8

1 3

4

0.

8

1 3

8

O0

1

H

5

1 C

n

it

e

g

a

t

e

8

6.

3

8 6

86

1

3.

0

6 3

8

0.

0

6 3

8

O61

H

81

C

-

7

,

6,

3-

n

it

e

g

a

t

e

r

e

h

t

e

ly

ht

6

4,

9 3

6

4,

5

4,

9 3

6 4

0 7

93

4

2.

2

0 3

4

0.

2

0 3

7

O0

1

H5

1 C

n

it

e

8 6

9

2.

0

3 3

7

0.

0

3 3

7

O41

H71

C

-

0

3,

7

n

it

e

r

e

h

t

e

ly

h

) e

n

iz

a

n

6

4,

5 4

3

9 2

9

3,

6 4

6 4

9

1.

6

0 2

6

0.

6

0 2

4

O0

1

H1

1 C

e

n

o

r

3

92

8

2.

4

2 3

8

0.

4

2 3

8

O61

H5

1 C

n

i

6

4,

9 3

6

4,

5

4,

9 3

6

4,

3

9 2

6

4,

9 3

6 4

6 4

4

1.

2

6 1

3

0.

2

6 1

3

O6

H

9 C

e

n

o

r

e

fi

ll

,

)7

7

9 1

,

.

l a

t

e

s

u

kt

t

u

B

(

5

,

)2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

2

8

9 1

,

m

a

hg

n

i

kc

u

B

(

4

,

)5

7

9 1

,

.

l a

t

e

n

w

o

r

B

(

3

,

)5

8

9 1

,

h

c

le

W

d

n

a

n

a

he

B

(

2

,

)4

3

9 1

,

gr

e

b

ka

O

d

n

a

s

m

a

d

A(

1

:

s

a

d

e

r

e

b

m

u

n

2

,

.

l a

t

e

a

n

e

dr

a

w

a

n

u

G(

3

1

,

)3

8

9 1

,

.

l a

t

e

r

e

g

e

r

G(

2

1

,

)

2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

2

8

9 1

,

y

bs

a

l

G(

1

1

,

)

1

9

9 1

,

.

l a

t

e

n

i

e

t

s

p

E

(

0

1

,

)4

8

9 1

,

.

l a

t

e

n

i

e

t

s

p

E

(

9 ,

)3

7

9 1

,

r

e

t

l

u

o

P

d

n

a

n

i

e

t

s

p

E

(

8 ,

)4

t

e

y

e

s

le

K

(

1

2

,

)

2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

3

8

9 1

,

i

n

a

t

e

m

a

K

(

0

2

,

)0

1

0 2

,

.

l a

t

e

i

b

s

s

a

J(

9

1

,

)7

7

9 1

,

.

l a

t

e

ll

o

hc

S(

8

1

,

)e

37

9 1

,

n

a

m

s

s

ie

G

d

n

a

n

i

w

r

I

(

7

1

,

)

1

7

9 1

,

n

a

m

s

s

ie

G

d

n

a

n

i

w

r

I

(

6

1

,

)

d3

a

r

r

u

M

(

9

2

,

)2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

7

8

9 1

,

e

r

o

o

M

(

8

2

,

)

9

9

9 1

,

.

l a

t

e

c

i

v

e

jl

v

a

s

o

li

M

(

7

2

,

)a

8

0

0 2

,

.

l a

t

e

z

t

u

L

-

s

e

p

o

L

(

6

2

,

)

b

80

0 2

,

.

l a

t

e

z

t

u

L

-

s

e

p

o

L

(

5

2

,

)9

6

9 1

,

.

l a

t

e

e

e

L

(

4

2

,

)1

4

9 1

,

.

l a

le

M

d

n

a

he

d

a

z

fia

h

S(

5

3,

)5

7

9 1

,

he

d

a

z

fia

h S

d

n

a

e

n

a

da

h

B

(

4

3,

)b

3

7

9 1

,

e

n

a

da

h B

d

n

a

he

d

a

z

fia

h

S(

3

3,

)1

9

9 1

,

y

e

s

l

e

K

d

n

a

r

e

t

e

r

t

n

e

s

o

R

(

2

3,

)6

7

9 1

,

.

l a

t

e

z

e

u

gi

r

do

R

(

1

3,

)

b7

7

9

l a

t

e

y

e

ll

e

K

n

i

7

5

9 1

,

n

i

a

r

T

(

2

4

,

)2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

8

7

9 1

,

n

o

s

p

m

o

h

T

(

1

4

,

)2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

07

9 1

,

y

n

e

t

e

T

(

0

4

,

)5

8

9 1

,

.

l a

t

e

a

m

m

a

T

(

9

3,

)

5

7

9 1

,

.

l a

t

e

w

a

h

S(

8

3,

)4

7

9 1

,

.

l a

S

d

n

a

y

e

s

le

K

(

0

5

,

)a

3

7

9 1

,

n

a

m

s

s

ie

G

d

n

a

n

i

w

r

I

(

9

4

,

)

80

0 2

,

.

l a

t

e

e

i

X

(

8

4

,

)

2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

3

8

9 1

,

.

l a

t

e

m

o

d

s

i

W

(

7

4

,

)

2

9

9 1

,

.

l a

t

e

t

li

W

(

6

4

,

)

2

9

9 1

,

r

e

lli

M

d

n

a

t

li

W

(

5

4

,

)

2

89

(

8

5

,

)7

7

9 1

,

e

s

o

B

d

n

a

s

u

kt

t

u

B

(

7

5

,

)5

6

9 1

,

a

n

a

ht

n

a

S

d

n

a

z

r

e

H

(

6

5

,

)a

96

9 1

,

n

a

m

s

s

ie

G

d

n

a

n

i

w

r

I

(

5

5

,

)

b

96

9 1

,

n

a

m

s

s

ie

G

d

n

a

n

i

w

r

I

(

4

5

,

)5

7

9 1

,

.

l a

t

e

e

n

a

da

h

B

(

3

5

,

)3

7

9 1

,

.

l

n

a

he

d

a

z

fia

h

S(

5

6,

)a

2

7

9 1

,

e

n

a

da

h B

d

n

a

he

d

a

z

fia

h

S(

4

6,

)a

37

9 1

,

e

n

a

da

h B

d

n

a

he

d

a

z

fia

h

S(

3

6,

)9

7

9 1

,

o

s

o

id

u

a

G

d

n

a

n

i

e

t

s

p

E

(

2

6,

)

9

6

9 1

,

.

l a

t

e

n

i

w

r

I

(

1

6,

)9

6

9 1

,

.

l a

t

e

n

a

m

s

s

i

.

)

30

0 2

,

.

l a

t

e

k

e

r

o

B

(

1

7

,

)

89

9 1

,

.

l a

t

e

h

c

ir

n

ie

H

(

0

7

,

)

b3

7

9 1

,

n

a

m

s

s

ie

G

d

n

a

n

i

w

r

I

(

9

6,

)2

7

9 1

,

.

l a

t

e

e

u

gi

r

do

R

(

8

6,

)

2

8

9 1

,

o

s

o

id

u

a

G

d

n

a

n

i

e

t

s

3

e

l

ba

T

o

n

e

p

o

r

pl

y

n

e

hP

it

n

e

dI

n

o

it

a

c

fi

r

e

b

m

u

n

s

c

il

o

n

e

hP

dy

hi

D

1

d

-

0

3,

7

il

e

t

r

A2

il

u

c

s

E3

y

ht

e

m

ht

e

m

(

il

u

c

s

E4

o

p

o

c

S5

o

r

dy

h

o

ht

e

m

a

lli

x

A6

e

l

u

c

s

E7

o

c

s

o

s

I8

te

B-

69

o

ht

e

m

i

D0

4,

5

0 -

S

3,

7,

6,

3

m

a

rt

et

e

gi

pA

1 -

S

e

gi

pA

2 -

S

r

e

ht

e

e

gi

pA

3 -

S

o

c

u

lg

o

h

c

iC

4 -

S

g-

O-

7

fa

p

u

E

5 -

S

a

r

f

o

s

I

6 -

S

o

r

dy

h

te

m

id

m

e

a

K

7 -

S

m

e

a

K

8 -

S

y

ht

e

m

o

e

t

u

L

9 -

S

o

e

t

u

L

0

1-

S

o

c

u

lg

n

ga

M

1

1-

S

u

d

n

e

P

2

1-

S

c

r

e

u

Q

3

1-

S

c

r

e

u

Q

4

1-

S

e

m

i

r

t

c

r

e

u

Q

5

1-

S

c

r

e

u

Q

6

1-

S

te

m

id

m

a

h

R

(

a

p

o

c

S

7

1-

S

m

m

i

kS

8

1-

S

e

b

m

U

9

1-

S

e

r

a

s

e

c

n

e

r

e

fe

R

8

9 1,

o

s

o

id

u

a

G

7

9 1,

n

a

m

s

s

ie

G

t

e

ye

n

n

i

K

(

3 2

1

,

n

i

e

t

s

p E

d

n

a

t

e

he

d

a

z

fia

h

S(

1

,

.

l a

t

e

e

t

ih

W

(

a

t

e

y

e

s

le

K

(

2 5

e

G(

0

6,

)a

7

7

91

p

E

(

7

6,

)c

37

91

C.E. Turi et al. / Phytochemistry 98 (2014) 9–26 15

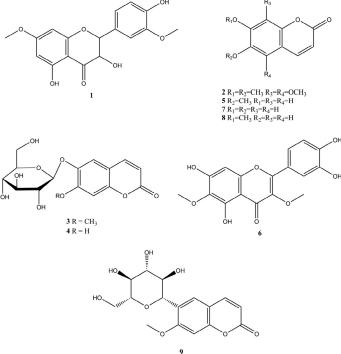


Fig. 4. Characteristic phenylpropenoids in the Tridentatae. Please note: structures of the additional phenylpropenoids are in the Supplemental Files.

Other phytochemicals

An assortment of polyketides, fatty acids, polysaccharides, tan nins, alkaloids, carbohydrates and proteins have also been de scribed in A. tridentata and/or A. tripartita (Table 6).

Bioassay

The majority of bioassay data describing the activity of Artemi sia species in the Tridentatae indicates antimicrobial, antioxidant, antiviral and insecticidal activity.

Antimicrobial

Plant-based antimicrobial compounds that have the potential to combat food spoilage (Tiwari et al., 2009) and multi-drug resis tance (Saleem et al., 2010) are under extensive investigation. Amongst members of the Tridentatae, antimicrobial activity has been observed in oils collected from A. cana, A. nova, and A. tridentata (Lopes-Lutz et al., 2008a, 2008b; Nagy and Tengerdy, 1967) and methanol extracts of A. arbuscula, A. bigelovii, A. cana subsp. bolanderi, A. nova, A. rothrockii, A. spiciformis, A. tridentata subsp. parishii, A. tridentata subsp. tridentata, A. tridentata subsp. vaseyana, A. tridentata subsp. wyomingensis, and A. tripartita subsp. tripartita, (McCutcheon, 1996; McCutcheon et al., 1994) using in vitro bioassays with various strains of bacteria, yeast, and fungi. A common mechanism or specific mode of action has

not been determined and the diversity of extracts makes data interpretation difficult.

Antimycobacterium

Antimycobacterials isolated from plants may provide less inva sive treatments to combat tuberculosis (TB), (Negi et al., 2010). For example, potent activity against Mycobacterium tuberculosis has been observed for the following terpenes: aegicerin (1.6–3.1 lg/mL), phytol (2 lg/mL), and sapintoxin A (3.15 lg/ mL) (Negi et al., 2010). Methanolic extracts from A. arbuscula, A. bigelovii, A. cana subsp. bolanderi, A. cana subsp. cana, A. nova, A. rothrockii, A. spiciformis, A. tridentata subsp. tridentata, A. tridentata subsp. vaseyana, and A. tripartita subsp. tripartita all displayed varying degrees of antimycobacterial activity (McCutcheon, 1996). Furthermore, from the above extracts, A. cana, A. nova, A. tridentata subsp. tridentata, and A. tripartita show the greatest po tential for the discovery of new TB drugs since they were found to exhibit the most activity against Mycobacterium tuberculosis and/ or Mycobacterium avium (McCutcheon, 1996). Further investiga tion is required to determine the specific mechanisms involved in the growth inhibition.

Antioxidant activity

Antioxidants are classically defined as ‘‘any substance that de lays, prevents or removes oxidative damage to a target molecule’’

16 C.E. Turi et al. / Phytochemistry 98 (2014) 9–26a

4

e

l

ba

T

.

e

a

t

a

t

n

e

di

r

T

e

h t

n

i

s

e

n

e

pr

e

t

o

n

o

.

A

.

A

.

A

.

A

.

A

a

t

a

t

n

e

di

r

t

.

A

.

A

.

A

.

A

.

A

.

A

.

A

.

A

a

n

a

c

.

A

a

n

a

c

.

A

.

A

.

A

.

A

.

A

.

A

.

A

.

A

r

a

l

u

c

e

lo

M

Z

/M

l

a

c

i

m

e

hC

fii

t

n

e

dI

t

it

r

a

pi

r

t

a

t

it

r

a

pi

r

t

a

t

it

r

a

pi

r

t

a

t

a

t

n

e

di

r

t

a

t

a

t

n

e

di

r

t

.

ps

b

u

s

a

t

a

t

n

e

di

r

t

n

e

di

r

t

i

c

i

ps

ht

o

r

a

di

gi

r

a

e

a

m

gy

p

a

v

o

n

.

ps

b

u

s

.

ps

b

u

s

a

n

a

c

a

n

a

c

le

gi

b

a

l

u

c

s

u

br

a

a

l

u

c

s

u

br

a

a

l

u

c

s

u

br

a

a

l

u

c

s

u

br

a

t

h

gi

e

w

a

lu

m

r

o

f

n

o

it

a

c

.

ps

b

u

s

.

ps

b

u

s

.

ps

b

u

s

.

ps

b

u

s

s

is

n

e

g

n

i

m

o

yw

.

ps

b

u

s

a

t

a

t

s

i

m

r

o

f

i i

kc

o

r

r

e

d

n

a

l

u

o

b

a

l

u

di

c

s

iv

.

ps

b

u

s

i i

v

o

.

ps

b

u

s

.

ps

b

u

s

.

ps

b

u

s

r

e

b

m

u

n

a

l

o

c

ip

u

r

a

t

it

r

a

pi

r

t

i i

h

s

ir

a

p

a

t

a

t

n

e

di

r

t

a

n

a

y

e

s

a

v

a

n

a

c

a

lo

po

m

r

e

ht

a

b

o

li

g

n

o

l

a

l

u

c

s

u

br

a

e

n

e

pr

e

t

o

n

o

M

3 1

3 1

0 1

5

2

.

4

5

1

4

1

.

4

5

1

O81

H

0

1

C

lo

m

e

ht

n

a

s

yr

hC

0 1

3 1

4

2

.

2

5

1

2

1

.

2

5

1

O61

H

0

1

C

la

m

e

ht

n

a

s

yr

h

c

-

s

n

a

r

T

1 1

8 3

,

1

2

,

2

3

1

2

9,

1

2

,

2

3

1

1

7

6

2

.

2

8 1

3

1

.

2

8 1

2

O81

H

1

1

C

e

t

a

n

il

o

t

n

a

s

ly

ht

e

M

2 1

1

2,

9 1

1 2

1 2

,

9

8

3 1

8

3 1

6

2,

5 2

7

8

3

2.

6

3 1

3

1.

6

3 1

61

H0

1 C

e

n

e

i

r

t

a

n

il

o

t

n

a

S

3 1

9

,

1 1

,

0 3

31

3

2.

2

5 1

2

1.

2

5 1

O6

1

H0

1 C

e

n

e

i

r

t

a

n

il

o

t

n

a

s

o

di

x

O

4 1

9 1

8

3 1

8

3

2.

6

3 1

3

1.

6

3 1

61

H0

1 C

e

n

e

i

r

t

a

i

s

i

m

e

tr

A

5 1

2 6

11

2

2.

6

6 1

1.

6

6 1

2

O4

1

H0

1 C

A-

e

d

il

o

n

il

o

t

n

a

S

6 1

2 6

0

2,

4,

11

2

2.

6

6 1

1.

6

6 1

2

O4

1

H0

1 C

B-

e

dil

o

n

il

o

t

n

a

S

7 1

1

2,

8

1,

2 3

1 2

,

81

,

8

1,

2 3

,

9

,

4,

1

1,

7 5

8 1

8 1

3 1

,

8 1

6

2,

5 2

7,

8 1

3

2.

2

5 1

2

1.

2

5 1

O61

H0

1C

,

e

l

o

e

s

e

m

e

t

r

a

,

e

l

o

e

s

i

m

e

t

r

A

8 1

1 2

9 5

e

lo

ht

r

a

7 6

,

9

3 1

3 1

3

2.

6

3 1

3

1.

6

3 1

61

H0

1 C

e

n

e

kc

o

r

ht

o

R

9 1

9

4

2

.

2

5

1

2

1

.

2

5

1

O61

H

0

1

C

l

o

t

a

r

yl

o

e

N

0 2

7 5

4

2

.

2

5

1

2

1

.

2

5

1

O61

H

01

C

o

x

e

-

ly

n

e

ht

e

-

4

-

ly

ht

e

m

ir

T

-

6,

6,

1

1 2

e

n

a

x

e

h]

0.

1

.

3[

o

lc

y

c

i

ba

x

o

-

2

3 1

5

2.

4

5 1

4

1.

4

5 1

O81

H0

1 C

l

o

l

u

d

n

a

v

a

L

2 2

7

1

2.

4

5 1

1.

4

5 1

2

O41

H

9 C

e

n

o

l

u

c

s

u

br

A

3 2

3 1

3 1

2

2

.

0

5

1

1

.

0

5

1

O4

1

H

01

C

H

2

-

ly

n

e

p

o

r

p

o

s

i-

6

-

ly

ht

e

m

i

D

-

2

,

2

4 2

n

a

r

yp

3 1

3 1

3

2

.

2

5

1

1

.

2

5

1

O61

H

01

C

H

4

-

ly

p

o

r

p

o

s

i-

6

-

ly

ht

e

m

i

D

-

3,

2

5 2

n

a

r

yp

3 1

3 1

3

2

.

2

5

1

2

1

.

2

5

1

O61

H

01

C

a

x

e

hl

y

ht

e

m

-

5

-

ly

n

e

p

o

r

p

o

s

I

-

2

6 2

l

o

-

1-

n

e

i

d-

5,

3-

s

n

a

r

t

,

8 1

,

3 4

1

2

,

8 1

,

34

,

8 1

,

9,

34

,

1

,

5

,

3 2

3 1

8 1

8

1

,

2

8 1

,

3 1

6

2

,

5

2

8 1

3

2

.

6

3 1

3

1

.

6

3 1

61

H

0

1

C

e

n

e

n

i

p-

a

h

pl

A

7 2

,

9 1

,

12

4

4,

6,

12

1 7

4

4,

41

,

2

3,

9 1

3

4

,

1

2

,

2

3,

9

,

5

,

3 2

3 1

2

3 1

6

2

,

5

2

7

4

2

.

2

5

1

2

1

.

2

5

1

O61

H

0

1

C

r

o

hp

m

a

C

8 2

,

12

3

4,

4

4,

6,

12

,

0

7,

04

3

4,

4

4,

41

1 ,

17

,

2 3

,

8 1

1 2

,

8 1

1 2

,

2 3

,

8 1

0

4,

3 2

8 1

8 1

8 1

8 1

8 1

9

0.

0 7

4

0.

0 7

06

H

4 C

e

n

i

e

l

o

r

c

a

ht

e

M

9 2

1 2

3

4,

1 2

3

4,

1 2

3 4

,

9,

1 2

1 7

3 1

2

3 1

6

2,

5 2

7

4

2.

2

5 1

2

1.

2

5 1

O61

H0

1 C

e

n

e

m

y

C-

p

0 3

,

9 1

,

3 4

1

2

,

34

,

3 4

0 7

,

0 4

,

5

3 1

2

6

2

,

5

2

7

3

2

.

6

3 1

3

1

.

6

3 1

61

H

0

1

C

e

n

e

hp

m

a

C

1 3

2

3,

4

1,

12

2

3,

1

2,

9

,

9 1

,

3 4

1

2

,

34

,

9,

3

4

,

31

,

5

,

3

2

,

1

3 1

2

3 1

6

2

,

5

2

7

5

2

.

4

5

1

4

1

.

4

5

1

O81

H

0

1

C

e

l

o

e

n

i c

,

e

l

o

e

n

i

c

-

8,

1

,

l

o

t

p

yl

a

c

u

E

2 3

,

1

2,

23

,

23

,

04

4

4,

41

4

4,

6,

12

1

7,

07

3 1

9

1

.

2

5

1

8

0.

2

5

1

2

O2

1

H

9 C

n

a

r

y

p-

H

2

-

l

yt

e

c

a

6

-

ly

ht

e

m

i

D

-

,

2

,

2

0

2

-

S

3 4

3 4

3 4

52

3

2.

6

3 1

3

1.

6

3 1

61

H0

1 C

e

n

e

r

a

C-

3-

6

1

2-

S

3 4

3 4

3 4

5

3

2

.

6

3 1

3

1

.

6

3 1

61

H

0

1

C

e

n

e

r

d

n

a

ll

e

h

p-

a

h

pl

A

2

2

-

S

3 1

5

2

.

4

5

1

4

1

.

4

5

1

O81

H

0

1

C

lo

h

o

c

l a

a

n

il

o

t

n

a

s

-

a

h

pl

A

3

2

-

S

6

2

,

5

2

3

2

.

6

3 1

3

1

.

6

3 1

61

H

0

1

C

e

n

e

n

i

pr

e

t

-

a

h

pl

A

4

2

-

S

5

6

2

,

5

2

5

2

.

4

5

1

4

1

.

4

5

1

O81

H

0

1

C

l

o

e

n

i

pr

e

t

-

a

h

pl

A

5

2

-

S

9 1

6

2

,

5

2

3

2

.

6

3 1

3

1

.

6

3 1

61

H

0

1

C

e

n

e

ju

ht

-

a

h

pl

A

6

2

-

S

,

9 1

,

3 4

3 4

4

4

,

34

3

2

.

2

5

1

2

1

.

2

5

1

O61

H

0

1

C

e

n

o

ju

ht

-

a

h

pl

A

7

2

-

S

4

4,

41

1 2

1 2

12

9

2.

6

9 1

5

1.

6

9 1

2

O0

2

H2

1 C

e

t

a

t

e

c

a

a

i

s

i

m

e

tr

A

8

2-

S

1 2

1 2

9,

1 2

,

2 3

04

5

2.

4

5 1

4

1.

4

5 1

O81

H0

1 C

lo

h

o

c

l a

a

i

s

i

m

e

t

r

A

9

2-

S

1 2

1 2

2

3,

1 2

3 1

7

8

3

2.

2

5 1

2

1.

2

5 1

O61

H0

1 C

e

n

o

t

e

k

a

i

s

i

m

e

t

r

A

0

3-

S

7

9

2

.

6

9 1

5

1

.

5

9 1

2

O0

2

H

2

1

C

e

t

a

t

e

c

a

l

y

s

i

m

e

t

r

A

1

3-

S

1 7

4

2.

6

3 1

3

1.

6

3 1

61

H0

1 C

e

n

e

m

ic

o

-

a

te

B

2

3-

S

1 2

1 2

,

9,

1 2

1 7

,

5

3 1

3 1

6

2,

5 2

3

2.

6

3 1

3

1.

6

3 1

61

H

0

1 C

e

n

e

n

i

p-

a

t

e

B

3

3-

S

4

4

,

4

1

,

3 4

3 4

4

4

,

34

3

2

.

2

5

1

2

1

.

2

5

1

O61

H

0

1

C

e

n

o

ju

ht

-

a

t

e

B

4

3-

S

4

1,

2 3

2 3

1 7

,

5

6

2,

5 2

5

2.

4

5 1

4

1.

4

5 1

O81

H0

1 C

l

o

e

n

r

o

B

5

3-

S

4 1

,

2

3

2

3

1

7

6

2

,

5

2

9

2

.

6

9 1

5

1

.

6

9 1

2

O0

2

H

2

1

C

e

t

a

t

e

c

a

ly

n

r

o

B

6

3-

S

5

2

2.

0

5 1

1.

0

5 1

O41

H0

1 C

l

o

r

c

a

v

r

a

C

7

3-

S

6

2,

5 2

2

2.

0

5 1

1.

0

5 1

O41

H0

1 C

e

n

o

v

r

a

C

8

3-

S

3 1

3 1

3 1

0 1

9

2

.

6

9 1

5

1

.

6

9 1

2

O0

2

H

2

1

C

e

t

a

t

e

c

a

ly

m

e

ht

n

a

s

yr

hC

9

3-

S

9 1

6

2

,

5

2

2

2

.

0

5

1

1

.

0

5

1

O4

1

H

0

1

C

e

n

o

n

e

ht

n

a

s

yr

hC

0

4

-

S

6

2

,

5

2

5

2

.

4

5

1

4

1

.

4

5

1

O81

H

0

1

C

e

t

a

r

d

y h

e

n

e

n

i

b

a

s

-

s

iC

1

4

-

S

5

3

2.

2

5 1

2

1.

2

5 1

O61

H0

1 C

e

n

o

hc

n

e

F

2

4-

S

5

4

1

.

4

5

1

4

1

.

4

5

1

O81

H

0

1

C

)l

o

hc

n

e

f (

lo

h

o

c

l a

ly

hc

n

e

F

3

4

-

S

6

2,

5 2

2

2.

0

5 1

1.

0

5 1

O41

H0

1 C

e

n

o

l

o

fi

li

F

4

4-

S

3 1

3 1

5

2

.

4

5

1

4

1

.

4

5

1

O

81

H

0

1

C

lo

n

a

g

a

r

F

5

4

-

S

3 1

3 1

9

2

.

6

9 1

5

1

.

6

9 1

2

O0

2

H

2

1

C

e

t

a

t

e

c

a

ly

n

a

g

a

r

F

6

4

-

S

M

6

2,

5 2

3

2.

6

3 1

3

1.

6

3 1

61

H

0

1 C

e

n

e

n

i

pr

e

t

-

a

m

m

a

G

7

4

-

S

1 7

9

2

.

6

9 1

5

1

.

6

9 1

1

O0

2

H

2

1

C

e

t

a

t

e

c

a

ly

n

a

r

e

G

8

4

-

S

4

3.

4

2

2

8

1

.

4

2

2

2

O4

2

H

4

1

C

e

t

a

o

n

a

t

u

b

o

s

i

ly

n

a

r

e

G

9

4

-

S

3 1

3 1

7

3

2

.

2

5

1

2

1

.

2

5

1

O

61

H

0

1

C

l

o

t

a

r

yl

o

s

I

0

5

-

S

5

5

2

.

4

5

1

4

1

.

4

5

1

O

81

H

0

1

C

l

o

g

e

l

u

p

o

s

I

1

5

-

S

9

3 1

6

2,

5 2

3

2.

6

3 1

3

1.

6

3 1

61

H0

1 C

e

n

e

n

o

m

iL

2

5-

S

3 1

3 1

0 1

2

2

.

0

5

1

1

.

0

5

1

O4

1

H

0

1

C

l

a

t

a

r

yL

3

5

-

S

3 1

3 1

0 1

3

2

.

2

5

1

2

1

.

2

5

1

O61

H

0

1

C

l

o

t

a

r

yL

4

5

-

S

3 1

0 1

7

2

.

4

9 1

3

1

.

4

9 1

2

O81

H

2

1

C

e

t

a

t

e

c

a

l

yt

a

r

yL

5

5

-

S

5

3

2.

6

3 1

3

1.

6

3 1

61

H0

1 C

e

n

e

c

r

yM

6

5-

S

6

2

,

6 2

3

2

.

2

5

1

2

1

.

2

5

1

O

61

H

0

1

C

lo

n

e

t

r

yM

7

5

-

S

5

3

2.

2

5 1

2

1.

2

5 1

O61

H0

1 C

l

a

r

e

N

8

5-

S

7

3.

8

3 2

9

1

.

8

3 2

2

O62

H

5

1

C

e

t

a

r

e

la

v

o

s

i

l

yr

e

N

9

5

-

S

6

2

,

5

2

1

2

.

4

5

1

1

.

4

5

1

2

O4

1

H

9C

l y

ht

e

m

di

c

a

c

i

m

e

ht

n

a

s

yr

h

c

-

r

o

N

0

6-

S

r

e

ts

e

1 7

A /

N

A/

N

A/

N

e

t

a

t

e

c

a

e

n

e

m

y

C-

p

1

6-

S

4 ,

04

2

2.

4

3 1

1

1.

4

3 1

O41

H0

1 C

e

n

e

n

iP

2

6-

S

2

2.

0

5 1

1.

0

5 1

O4

1

H0

1 C

e

n

o

v

r

a

c

o

n

iP

3

6-

S

9

1 7

6

2,

5 2

3

2.

6

3 1

3

1.

6

3 1

61

H0

1 C

e

n

e

n

i

ba

S

4

6-

S

3 1

31

3

2.

2

5 1

2

1.

2

5 1

O61

H0

1 C

lo

n

i

ba

S

5

6-

S

31

7

2

.

4

9 1

3

1

.

4

9 1

2

O81

H

2

1

C

e

t

a

t

e

c

a

ly

n

i

ba

S

6

6-

S

1

2

3

2

.

2

5

1

2

1

.

2

5

1

O61

H

0

1

C

e

di

x

o

p e

a

n

il

o

t

n

a

S

7

6-

S

4

3

2.

8

6 1

2

1.

8

6 1

2

O61

H0

1 C

di

c

a

c

i

n

il

o

t

n

a

S

8

6-

S

11

2

2.

6

6 1

1.

6

6 1

2

O41

H0

1 C

’

B-

e

dil

o

n

il

o

t

n

a

S

9

6-

S

5

6

2

.

2

8 1

3

1

.

2

8 1

2

O81

H

1

1

C

r

e

t

s

e

ly

n

il

o

t

n

a

S

0

7

-

S

11

2

2.

6

6 1

1.

6

6 1

2

O4

1

H0

1 C

C-

e

dil

o

n

il

n

o

t

a

S

1

7-

S

5

6

2

,

5

2

5

2

.

4

5

1

4

1

.

4

5

1

O8

1

H

0

1

C

l

o

-

4

-

n

e

n

i

pr

e

T

2

7

-

S

3 4

4

4

,

3 4

2

5

2

.

4

5

1

4

1

.

4

5

1

O

81

H

0

1

C

l

o

e

n

i

pr

e

T

3

7

-

S

5 2

3

2

.

6

3 1

3

1

.

6

3 1

61

H

0

1

C

e

n

e

lo

n

i

pr

e

T

4

7

-

S

6

2

,

5

2

2

2

.

4

3 1

1

1

.

4

3 1

4

1

H

0

1

C

e

n

e

i

d

-

)0

1

(

4

,

2

-

a

ju

hT

5

7

-

S

3 1

,

1

2

,

8 2

,

5

31

3

2

.

2

5

1

2

1

.

2

5

1

O

61

H

0

1

C

e

n

o

ju

hT

6

7

-

S

,

1

4,

04

1 7

,

07

5

5

2

.

4

5

1

4

1

.

4

5

1

O8

1

H

0

1

C

lo

h

o

c

l a

l

yj

u

hT

7

7

-

S

3 1

3 1

3

1

.

8

6 1

2

1

.

8

6 1

2

O61

H

01

C

-

2

-

ly

ht

e

m

-

2

-

o

x

o

-

1

(-

3-

s

n

a

r

T

8

7

-

S

-

2

,

2

-

)l

y

n

e

p

o

r

p

l o

n

a

ht

e

m

ly

p

o

r

p

o

lc

y

c

ly

ht

e

m

id

6

2,

5 2

5

2.

4

5 1

4

1.

4

5 1

O8

1

H0

1 C

l

o

e

v

r

a

c

-

s

n

a

r

T

9

7-

S

5

2,

5 2

5

2.

4

5 1

4

1.

4

5 1

O81

H0

1 C

l

o

e

v

r

a

c

o

s

i-

s

n

a

r

T

0

8-

S

6

2

,

5

2

5

2

.

4

5

1

4

1

.

4

5

1

O81

H

0

1

C

l

o

-

1

-

n

e

-

2

-

ht

n

e

m

-

a

r

a

p-

s

n

a

r

T

1

8-

S

5

2

,

5

2

3

2

.

2

5

1

2

1

.

2

5

1

O61

H

0

1

C

l

o

e

v

r

a

c

o

n

i

p-

s

n

a

r

T

2

8-

S

5

2

,

5

2

5

2

.

4

5

1

4

1

.

4

5

1

O8

1

H

0

1

C

l

o

t

ir

e

pi

p-

s

n

a

r

T

3

8-

S

1 7

6

2

,

5

2

3

2

.

6

3 1

3

1

.

6

3 1

61

H

0

1

C

e

n

e

lc

y

c

ir

T

4

8-

S

1

2

1

2

,

2

3

3 1

5

2

.

4

5

1

4

1

.

4

5

1

O8

1

H

0

1

C

lo

h

o

c

l a

ig

o

m

o

Y

5

8-

S

E

(

7 ,

)8

9

9 1

,

s

r

a

e

S

d

n

a

le

k

n

u

D

(

6 ,

)7

7

9 1

,

.

l a

t

e

s

u

kt

t

u

B

(

5 ,

)2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

2

8

9 1

,

m

a

hg

n

i

kc

u

B

(

4 ,

)5

7

9 1

,

.

l a

t

e

n

w

o

r

B

(

3 ,

)5

8

9 1

,

h

c

le

W

d

n

a

n

a

he

B

(

2 ,

)4

3

9 1

,

gr

e

b

ka

O

d

n

a

s

m

a

d

A(

1

5

1

,

)2

1

0 2

,

.

l a

t

e

i

k

a

z

i

h

s

I

(

4

1

,

)

2

0

0 2

,

.

l a

t

e

a

n

e

dr

a

w

a

n

u

G(

3

1

,

)3

8

9 1

,

.

l a

t

e

r

e

g

e

r

G(

2

1

,

)2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

2

8

9 1

,

y

bs

a

l

G(

1

1

,

)1

9

9 1

,

.

l a

t

e

n

i

e

t

s

p

E

(

0

1

,

)4

8

9 1

,

.

l a

t

e

n

i

e

t

s

p

E

(

9 ,

)3

7

9 1

,

r

e

t

l

u

o

P

ig

u

S

d

n

a

ye

n

n

i

K

(

2

2

,

)

b3

8

9 1

,

.

l a

t

e

y

e

s

le

K

(

1

2

,

)2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

38

9 1

,

i

n

a

t

e

m

a

K

(

0

2

,

)0

1

0 2

,

.

l a

t

e

i

b

s

s

a

J(

9

1

,

)

7

7

9 1

,

.

l a

t

e

ll

o

hc

S(

8

1

,

)e

3

7

9 1

,

n

a

m

s

s

ie

G

d

n

a

n

i

w

r

I

(

7

1

,

)1

7

9 1

,

n

a

m

s

s

ie

G

.

l a

t

e

y

e

ll

e

K

(

2

8

9 1

,

.

l a

t

e

y

a

r

r

u

M

(

9

2

,

)

2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

7

8

9 1

,

e

r

o

o

M

(

8

2

,

)

99

9 1

,

.

l a

t

e

c

i

v

e

jl

v

a

s

o

li

M

(

7

2

,

)a

8

0

0 2

,

.

l a

t

e

z

t

u

L

-

s

e

p

o

L

(

6

2

,

)

b

8

0

0 2

,

.

l a

t

e

z

t

u

L

-

s

e

p

o

L

(

5

2

,

)9

6

9 1

,

.

l a

t

e

he

d

a

z

fia

h

S(

6

3,

)0

7

9 1

,

f

o

ki

n

le

M

d

n

a

he

d

a

z

fia

h

S(

5

3,

)5

7

9 1

,

he

d

a

z

fia

h S

d

n

a

e

n

a

da

h

B

(

4

3,

)

b3

7

9 1

,

e

n

a

da

h B

d

n

a

he

d

a

z

fia

h

S(

3

3,

)1

9

9 1

,

y

e

s

l

e

K

d

n

a

r

e

t

e

r

t

n

e

s

o

R

(

2

3,

)

6

7

9 1

,

.

l a

t

e

z

e

u

gi

r

do

R

(

r

Ac

M

d

n

a

h

c

le

W

(

3

4

,

)

2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

7

5

9 1

,

n

i

a

r

T

(

2

4

,

)2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

87

9 1

,

n

o

s

p

m

o

h

T

(

1

4

,

)

2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

07

9 1

,

y

n

e

t

e

T

(

0

4

,

)5

8

9 1

,

.

l a

t

e

a

m

m

a

T

(

9

3,

)

5

7

9 1

,

.

l a

t

e

w

a

h

S(

s

s

ie

G(

1

5

,

)9

7

9 1

,

he

d

a

z

fia

h S

d

n

a

y

e

s

le

K

(

0

5

,

)a

37

9 1

,

n

a

m

s

s

ie

G

d

n

a

n

i

w

r

I

(

9

4

,

)

80

0 2

,

.

l a

t

e

e

i

X

(

8

4

,

)

2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

38

9 1

,

.

l a

t

e

m

o

d

s

i

W

(

7

4

,

)2

9

9 1

,

.

l a

t

e

t

li

W

(

6

4

,

)2

9

9 1

,

r

e

l

li

M

d

n

a

bo

N

(

9

5

,

)a

38

9 1

,

.

l a

t

e

y

e

s

le

K

(

8

5

,

)7

7

9 1

,

e

s

o

B

d

n

a

s

u

kt

t

u

B

(

7

5

,

)

5

6

9 1

,

a

n

a

ht

n

a

S

d

n

a

z

r

e

H

(

6

5

,

)a

9

6

9 1

,

n

a

m

s

s

ie

G

d

n

a

n

i

w

r

I

(

5

5

,

)b

96

9 1

,

n

a

m

s

s

ie

G

d

n

a

n

i

w

r

I

(

4

5

,

)5

7

9 1

,

.

l a

t

e

e

n

a

da

h

B

(

r

I

(

6

6,

)

b

2

7

9 1

,

e

n

a

da

h B

d

n

a

he

d

a

z

fia

h

S(

5

6,

)a

2

7

9 1

,

e

n

a

da

h B

d

n

a

he

d

a

z

fia

h

S(

4

6,

)a

3

7

9 1

,

e

n

a

da

h B

d

n

a

he

d

a

z

fia

h

S(

3

6,

)9

7

9 1

,

o

s

o

id

u

a

G

d

n

a

n

i

e

t

s

p

E

(

2

6,

)9

6

9 1

,

.

l a

t

e

n

i

w

r

I

(

1

6,

)9

6

91

.

)

30

0 2

,

.

l a

t

e

k

e

r

o

B

(

1

7

,

)

89

9 1

,

.

l a

t

e

h

c

ir

n

ie

H

(

0

7

,

)

b

37

9 1

,

n

a

m

s

s

ie

G

d

n

a

n

i

w

r

I

(

9

6,

)2

7

9 1

,

.

l a

t

e

e

u

gi

r

do

R

(

8

6,

)

2

8

9 1

,

o

s

o

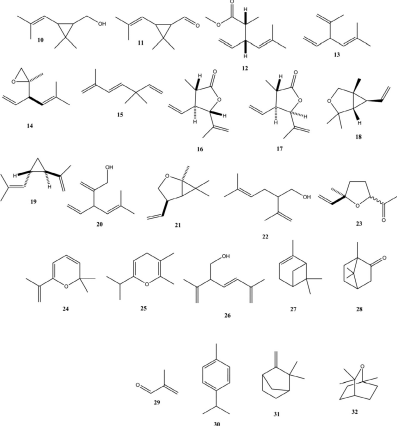
id

u

a

G

18 C.E. Turi et al. / Phytochemistry 98 (2014) 9–26

Fig. 5. Characteristic monoterpenes in the Tridentatae. Please note: structures of the additional monoterpeness are in the Supplemental Files.

(López-Alarcón and Denicola, 2013). Consumption of an antioxi dant rich diet has shown to have preventative effects against car diovascular and neurodegenerative diseases as well as against cancer (Obrenovich et al., 2011). Oils extracted from A. cana and A. tridentata exhibited weak antioxidant activity in 2,2-diphenyl 1-picrylhydrazyl (DPPH) and b-carotene/linoleate model assays (Lopes-Lutz et al., 2008a).

Antiviral activity

Ethnopharmacological investigation of traditional medicines to treat influenza has provided promising leads for the discovery of plant-derived antivirals, particularly against HSV and HIV (Chatto padhyay and Naik, 2007). Methanolic extracts from A. rothrockii displayed weak antiviral activity in vitro against Coxsackie B6, Po lio 1, and Sindbis viruses at concentrations equal to the threshold for non-cytotoxic behaviour (McCutcheon, 1996). Further investi gation of these plants may provide new mechanisms and treat ments for viral infections.

Cytotoxicity

In the last 70 years, over 70% of new drugs for cancer treatment were of natural origin or inspired by naturally occurring structures (Newman and Cragg, 2012). Culturing cancer cells in the presence of crude extracts or isolated compounds and monitoring their via bility is often used to screen for anti-cancer potential (Harvey and Cree, 2010). Variability for cytotoxicity has been observed in mono-layer forming ‘‘Vero’’ cells (Green Monkey Kidney) exposed to extracts of A. arbuscula, A. bigelovii, A. cana, A. rothrockii, A. spic iformis, A. tridentata subsp. parishii, A. tridentata subsp. tridentata, A. tridentata subsp. wyomingensis (McCutcheon, 1996). Of the species described above, A. arbuscula, A. cana, A. rothrockii and A. spiciformis were the most toxic (McCutcheon, 1996) and may provide promis ing pharmacological leads.

Fumigant and insecticidal activity

In agriculture, allelochemicals found in essential oils or as single isolated compounds (i.e. D-limonene and Azadirachtin) are em

5

e

l

ba

T

.

e

a

t

a

t

n

e

di

r

T

e

h t

n

i

s

e

n

e

pr

e

t

i

u

qs

e

a

t

a

t

n

e

di

r

t

.

A

.

A

.

A

.

A

.

A

.

A

.

A

.

A

a

n

a

c

.

A

a

n

a

c

.

A

a

n

a

c

.

A

.

A

.

A

.

A

.

A

a

l

u

c

s

u

b

r

a

.

A

.

A

r

a

l

u

c

e

lo

M

Z

/M

l

a

c

i

m

e

hC

it

n

e

dI

.

ps

b

u

s

a

t

a

t

n

e

di

r

t

a

t

a

t

n

e

di

r

t

i

c

i

ps

ht

o

r

a

di

gi

r

a

e

a

m

gy

p

a

v

o

n

.

ps

b

u

s

.

ps

b

u

s

.

ps

b

u

s

a

n

a

c

le

gi

b

a

l

u

c

s

u

br

a

a

l

u

c

s

u

br

a

.

ps

b

u

s

a

l

u

c

s

u

br

a

t

h

gi

e

w

a

lu

m

r

o

f

n

o

it

a

c

fi

s

is

n

e

g

n

i

m

o

yw

.

ps

b

u

s

s

i

m

r

o

f

i i

kc

o

r

r

e

d

n

a

l

u

o

b

a

l

u

di

c

s

iv

a

n

a

c

i i

v

o

.

ps

b

u

s

.

ps

b

u

s

a

l

u

c

s

u

br

a

r

e

b

m

u

n

a

n

a

y

e

s

a

v

a

lo

po

m

r

e

ht

a

b

o

li

g

n

o

l

s

e

n

e

pr

e

t

i

u

qs

e

S

,

0 5

,

13

,

61

,

4

5,

6 3

3

3.

0

5 2

6

1.

0

5 2

3

O

22

H5

1 C

A-

n

il

u

c

s

u

br

A

3 3

2

5,

63

0 5

7

1,

6

1,

05

6 3

,

2 5

,

0 5

0 5

,

61

,

4

5,

7

1,

6

1,

6 3

2

3.

2

3 2

5

1.

2

3 2

2

O0

2

H5

1 C

B-

n

il

u

c

s

u

br

A

4 3

0 5

6

3,

2

5,

0 5

11

,

61

6

3,

0 5

,

6 1

2

3.

8

4 2

4

1.

8

4 2

3

O0

2

H5

1 C

C-

n

il

u

c

s

u

br

A

5 3

0 5

7 1

0

5,

7

1,

6 1

3

3.

6

6 2

5

1.

6

6 2

4

O

22

H5

1 C

D

n

il

u

c

s

u

br

A

6 3

7

1,

6

1,

0 5

,

4 5

5

3.

8

6 2

7

2.

8

6 2

4

O

42

H5

1 C

E-

n

il

u

c

s

u

br

A

7 3

5

3.

2

5 2

7

1.

2

5 2

3

O42

H5

1 C

n

it

r

a

lo

C

8 3

2

3.

4

6 2

4

1.

4

6 2

4

O0

2

H5

1 C

B

n

it

n

e

di

R

9 3

2

5,

05

,

61

2

3.

8

4 2

4

1.

8

4 2

3

O0

2

H5

1 C

A-

n

i

ht

o

R

0 4

0 5

2 5

,

05

,

61

2

3.

4

6 2

4

1.

4

6 2

4

O0

2

H5

1 C

B-

n

i

ht

o

R

1 4

0 5

2 5

,

6 3

,

05

3

3.

0

5

2

6

1

.

0

5

2

3

O2

2

H

5

1

C

-

3

-

t

n

a

s

yx

o

r

dy

h-

a

t

e

B

-

1

2 4

)

A-

W

(

C-

e

di

l

o

-

2

1

,

6-

n

e

2 5

,

6 3

,

05

3

3.

0

5

2

6

1

.

0

5

2

3

O2

2

H

5

1

C

t

n

a

s

yx

o

r

dy

h-

a

t

e

B

-

1

3 4

e

dil

o

-

2

1

,

6-

n

e

-

)4

1

(4

)

B

-

W

(C

0 5

,

3 5

4

0 5

.

4 3

2

3.

0

8 2

3

1.

0

8 2

5

O0

2

H

5

1 C

n

is

a

v

e

t

r

A

4 4

.

51

5

3.

0

9 2

5

1.

0

9 2

4

O22

H

7

1 C

n

i

n

a

v

o

N

5 4

0 5

2 5

,

05

0

5

,

2

5

,

4

6

2

3.

0

8 2

3

1

.

0

8 2

5

O0

2

H

5

1

C

n

ir

e

g

da

B

6 4

,

3

3,

05

0 5

,

2

5

,

3 3

2

3.

8

4

2

4

1

.

8

4

2

3

O0

2

H

5

1

C

e

d

il

o

i

bo

n

e

r

u

a

ll

yt

e

c

a

e

D

7 4

3 5

,

3 3

,

05

0 5

,

2

5

,

3 3

2

3.

4

6 2

4

1

.

4

6 2

4

O0

2

H

5

1

C

n

i

m

r

o

fi

c

i

pS

8 4

2 5

,

05

,

2 5

,

3 3

,

4 6

2

3.

4

6 2

4

1.

4

6 2

4

O0

2

H5

1 C

A-

n

i

di

r

t

a

T

9 4

2

5,

33

0 5

,

05

0 5

,

2

5,

3 3

2

3.

4

6 2

4

1.

4

6 2

4

O0

2

H5

1 C

B-

n

i

di

r

t

a

T

0 5

2

5,

33

,

6 5

3.

6

4

2

3

1

.

6

4

2

3

O81

H

5

1

C

n

iv

o

l

gi

br

A

1 5

0 5

,

4 3

,

4 2

3.

8

7 2

2

1.

8

7 2

5

O81

H5

1 C

n

i

n

a

c

e

t

r

A

2 5

0 5

,

4 2

1 3

3.

8

7 2

2

1.

8

7 2

5

O81

H5

1 C

n

i

n

a

C

3 5

,

8

5,

43

0 5

,

55

5

3.

6

0 3

5

1.

6

0 3

5

O22

H7

1 C

A

n

ir

b

m

a

m

u

C

4 5

9

4,

05

,

55

2

3.

4

6 2

4

1.

4

6 2

4

O0

2

H5

1 C

B

n

ir

b

m

a

m

u

C

5 5

9

4,

05

,

5

5

2

3.

8

4

2

4

1

.

8

4

2

3

O0

2

H

5

1

C

B

n

ir

b

m

a

m

u

c

yx

o

e

D

-

8

6 5

0 5

2

3.

0

8 2

3

1.

0

8 2

5

O0

2

H

5

1 C

e

di

x

o

B

n

ir

b

m

a

m

u

C

7 5

4

2,

6

1,

0 5

4

3.

4

0 3

3

1.

4

0 3

5

O0

2

H7

1 C

n

ir

a

c

i

r

t

a

M

8 5

0

5,

5 6

0 5

3.

6

4 2

3

1.

6

4 2

3

O81

H

5

1 C

n

ir

a

c

i

r

t

a

m

yx

o

t

e

c

a

e

D

9 5

,

4

3,

4

2

3.

6

4

2

3

1

.

6

4

2

3

O81

H

5

1

C

n

ir

a

c

i

r

t

a

m

l

yt

e

c

a

e

D

0 6

0 5

3 .

2

6 2

2

1

.

2

6 2

4

O81

H

5

1

C

A

n

il

o

c

ip

u

R

1 6

3 .

2

6 2

2

1

.

2

6 2

4

O81

H

5

1

C

B

n

il

o

c

ip

u

R

2 6

3 .

4

9 2

1

1.

4

9 2

6

O81

H

5

1 C

A

n

ip

u

R

3 6

4

3.

6

3 3

2

1.

6

3 3

7

O0

2

H

7

1 C

B

n

ip

u

R

4 6

0 5

,

56

5

3.

6

0 3

5

1.

6

0 3

5

O22

H7

1 C

A-

n

il

u

di

c

s

iV

5 6

1 3

0 5

,

56

5

3.

6

0 3

5

1.

6

0 3

5

O22

H7

1 C

B-

n

il

u

di

c

s

iV

6 6

1 3

0 5

,

56

2

3.

4

6 2

4

1.

4

6 2

4

O0

2

H5

1 C

C-

n

il

u

di

c

s

iV

7 6

4

5

.

2

4

4

4

2

.

2

4

4

6

O4

3

H

6

2

C

l

o

t

r

a

pi

r

T

8 6

7

5.

4

4 4

5

2.

4

4 4

6

O63

H6

2 C

l

o

ir

d

n

o

c

e

S

9 6

4

5.

2

4 4

4

2.

2

4 4

6

O43

H6

2 C

l

a

ir

d

n

o

c

e

S

0 7

4

5.

2

4 4

4

2.

2

4 4

6

O43

H6

2 C

e

n

o

hc

a

m

ir

D

1 7

0 5

,

3 6

7

3.

4

5

2

9

1

.

4

5

2

3

O62

H

5

1

C

lo

b

o

li

g

n

o

L

2 7

6

6,

05

5

3.

8

5

2

8

1

.

8

5

2

4

O62

H

4

1

C

lo

m

gy

P

3 7

S

)

de

u

n

it

n

o

c

( 5

e

l

ba

T

a

t

a

t

n

e

di

r

t

.

A

.

A

.

A

.

A

.

A

.

A

.

A

.

A

a

n

a

c

.

A

a

n

a

c

.

A

a

n

a

c

.

A

.

A

.

A

.

A

.

A

a

l

u

c

s

u

b

r

a

.

A

.

A

r

a

l

u

c

e

lo

M

Z

/M

l

a

c

i

m

e

hC

it

n

e

dI

.

ps

b

u

s

a

t

a

t

n

e

di

r

t

a

t

a

t

n

e

di

r

t

i

c

i

ps

ht

o

r

a

di

gi

r

a

e

a

m

gy

p

a

v

o

n

.

ps

b

u

s

.

ps

b

u

s

.

ps

b

u

s

a

n

a

c

le

gi

b

a

l

u

c

s

u

br

a

a

l

u

c

s

u

br

a

.

ps

b

u

s

a

l

u

c

s

u

br

a

t

h

gi

e

w

a

lu

m

r

o

f

n

o

it

a

c

fi

s

is

n

e

g

n

i

m

o

yw

.

ps

b

u

s

s

i

m

r

o

f

i i

kc

o

r

r

e

d

n

a

l

u

o

b

a

l

u

di

c

s

iv

a

n

a

c

i i

v

o

.

ps

b

u

s

.

ps

b

u

s

a

l

u

c

s

u

br

a

r

e

b

m

u

n

a

n

a

y

e

s

a

v

a

lo

po

m

r

e

ht

a

b

o

li

g

n

o

l

13

4 3

3.

6

4 2

3

1.

6

4 2

3

O81

H

5

1 C

n

ir

a

c

i

r

t

a

m

yx

o

t

e

c

a

s

e

D

4 7

05

,

0 5

,

4 2

2

3.

4

6 2

2

1.

4

6 2

4

O0

2

H5

1 C

n

it

n

e

di

R

5 7

1 6

5

3.

2

5 2

7

1.

2

5 2

3

O42

H51

C

-

3

1,

11

6

8-

S

n

il

u

c

s

u

br

a

o

r

dy

hi

D

13

3 .

6

4 2

3

1.

6

4 2

3

O81

H5

1 C

n

i

ll

i

hc

A

7

8-

S

5

3.

4

0 2

9

1

.

4

0 2

4

2

H

5

1

C

e

n

e

s

e

n

l

u

b-

a

h

pl

A

8

8-

S

1

7

5

3.

4

0 2

9

1

.

4

0 2

4

2

H

5

1

C

e

n

e

a

p

o

c

-

a

h

pl

A

9

8-

S

8

3.

8

1

2

2

.

8

1

2

62

H

6

1

C

e

n

e

la

hc

a

m

i

h-

a

h

pl

A

0

9-

S

5

3.

4

0 2

9

1

.

4

0 2

4

2

H

5

1

C

e

n

e

lu

m

u

h-

a

h

pl

A

1

9-

S

5

3 .

2

9 1

5

1

.

2

9 1

O0

2

H

3

1

C

e

n

o

n

o

i-

a

h

pl

A

2

9-

S

5

3.

4

0 2

9

1

.

4

0 2

4

2

H

5

1

C

e

n

e

n

i

pi

g

n

o

l-

a

h

pl

A

3

9-

S

2

3.

4

6 2

4

1.

4

6 2

4

O0

2

H5

1 C

n

il

a

c

e

t

r

A

4

9-

S

8 2

3 .

2

6 2

2

1.

2

6 2

4

O

81

H5

1 C

n

i

s

i

m

e

tr

A

5

9-

S

1

7

,

5

5

3.

4

0 2

9

1

.

4

0 2

4

2

H

5

1

C

e

n

e

ll

y

h

p

o

yr

a

c

-

a

t

e

B

6

9-

S

5

3.

4

0 2

9

1

.

4

0 2

4

2

H

5

1

C

e

n

e

r

gi

m

a

h

c

-

a

t

e

B

7

9-

S

6

2

,

5

2

5

3.

0

2

2

8

1

.

0

2

2

O4

2

H

5

1

C

l

o

-

a

h

pl

a

-

4

-

n

e

a

p

o

c

-

a

t

e

B

8

9-

S

5

3.

4

0 2

9

1.

4

0 2

42

H

5

1 C

e

n

e

m

e

l

e

-

a

t

e

B

9

9-

S

1 7

5

3.

4

0 2

9

1.

4

0 2

42

H

5

1 C

e

n

e

n

u

jr

u

g-

a

t

e

B

0 0

1-

S

8

3.

8

1 2

2.

8

1 2

62

H6

1 C

e

n

e

la

hc

a

m

i

h-

a

t

e

B

1 0

1-

S

5

3.

4

0 2

9

1.

4

0 2

42

H5

1 C

e

n

e

n

il

e

s

-

a

t

e

B

2 0

1-

S

5

3.

4

0 2

9

1

.

4

0 2

4

2

H

5

1

C

e

n

e

r

c

a

m

r

e

g

o

lc

y

c

iB

3 0

1

-

S

6

6,

05

5

3.

2

4

2

9

1

.

2

4

2

3

O6

2

H

4

1

C

l

o

i

di

r

e

m

o

t

p

yr

C

4 0

1

-

S

5

3.

4

0 2

9

1

.

4

0 2

4

2

H

5

1

C

e

n

e

v

it

a

s

o

lc

yC

5 0

1

-

S

0 5

,

3 5

7

4

9

2

.

4

4

2

1

1

.

4

4

2

3

O61

H

5

1

C

n

i

d

o

c

u

e

l

o

r

dy

he

D

6 0

1

-

S

0 2

2

3.

2

0 3

2

1

.

2

0 3

5

O8

1

H

7

1

C

n

ir

a

c

i

r

t

a

m

o

r

dy

he

D

7 0

1

-

S

1 7

5

3.

4

0 2

9

1.

4

0 2

42

H5

1 C

e

n

e

i

d

a

c

-

a

t

le

D

8 0

1-

S

2

3.

4

6 2

4

1.

4

6 2

4

O0

2

H5

1 C

A-

n

it

a

t

n

e

D

9 0

1-

S

2

3.

4

6 2

4

1.

4

6 2

4

O0

2

H5

1 C

B-

n

it

a

t

n

e

D

0 1

1-

S

4

5.

2

4 4

4

2.

2

4 4

6

O43

H6

2 C

B

l

o

t

r

a

m

ir

D

1 1

1-

S

4

5

.

2

4

4

4

2

.

2

4

4

6

O4

3

H

6

2

C

l

o

r

hc

o

n

r

a

f

yx

o

pE

2 1

1

-

S

5

5.

6

2 4

4

2.

6

2 4

5

O43

H6

2 C

l

o

r

hc

o

n

r

a

F

3 1

1-

S

4

3.

2

0 2

7

1.

2

0 2

22

H5

1 C

e

n

e

m

u

c

r

u

c

-

a

m

m

a

G

4 1

1-

S

5

3.

4

0 2

9

1.

4

0 2

42

H5

1 C

e

n

e

la

hc

a

m

i

h-

a

m

m

a

G

5 1

1-

S

5

3.

4

0 2

9

1.

4

0 2

42

H5

1 C

D-

e

n

e

r

c

a

m

r

e

G

6 1

1-

S

2

3.

4

6 2

4

1

.

4

6 2

4

O0

2

H

5

1

C

c

i

n

o

t

n

a

s

o

t

o

h

p

o

s

I

7 1

1

-

S

e

n

o

tc

a

l

5

3.

4

0 2

9

1

.

4

0 2

4

2

H

5

1

C

e

n

e

lc

y

c

ig

n

o

L

8 1

1

-

S

5

3.

4

0 2

9

1

.

4

0 2

4

2

H

5

1

C

e

n

e

l

o

fi

g

n

o

L

9 1

1

-

S

5

7

3.

2

2 2

2.

2

2 2

O62

H5

1 C

lo

di

l

o

r

e

N

0 2

1-

S

3 .

2

6 2

2

1.

2

6 2

4

O

81

H5

1 C

A-

n

i

h

s

ir

a

P

1 2

1-

S

3 .

6

4 2

3

1.

6

4 2

3

O

81

H5

1 C

B-

n

i

h

s

ir

a

P

2 2

1-

S

3 .

2

6 2

2

1.

2

6 2

4

O81

H5

1 C

C-

n

i

h

s

ir

a

P

3 2

1-

S

8 2

3 .

6

4 2

3

1.

6

4 2

3

O81

H5

1 C

n

i

n

o

t

n

a

S

4 2

1-

S

5

3.

4

0 2

9

1

.

4

0 2

4

2

H

5

1

C

e

n

e

n

i

h

pl

iS

5 2

1

-

S

6

2

,

5

2

5

3.

0

2

2

8

1

.

0

2

2

O4

2

H

5

1

C

lo

n

e

l

u

ht

a

pS

6 2

1

-

S

3 .

2

6 2

2

1.

2

6 2

4

O81

H5

1 C

C-

n

i

di

r

t

a

T

7 2

1-

S

7

3

1.

2

1 1

5

0.

2

1 1

O8

H

6 C

e

n

o

t

c

a

l

e

r

e

T

8 2

1-

S

,

)7

7

9 1

,

.

l a

t

e

s

u

kt

t

u

B

(

5

,

)2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

2

8

9 1

,

m

a

hg

n

i

kc

u

B

(

4

,

)5

7

9 1

,

.

l a

t

e

n

w

o

r

B

(

3

,

)5

8

9 1

,

h

c

le

W

d

n

a

n

a

he

B

(

2

,

)

4

3

9 1

,

gr

e

b

ka

O

d

n

a

s

m

a

d

A(

1

:

s

a

d

e

r

e

b

m

u

n

e

r

a

s

e

c

n

e

r

e

fe

R

2

,

.

l a

t

e

a

n

e

dr

a

w

a

n

u

G(

3

1

,

)

38

9 1

,

.

l a

t

e

r

e

g

e

r

G(

2

1

,

)

2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

2

8

9 1

,

y

bs

a

l

G(

1

1

,

)1

9

9 1

,

.

l a

t

e

n

i

e

t

s

p

E

(

0

1

,

)4

8

9 1

,

.

l a

t

e

n

i

e

t

s

p

E

(

9 ,

)

37

9 1

,

r

e

t

l

u

o

P

d

n

a

n

i

e

t

s

p

E

(

8 ,

)4

8

9 1

,

o

s

o

id

u

a

G

t

e

y

e

s

le

K

(

1

2

,

)

2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

38

9 1

,

i

n

a

t

e

m

a

K

(

0

2

,

)0

1

0 2

,

.

l a

t

e

i

b

s

s

a

J(

9

1

,

)7

7

9 1

,

.

l a

t

e

ll

o

hc

S(

8

1

,

)e

37

9 1

,

n

a

m

s

s

ie

G

d

n

a

n

i

w

r

I

(

7

1

,

)1

7

9 1

,

n

a

m

s

s

ie

G

d

n

a

n

i

w

r

I

(

6

1

,

)

d

37

9 1

,

n

a

m

s

s

ie

G

a

r

r

u

M

(

9

2

,

)2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

7

8

9 1

,

e

r

o

o

M

(

8

2

,

)

9

9

9 1

,

.

l a

t

e

c

i

v

e

jl

v

a

s

o

li

M

(

7

2

,

)a

8

0

0 2

,

.

l a

t

e

z

t

u

L

-

s

e

p

o

L

(

6

2

,

)b

80

0 2

,

.

l a

t

e

z

t

u

L

-

s

e

p

o

L

(

5

2

,

)

96

9 1

,

.

l a

t

e

e

e

L

(

4

2

,

)1

4

9 1

,

.

l a

t

e

ye

n

n

i

K

(

3 2

le

M

d

n

a

he

d

a

z

fia

h

S(

5

3,

)

5

7

9 1

,

he

d

a

z

fia

h S

d

n

a

e

n

a

da

h

B

(

4

3,

)b

37

9 1

,

e

n

a

da

h B

d

n

a

he

d

a

z

fia

h

S(

3

3,

)

1

9

9 1

,

y

e

s

l

e

K

d

n

a

r

e

t

e

r

t

n

e

s

o

R

(

2

3,

)

67

9 1

,

.

l a

t

e

z

e

u

gi

r

do

R

(

1

3,

)

b7

7

9 1

,

n

i

e

t

s

p E

d

n

a

l a

t

e

y

e

ll

e

K

n

i

7

5

9 1

,

n

i

a

r

T

(

2

4

,

)2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

8

7

9 1

,

n

o

s

p

m

o

h

T

(

1

4

,

)2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

07

9 1

,

y

n

e

t

e

T

(

0

4

,

)5

8

9 1

,

.

l a

t

e

a

m

m

a

T

(

9

3,

)5

7

9 1

,

.

l a

t

e

w

a

h

S(

8

3,

)4

7

9 1

,

.

l a

t

e

he

d

a

z

fia

h

S(

S

d

n

a

y

e

s

le

K

(

0

5

,

)a

37

9 1

,

n

a

m

s

s

ie

G

d

n

a

n

i

w

r

I

(

9

4

,

)

80

0 2

,

.

l a

t

e

e

i

X

(

8

4

,

)

2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

38

9 1

,

.

l a

t

e

m

o

d

s

i

W

(

7

4

,

)

2

9

9 1

,

.

l a

t

e

t

li

W

(

6

4

,

)2

9

9 1

,

r

e

lli

M

d

n

a

t

li

W

(

5

4

,

)

2

8

9 1

,

.

l a

t

e

e

t

ih

W

(

(

8

5

,

)7

7

9 1

,

e

s

o

B

d

n

a

s

u

kt

t

u

B

(

7

5

,

)5

6

9 1

,

a

n

a

ht

n

a

S

d

n

a

z

r

e

H

(

6

5

,

)a

9

6

9 1

,

n

a

m

s

s

ie

G

d

n

a

n

i

w

r

I

(

5

5

,

)

b96

9 1

,

n

a

m

s

s

ie

G

d

n

a

n

i

w

r

I

(

4

5

,

)

5

7

9 1

,

.

l a

t

e

e

n

a

da

h

B

(

3

5

,

)3

7

9 1

,

.

l a

t

e

y

e

s

le

K

(

2 5

n

a

he

d

a

z

fia

h

S(

5

6,

)a

2

7

9 1

,

e

n

a

da

h B

d

n

a

he

d

a

z

fia

h

S(

4

6,

)a

3

7

9 1

,

e

n

a

da

h B

d

n

a

he

d

a

z

fia

h

S(

3

6,

)

97

9 1

,

o

s

o

id

u

a

G

d

n

a

n

i

e

t

s

p

E

(

2

6,

)

9

6

9 1

,

.

l a

t

e

n

i

w

r

I

(

1

6,

)

96

9 1

,

.

l a

t

e

n

a

m

s

s

ie

G(

0

6,

)a

7

7

91

.

)

30

0 2

,

.

l a

t

e

k

e

r

o

B

(

1

7

,

)8

9

9 1

,

.

l a

t

e

h

c

ir

n

ie

H

(

0

7

,

)

b3

7

9 1

,

n

a

m

s

s

ie

G

d

n

a

n

i

w

r

I

(

9

6,

)2

7

9 1

,

.

l a

t

e

e

u

gi

r

do

R

(

8

6,

)2

8

9 1

,

o

s

o

id

u

a

G

d

n

a

n

i

e

t

s

p

E

(

7

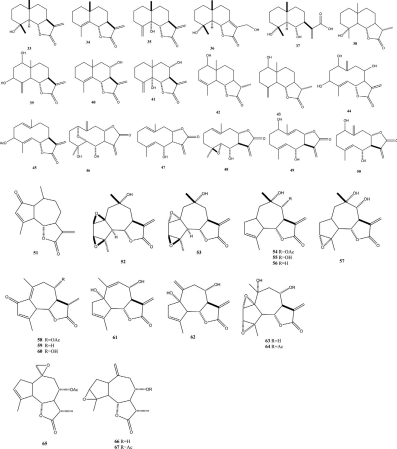
6,

)c

37

91

C.E. Turi et al. / Phytochemistry 98 (2014) 9–26 21

Fig. 6. Characteristic sesquiterpenes in the Tridentatae. Please note: structures of the additional sesquiterpenes are in the Supplemental Files.

ployed as alternative products to synthetic pesticides (Isman et al., 2011). Ethanolic extracts from A. tridentata inhibited growth of Peridroma saucia (Hbn) (variegated cutworm) (Salloum and Isman, 1989), while volatile compounds released from leaves inhibited oviposition for Zabrotes subfasciatus (Boheman) (Mexican bean weevil) (Weaver et al., 1995). Artemisia tridentata ssp. vaseyana demonstrated activity against Rhyzopetha dominica (F.) (lesser grain borer) and Plodia interpunctella (Hubner) (Indian meal moth) (Dunkel and Sears, 1998). To date, there are no commercial prod ucts based on the allelochemical or insecticidal constituents of Artemisia and these species have excellent potential applications for production of industrial chemicals, synergists and/or adjutants for use in agricultural applications.

Concluding remarks

Recent advancements in ultra-performance liquid chromatog raphy (UPLC), newer chromatography columns and separations

technologies, improvements in mass spectrometry and more sensitive instruments such as the quantitative time of flight (QTOF) and tandem time of flight (QTOF-TOF) coupled with new approaches to experimental design, statistical tools, chemo metric analysis, and ‘omics technologies’ have enormous poten tial for the discovery of new biologically active phytochemicals (Brown and Murch, 2012; Gad et al., 2013; Wu et al., 2013). With the success of artemisinin as an antimalarial drug, studies of the genus Artemisia species are increasingly popular and interesting (Bora and Sharma, 2011; Jose Abad et al., 2012; Tan et al., 1998). Although various groups of compounds have been identified in A. arbuscula, A. cana, and A. tridentata, far less is known for other members of Sagebrush such as A. bigelovii, A. pygmaea, A. rigida, and A. rothrockii. Furthermore, the mecha nisms of activity or identity of specific biologically active phyto chemicals has not been fully elucidated. Overall, North American Artemisia species have great potential for providing exciting leads.

22 C.E. Turi et al. / Phytochemistry 98 (2014) 9–26

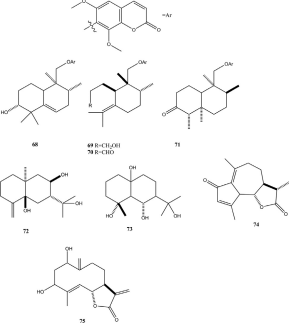


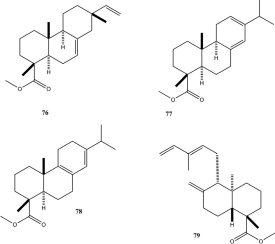
Fig. 7. Characteristic sesquicourmarins in the Tridentatae. Please note: structures of the additional sesquicourmarins are in the Supplemental Files. 

Fig. 8. Characteristic diterpenes in the Tridentatae. Please note: structures of the additional diterpenes are in the Supplemental Files.

6

e

l

ba

T

.

e

a

t

a

t

n

e

di

r

T

e

h t

n

i

s

e

n

e

pr

e

t

iD

a

t

a

t

n

e

di

r

t

.

A

.

A

.

A

.

A

.

A

.

A

.

A

.

A

a

n

a

c

.

A

a

n

a

c

.

A

.

A

.

A

.

A

.

A

.

A

.

A

.

A

r

a

l

u

c

e

lo

M

Z

/M

l

a

c

i

m

e

hC

it

n

e

dI

.

ps

b

u

s

a

t

a

t

n

e

di

r

t

a

t

a

t

n

e

di

r

t

s

i

m

r

o

fi

c

i

ps

i i

kc

o

r

ht

o

r

a

di

gi

r

a

e

a

m

gy

p

a

v

o

n

.

ps

b

u

s

.

ps

b

u

s

a

n

a

c

a

n

a

c

i i

v

o

le

gi

b

a

l

u

c

s

u

br

a

a

l

u

c

s

u

br

a

a

l

u

c

s

u

br

a

a

l

u

c

s

u

br

a

t

h

gi

e

w

a

lu

m

r

o

f

n

o

it

a

c

fi

i s

n

e

g

n

i

m

o

yw

.

ps

b

u

s

r

e

d

n

a

l

u

o

b

a

l

u

di

c

s

iv

.

ps

b

u

s

.

ps

b

u

s

.

ps

b

u

s

.

ps

b

u

s

r

e

b

m

u

n

a

n

a

y

e

s

a

v

a

n

a

c

a

lo

po

m

r

e

ht

a

b

o

li

g

n

o

l

a

l

u

c

s

u

br

a

e

n

e

pr

e

t

iD

5

8

4

.

6

1

3

4

2

.

6

1

3

2

O2

3

H

1

2

C

e

t

a

r

a

m

i

p

o

s

i

ly

ht

e

M

6 7

5

8

4

.

6

1

3

4

2

.

6

1

3

2

O2

3

H

1

2

C

l y

ht

e

M

7 7

e

t

a

r

a

m

i

p

o

v

e

l

5

8

4

.

6

1

3

4

2

.

6

1

3

2

O

2

3

H

1

2

C

e

t

a

r

t

s

u

l

a

p

ly

ht

e

M

8 7

5

8

4

.

6

1

3

4

2

.

6

1

3

2

O2

3

H

1

2

C

s

n

a

r

t

ly

ht

e

M

9 7

e t

a

n

u

m

m

o

c

s

di

c

a

yt

t

a

f

d

n

a

s

e

di

t

e

k

yl

o

P

l

a

-

1

-

n

e

c

e

dn

U

-

)E

9(

l

a

-

1

-

n

e

-

c

e

dn

U

-

)Z

9(

1 7

n

a

r

u

fl

yt

e

c

A-

2

l o

n

e

n

o

n

-

)

E

(-

2

e t

a

t

e

c

a

e

a

t

e

c

a

l

yt

pe

H

-

2

e

n

o

n

a

tc

O-

2

l

o

-

2

-

n

e

t

c

o

-

)

E

(-

3

yx

o

-

ly

n

e

x

e

h

-

)

Z

(-

3

e

dy

he

dl

a

t

e

c

a

l o

n

e

t

c

o

-

)

Z

(-

5

e

n

a

c

e

dn

U-

n

-

4

,

2

(-

2

-

)

E

(

-

)e

n

e

d

il

y

n

yi

da

x

e

h

-

6,

1

c

e

d}

5

.

4

{

o

r

i

ps

a

x

o

id

e

n

e

-

3

2 4

d i

c

a

c

i

br

o

c

s

A

r

e

ht

O

s

e

di

r

a

hc

c

a

s

yl

o

P

2 2

s

n

in

n

a

T

2 2

s

di

o

la

kl

A

2 2

s

e

t

a

r

dy

ho

br

a

C

2 2

s

n

i

e

t

o

r

P

,

)7

7

9 1

,

.

l a

t

e

s

u

kt

t

u

B

(

5

,

)2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

2

8

9 1

,

m

a

hg

n

i

kc

u

B

(

4

,

)5

7

9 1

,

.

l a

t

e

n

w

o

r

B

(

3

,

)5

8

9 1

,

h

c

le

W

d

n

a

n

a

he

B

(

2

,

)

4

3

9 1

,

gr

e

b

ka

O

d

n

a

s

m

a

d

A(

1

:

s

a

d

e

r

e

b

m

u

n

e

r

a

s

e

c

n

e

r

e

fe

R

2

,

.

l a

t

e

a

n

e

dr

a

w

a

n

u

G(

3

1

,

)

38

9 1

,

.

l a

t

e

r

e

g

e

r

G(

2

1

,

)

2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

2

8

9 1

,

y

bs

a

l

G(

1

1

,

)1

9

9 1

,

.

l a

t

e

n

i

e

t

s

p

E

(

0

1

,

)4

8

9 1

,

.

l a

t

e

n

i

e

t

s

p

E

(

9 ,

)3

7

9 1

,

r

e

t

l

u

o

P

d

n

a

n

i

e

t

s

p

E

(

8 ,

)4

8

9 1

,

o

s

o

id

u

a

G

t

e

y

e

s

le

K

(

1

2

,

)2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

38

9 1

,

i

n

a

t

e

m

a

K

(

0

2

,

)0

1

0 2

,

.

l a

t

e

i

b

s

s

a

J(

9

1

,

)7

7

9 1

,

.

l a

t

e

ll

o

hc

S(

8

1

,

)e

37

9 1

,

n

a

m

s

s

ie

G

d

n

a

n

i

w

r

I

(

7

1

,

)

1

7

9 1

,

n

a

m

s

s

ie

G

d

n

a

n

i

w

r

I

(

6

1

,

)

d3

7

9 1

,

n

a

m

s

s

ie

G

a

r

r

u

M

(

9

2

,

)2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

7

8

9 1

,

e

r

o

o

M

(

8

2

,

)

9

9

9 1

,

.

l a

t

e

c

i

v

e

jl

v

a

s

o

li

M

(

7

2

,

)a

8

0

0 2

,

.

l a

t

e

z

t

u

L

-

s

e

p

o

L

(

6

2

,

)

b

80

0 2

,

.

l a

t

e

z

t

u

L

-

s

e

p

o

L

(

5

2

,

)

96

9 1

,

.

l a

t

e

e

e

L

(

4

2

,

)1

4

9 1

,

.

l a

t

e

ye

n

n

i

K

(

3 2

le

M

d

n

a

he

d

a

z

fia

h

S(

5

3,

)

5

7

9 1

,

he

d

a

z

fia

h S

d

n

a

e

n

a

da

h

B

(

4

3,

)b

37

9 1

,

e

n

a

da

h B

d

n

a

he

d

a

z

fia

h

S(

3

3,

)

1

9

9 1

,

y

e

s

l

e

K

d

n

a

r

e

t

e

r

t

n

e

s

o

R

(

2

3,

)

67

9 1

,

.

l a

t

e

z

e

u

gi

r

do

R

(

1

3,

)

b7

7

9 1

,

n

i

e

t

s

p E

d

n

a

.

l a

t

e

y

e

ll

e

K

n

i

7

5

9 1

,

n

i

a

r

T

(

2

4

,

)2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

8

7

9 1

,

n

o

s

p

m

o

h

T

(

1

4

,

)2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

07

9 1

,

y

n

e

t

e

T

(

0

4

,

)5

8

9 1

,

.

l a

t

e

a

m

m

a

T

(

9

3,

)5

7

9 1

,

.

l a

t

e

w

a

h

S(

8

3,

)4

7

9 1

,

.

l a

t

e

he

d

a

z

fia

h

S(

S

d

n

a

y

e

s

le

K

(

0

5

,

)a

37

9 1

,

n

a

m

s

s

ie

G

d

n

a

n

i

w

r

I

(

9

4

,

)

80

0 2

,

.

l a

t

e

e

i

X

(

8

4

,

)2

9

9 1

,

.

l a

t

e

y

e

ll

e

K

n

i

3

8

9 1

,

.

l a

t

e

m

o

d

s

i

W

(

7

4

,

)

2

9

9 1

,

.

l a

t

e

t

li

W

(

6

4

,

)2

9

9 1

,

r

e

lli

M

d

n

a

t

li

W

(

5

4

,

)

2

8

9 1

,

.

l a

t

e

e

t

ih

W

(

(

8

5

,

)

7

7

9 1

,

e

s

o

B

d

n

a

s

u

kt

t

u

B

(

7

5

,

)5

6

9 1

,

a

n

a

ht

n

a

S

d

n

a

z

r

e

H

(

6

5

,

)a

96

9 1

,

n

a

m

s

s

ie

G

d

n

a

n

i

w

r

I

(

5

5

,

)

b

96

9 1

,

n

a

m

s

s

ie

G

d

n

a

n

i

w

r

I

(

4

5

,

)

5

7

9 1

,

.

l a

t

e

e

n

a

da

h

B

(

3

5

,

)3

7

9 1

,

.

l a

t

e

y

e

s

le

K

(

2 5

n

a

he

d

a

z

fia

h

S(

5

6,

)a

2

7

9 1

,

e

n

a

da

h B

d

n

a

he

d

a

z

fia

h

S(

4

6,

)a

3

7

9 1

,

e

n

a

da

h B

d

n

a

he

d

a

z

fia

h

S(

3

6,

)

9

7

9 1

,

o

s

o

id

u

a

G

d

n

a

n

i

e

t

s

p

E

(

2

6,

)

9

6

9 1

,

.

l a

t

e

n

i

w

r

I

(

1

6,

)

96

9 1

,

.

l a

t

e

n

a

m

s

s

ie

G(

0

6,

)a

7

7

91

.

)

30

0 2

,

.

l a

t

e

k

e

r

o

B

(

1

7

,

)8

9

9 1

,

.

l a

t

e

h

c

ir

n

ie

H

(

0

7

,

)b

37

9 1

,

n

a

m

s

s

ie

G

d

n

a

n

i

w

r

I

(

9

6,

)2

7

9 1

,

.

l a

t

e

e

u

gi

r

do

R

(

8

6,

)2

8

9 1

,

o

s

o

id

u

a

G

d

n

a

n

i

e

t

s

p

E

(

7

6,

)c

37

91

24 C.E. Turi et al. / Phytochemistry 98 (2014) 9–26

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.phytochem.2013. 11.016.

References

Adams, M., Oakberg, F.S., 1934. Essential oil in desert plants III: examination of the oil of Artemisia tridentata typica. J. Am. Chem. Soc. 56, 457–459. http:// dx.doi.org/10.1021/ja01317a054.

Basu, S.K., Thomas, J.E., Acharya, S.N., 2007. Prospects for growth in global nutraceutical and functional food markets: A Canadian perspective. Aust.J. Basic Appl. Sci. 1, 637–649. http://dx.doi.org/10.2307/3898986.

Behan, B., Welch, B.L., 1985. Black Sagebrush – Mule Deer winter preference and monoterpenoid content. J. Range Manage. 38, 278–280. http://dx.doi.org/ 10.2307/3898986.

Bhadane, N.R., Shafizadeh, F., 1975. Sesquiterpene lactones of Sagebrush – structure of artecanin. Phytochemistry 14, 2651–2653. http://dx.doi.org/10.1016/0031- 9422(75)85243-5.

Bhadane, N.R., Kelsey, R.G., Shafizadeh, F., 1975. Sesquiterpene lactones of Artemisia-tridentata ssp vaseyana. Phytochemistry 14, 2084–2085. http:// dx.doi.org/10.1016/0031-9422(75)83134-7.

Bora, K.S., Sharma, A., 2011. The genus Artemisia: a comprehensive review. Pharm. Biol. 49, 101–109. http://dx.doi.org/10.3109/13880209.2010.497815. Borek, T.T., Hochrein, J.M., Irwin, A.N., 2003. Composition of the essential oils from Rocky Mountain Juniper (Juniperus scopulorum), Big Sagebrush (Artemisia tridentata), and White Sage (Salvia apiana). Sandia National Laboratories., United States Department of Commerce, Springfield, VA.

Brown, G.D., 2010. The biosynthesis of artemisinin (Qinghaosu) and the phytochemistry of Artemisia annua L. (Qinghao). Molecules 15, 7603–7698. http://dx.doi.org/10.3390/15117603.

Brown, P.N., Murch, S.J., 2012. Applications of metabolomics to medicinal plants for scientific study and drug discovery. Planta Med. 78, 1056.

Brown, D., Asplund, R.O., McMahon, V.A., 1975. Phenolic constituents of Artemisia tridentata spp vaseyana. Phytochemistry 14, 1083–1084. http://dx.doi.org/ 10.1016/0031-9422(75)85191-0.

Buttkus, H., Bose, R.J., 1977. Characterization of a monoterpenoid ether from essential oil of Sagebrush (Artemisia-tridentata). J. Am. Oil Chem. Soc. 54, 212– 214. http://dx.doi.org/10.1007/BF02676278.

Buttkus, H.A., Bose, R.J., Shearer, D.A., 1977. Terpenes in essential oil of Sagebrush (Artemisia-tridentata). J. Agric. Food Chem. 25, 288–291. http://dx.doi.org/ 10.1021/jf60210a021.

Chattopadhyay, D., Naik, T.N., 2007. Antivirals of ethnomedicinal origin: structure– activity relationship and scope. Mini Rev. Med. Chem. 7, 275–301. Douglas, G.W., Stanley, G.B., Meidinger, D., Pojar, J., 1998. Illustrated flora of British Columbia, gymnosperms and dicotyledons, vol. 1. Province of British Columbia, British Columbia.

Dunkel, F.V., Sears, L.J., 1998. Fumigant properties of physical preparations from mountain Big Sagebrush, Artemisia tridentata Nutt. ssp. vaseyana (Rydb.) beetle for stored grain insects. J. Stored Prod. Res. 34, 307–321. http://dx.doi.org/ 10.1016/S0022-474X(98)00015-0.

Epstein, W.W., Gaudioso, L.A., 1979. Santolinolide B[(2r,3s,4s)-4-hydroxy-2,5- dimethyl-3-vinyl-5-hexenoic acid lactone] – new irregular monoterpene from Artemisia-tridentata-tridentata. J. Org. Chem. 44, 3113–3117. http://dx.doi.org/ 10.1021/jo01332a006.

Epstein, W.W., Gaudioso, L.A., 1982. Trans-2-(2-propenyl)-1-(2-methyl-1- propenyl)cyclopropane (rothrockene) – a non head to tail monoterpenoid with a new skeletal system from Artemisia-tridentata rothrockii. J. Org. Chem. 47, 175–176. http://dx.doi.org/10.1021/jo00340a047.

Epstein, W.W., Gaudioso, L.A., 1984. Volatile oil constituents of Sagebrush. Phytochemistry 23, 2257–2262. http://dx.doi.org/10.1016/S0031- 9422(00)80531-2.

Epstein, W.W., Poulter, C.D., 1973. Survey of some irregular monoterpenes and their biogenetic analogies to presqualene alcohol. Phytochemistry 12, 737–747. http://dx.doi.org/10.1016/0031-9422(73)80670-3.

Epstein, W.W., Gaudioso, L.A., Brewster, G.B., 1984. Essential oil constituents of Artemisia-tridentata-rothrockii – the isolation and characterization of 2 new irregular monoterpenes. J. Org. Chem. 49, 2748–2754. http://dx.doi.org/ 10.1021/jo00189a021.

Epstein, W.W., Klobus, M.A., Edison, A.S., 1991. Irregular monoterpene constituents of Artemisia-tridentata-cana – the Isolation, characterization, and synthesis of 2 new chrysanthemyl derivatives. J. Org. Chem. 56, 4451–4456. http://dx.doi.org/ 10.1021/jo00014a023.

Gad, H.A., El-Ahmady, S.H., Abou-Shoer, M.I., Al-Azizi, M.M., 2013. Application of chemometrics in authentication of herbal medicines: a review. Phytochem. Anal. 24, 1–24. http://dx.doi.org/10.1002/pca.2378.

Garcia, S., Canela, M.A., Garnatje, T., Mcarthur, E.D., Pellicer, J., Sanderson, S.C., Valles, J., 2008. Evolutionary and ecological implications of genome size in the North American endemic Sagebrushes and allies (Artemisia, Asteraceae). Biol. J. Linn. Soc. 94, 631–649. http://dx.doi.org/10.1111/j.1095-8312.2008.01001.x.

Garcia, S., Garnatje, T., McArthur, E.D., Pellicer, J., Sanderson, S.C., Valles, J., 2011a. Taxonomic and nomenclatural rearrangements in Artemisia Subgen. Tridentatae,

including a redefinition of Sphaeromeria (Asteraceae, Anthemideae). West. North Am. Nat. 71, 158–163.

Garcia, S., McArthur, E.D., Pellicer, J., Sanderson, S.C., Valles, J., Garnatje, T., 2011b. A molecular phylogenetic approach to western North America endemic Artemisia and allies (Asteraceae): untangling the Sagebrushes. Am. J. Bot. 98, 638–653. http://dx.doi.org/10.3732/ajb.1000386.

Geissman, T.A., Stewart, T., Irwin, M.A., 1967. Sesquiterpene lactones of Artemisia Species. 2. Artemisia tridentata Nutt ssp tridentata. Phytochemistry 6, 901. http://dx.doi.org/10.1016/S0031-9422(00)86039-2.

Geissman, T.A., Griffin, T.S., Irwin, M.A., 1969. Sesquiterpene lactones of Artemisia. Artecalin from A. californica and A. tripartita ssp rupicola. Phytochemistry 8, 1297. http://dx.doi.org/10.1016/S0031-9422(00)85569-7.

Ghantous, A., Gali-Muhtasib, H., Vuorela, H., Saliba, N.A., Darwiche, N., 2010. What made sesquiterpene lactones reach cancer clinical trials? Drug Discovery Today 15, 668–678. http://dx.doi.org/10.1016/j.drudis.2010.06.002.

Greger, H., Hofer, O., Robien, W., 1983. Naturally-occurring sesquiterpene coumarin ethers. 4. Types of sesquiterpene-coumarin ethers from Achillea-ochroleuca and Artemisia-tripartita. Phytochemistry 22, 1997–2003. http://dx.doi.org/10.1016/ 0031-9422(83)80032-6.

Guimarães, A.G., Quintans, J.S.S., Quintans-Júnior, L.J., 2013. Monoterpenes with analgesic activity–a systematic review. Phytother. Res. 27, 1–15. http:// dx.doi.org/10.1002/ptr.4686.

Gunawardena, K., Rivera, S.B., Epstein, W.W., 2002. The monoterpenes of Artemisia tridentata ssp vaseyana, Artemisia cana ssp viscidula and Artemisia tridentata ssp spiciformis. Phytochemistry 59, 197–203. http://dx.doi.org/10.1016/S0031- 9422(01)00438-1.

Harvey, A.L., Cree, I.A., 2010. High-throughput screening of natural products for cancer thereapy. Planta Med. 76, 1080–1086. http://dx.doi.org/10.1055/s-0030- 1250162.

Heinrich, M., Robles, M., Oritz de Montellano, B.R.O., Rodriguez, E., 1998. Ethnopharmacology of Mexican Asteraceae (Compositae). Annu. Rev. Pharmacol. Toxicol. 38, 539–565.

Herz, W., Santhana, P.S., 1965. Arbiglovin. A new guaianolide from Artemisia bigelovii Gray. J. Org. Chem. 30, 4340. http://dx.doi.org/10.1021/jo01023a521. Irwin, M.A., Geissman, T.A., 1969a. Sesquiterpene lactones. Constituents of Artemisia nova Nels and A. tripartita Gray ssp rupicola. Phytochemistry 8, 305. http:// dx.doi.org/10.1016/S0031-9422(00)85829-X.

Irwin, M.A., Geissman, T.A., 1969b. Sesquiterpene lactones of Artemisia species. New lactones from A-arbuscula ssp arbuscula and A-tripartita ssp rupicola. Phytochemistry 8, 2411. http://dx.doi.org/10.1016/S0031-9422(00)88163-7.

Irwin, M.A., Geissman, T.A., 1971. Sesquiterpene lactones from Artemisia – arbusculin-C, rothin-a and rothin-B. Phytochemistry 10, 637. http:// dx.doi.org/10.1016/S0031-9422(00)94711-3.

Irwin, M.A., Geissman, T.A., 1973a. Rupicolin-a and rupicolin-B, rupin-a and rupin-B, and cumambrin-B oxide from Artemisia-tripartita ssp – rupicola. Phytochemistry 12, 863–869. http://dx.doi.org/10.1016/0031-9422(73)80692-2.

Irwin, M.A., Geissman, T.A., 1973b. Ridentin-B – eudesmanolide from Artemisia tripartita ssp – rupicola. Phytochemistry 12, 871–873. http://dx.doi.org/ 10.1016/0031-9422(73)80693-4.

Irwin, M.A., Geissman, T.A., 1973c. Sesquiterpene alcohols from Artemisia-pygmaea. Phytochemistry 12, 849–852. http://dx.doi.org/10.1016/0031-9422(73)80689- 2.

Irwin, M.A., Geissman, T.A., 1973d. Novanin – germacranolide from Artemisia-nova. Phytochemistry 12, 875–878. http://dx.doi.org/10.1016/0031-9422(73)80694- 6.

Irwin, M.A., Geissman, T.A., 1973e. Arbusculin-D from Artemisia-arbuscula ssp arbuscula. Phytochemistry 12, 853–855. http://dx.doi.org/10.1016/0031- 9422(73)80690-9.

Irwin, M.A., Lee, K.H., Simpson, R.F., Geissman, T.A., 1969. Sesquiterpene lactones of Artemisia ridentin. Phytochemistry 8, 2009. http://dx.doi.org/10.1016/S0031- 9422(00)88088-7.

Ishizaki, S., Shiojiri, K., Karban, R., Ohara, M., 2012. Clonal growth of Sagebrush (Artemisia tridentata) (Asteraceae) and its relationship to volatile communication. Plant Species Biol. 27, 69–76. http://dx.doi.org/10.1111/ j.1442-1984.2011.00333.x.

Isman, M.B., Miresmailli, S., Machial, C., 2011. Commercial opportunities for pesticides based on plant essential oils in agriculture, industry and consumer products. Phytochem. Rev. 10, 197–204. http://dx.doi.org/10.1007/s11101-010- 9170-4.

Jassbi, A.R., Zamanizadehnajari, S., Baldwin, I.T., 2010. Phytotoxic volatiles in the roots and shoots of Artemisia tridentata as detected by headspace solid-phase microextraction and gas chromatographic–mass spectrometry analysis. J. Chem. Ecol. 36, 1398–1407. http://dx.doi.org/10.1007/s10886-010-9885-0.

Jose Abad, M., Miguel Bedoya, L., Apaza, L., Bermejo, P., 2012. The Artemisia L. genus: a review of bioactive essential oils. Molecules 17, 2542–2566. http://dx.doi.org/ 10.3390/molecules17032542.

Kelley, B.D., Appelt, J.M., Appelt, G.D., 1992. Artemisia-tridentata (Basin Sagebrush) in the Southwestern United-States-of-America – medicinal uses and pharmacological implications. Int. J. Addict. 27, 347–366.

Kelsey, R.G., Shafizadeh, F., 1979. Sesquiterpene lactones and systematics of the genus Artemisia. Phytochemistry 18, 1591–1611. http://dx.doi.org/10.1016/ 0031-9422(79)80167-3.

Kelsey, R.G., Morris, M.S., Bhadane, N.R., Shafizad, F., 1973. Chemical composition of Sagebrush. 7. sesquiterpene lactones of Artemisia – tlc analysis and taxonomic significance. Phytochemistry 12, 1345–1350. http://dx.doi.org/10.1016/0031- 9422(73)80562-X.

C.E. Turi et al. / Phytochemistry 98 (2014) 9–26 25

Kelsey, R.G., Shafizadeh, F., Campbell, J.A., Craig, A.C., Campana, C.F., Craig, R.E.R., 1983a. Canin from Artemisia-cana Pursh ssp cana – crystal-structure and identification of chrysartemin-a. J. Org. Chem. 48, 125–127. http://dx.doi.org/ 10.1021/jo00149a026.

Kelsey, R.G.,Wright,W.E., Sneva, F.,Winward, A., Britton, C., 1983b. The concentration and composition of Big Sagebrush essential oils from Oregon. Biochem. Syst. Ecol. 11, 353–360. http://dx.doi.org/10.1016/0305-1978(83)90036-4.

Kinney, C.R., Sugihara, J., 1942. Constituents of Artemisia tridentata (American Sage Brush). II. J. Org. Chem. 8, 290–294.

Kinney, C.R., Jackson, T.W., DeMytt, L.E., Harris, A.W., 1941. Oil of Artemisia tridentata (American Sage Brush). J. Org. Chem. 6, 612–625. http://dx.doi.org/ 10.1021/jo01204a015.

Lee, K.H., Simpson, R.F., Geissman, T.A., 1969. Sesquiterpenoid lactones of Artemisia. Constituents of Artemisia cana ssp cana. Structure of canin. Phytochemistry 8, 1515. http://dx.doi.org/10.1016/S0031-9422(00)85924-5.

Lopes-Lutz, D., Alviano, D.S., Alviano, C.S., Kolodziejczyk, P.P., 2008a. Screening of chemical composition, antimicrobial and antioxidant activities of Artemisia essential oils. Phytochemistry 69, 1732–1738. http://dx.doi.org/10.1016/ j.phytochem.2008.02.014.

Lopes-Lutz, D., Mckay, T., Kolodziejczyk, P.P., 2008b. Distribution of volatiles in Artemisia cana. Pharm. Biol. 46, 373–376. http://dx.doi.org/10.1080/ 13880200802055792.

López-Alarcón, C., Denicola, A., 2013. Evaluating the antioxidant capacity of natural products: a review on chemical and cellular-based assays. Anlalytica Chimica Acta 763, 1–10. http://dx.doi.org/10.1016/j.aca.2012.11.051.

McCutcheon, A.R., 1996. Ethnopharmacology of Western North American plants with special focus on the genus Artemisia L. (PhD thesis). University of British Columbia.

McCutcheon, A.R., Ellis, S.M., Hancock, R.E.W., Towers, G.H.N., 1994. Antifungal screening of medicinal-plants of British-Columbian Native peoples. J. Ethnopharmacol. 44, 157–169. http://dx.doi.org/10.1016/0378-8741(94)01183-4.

Milosavljevic, S., Bulatovic, V., Stefanovic, M., 1999. Sesquiterpene lactones from the Yugoslavian wild growing plant families Asteraceae and Apiaceae. J. Serb. Chem. Soc. 64, 397–442.

Moerman, D.E., 2009. Native American ethnobotany. Timber Press Inc., Portland, OR, ISBN 0881924539.

Nagy, J.G., Tengerdy, R.P., 1967. Antibacterial action of essential oils of Artemisia as an ecological factor. I. Antibacterial action of volatile oils of Artemisia tridentata and Artemisia nova on aerobic bacteria. Appl. Microbiol. 15, 819.

Negi, A.S., Kumar, J.K., Luqman, S., Saikia, D., Khamuja, S.P.S., 2010. Antitubercular potential of plants: a brief account of some important molecules. Med. Res. Rev., 603–645.

Newman, D.J., Cragg, G.M., 2012. Natural products as sources of new drugs over the last 30 years from 1981 to 2010. J. Nat. Prod. 75, 311–335.

Noble, T.A., Epstein, W.W., 1977a. Absolute stereochemistry and corrected structure of monoterpene ether from Artemesia-tridentata. Tetrahedron Lett., 3931–3932. Noble, T.A., Epstein, W.W., 1977b. New non-head-to-tail monoterpene from Artemesia-tridentata - (2r, 3r)-1,2-epoxy-2,5-dimethyl-3-vinyl-4-hexene - (oxido santolina triene). Tetrahedron Lett., 3933–3936.

Obrenovich, M.E., Li, Y., Parvathaneni, K., Yendluri, B.B., Palacios, H.H., Leszek, J., Aliev, G., 2011. Antioxidants in health, disease, and aging. Eur. Food Res. Technol. 219, 561–571. http://dx.doi.org/10.1007/s00217-004-1012-4.

Riggins, C.W., Seigler, D.S., 2012. The genus Artemisia (Asteraceae: Anthemideae) at a continental crossroads: Molecular insights into migrations, disjunctions, and reticulations among Old and NewWorld species from a Beringian perspective. Mol. Phylogenet. Evol. 64, 471–490. http://dx.doi.org/10.1016/j.ympev.2012.05.003.

Rodrigue, E., Vanderve, G., Carman, N.J., Geissman, T.A., Irwin, M.A., McReynol, J.H., Mabry, T.J., 1972. Methoxylated flavonoids from Artemisia. Phytochemistry 2, 3509.

Rodriguez, E., Towers, G.H.N., Mitchell, J.C., 1976. Biological-activities of sesquiterpene lactones. Phytochemistry 15, 1573–1580. http://dx.doi.org/ 10.1016/S0031-9422(00)97430-2.

Rosentreter, R., Kelsey, R.G., 1991. Xeric Big Sagebrush, a new subspecies in the Artemisia-tridentata complex. J. Range Manage. 44, 330–335. http://dx.doi.org/ 10.2307/4002394.

Saleem, M., Nazir, M., Ali, M.S., Hussain, H., Lee, Y.S., Riaz, N., Jabbar, J., 2010. Antimicrobial natural products: an update on future antibiotic drug candidates. Nat. Prod. Rep. 27, 238–254. http://dx.doi.org/10.1039/b916096e.

Salloum, G.S., Isman, M.B., 1989. Crude extracts of Asteraceous weeds – growth inhibitors for variegated Cutworm. J. Chem. Ecol. 15, 1379–1389. http:// dx.doi.org/10.1007/BF01014837.

Scholl, J.P., Kelsey, R.G., Shafizadeh, F., 1977. Involvement of volatile compounds of Artemisia in browse preference by Mule Deer. Biochem. Syst. Ecol. 5, 291–295. http://dx.doi.org/10.1016/0305-1978(77)90028-X.

Shafizadeh, F., Bhadane, N.R., 1972a. Badgerin, a new germacranolide from Artemisia-arbuscula ssp arbuscula. J. Org. Chem. 37, 274. http://dx.doi.org/ 10.1021/jo00967a019.

Shafizadeh, F., Bhadane, N.R., 1972b. Chemical constituents of Sagebrush. 5. Sesquiterpene lactones of Sagebrush – new guaianolides from Artemisia-cana ssp viscidula. J. Org. Chem. 37, 3168. http://dx.doi.org/10.1021/jo00985a028.

Shafizadeh, F., Bhadane, N.R., 1973a. Chemical composition of Sagebrush. 8. Longilobol – new sesquiterpene triol from Artemisia-longiloba (Osterhout) Beetle. Tetrahedron Lett., 2171–2174.

Shafizadeh, F., Bhadane, N.R., 1973b. Chemical composition of Sagebrush. 6. Sesquiterpene lactones of Artemisia-arbuscula and A-tridentata. Phytochemistry 12, 857–862. http://dx.doi.org/10.1016/0031-9422(73)80691-0.

Shafizadeh, F., Melnikof, A.B., 1970. Chemical composition of Sagebrush. 2. Coumarins of Artemisia-tridentata ssp vaseyana. Phytochemistry 9, 1311. http://dx.doi.org/10.1016/S0031-9422(00)85324-8.

Shafizadeh, F., Bhadane, N.R., Morris, M.S., Kelsey, R.G., Khanna, S.N., 1971. Chemical composition of Sagebrush. 3. Sequiterpene lactones of Big Sagebrush. Phytochemistry 10, 2745. http://dx.doi.org/10.1016/S0031-9422(00)97274-1.

Shafizadeh, F., Bhadane, N.R., Kelsey, R.G., 1974. Chemical composition of Sagebrush. 9. Sesquiterpene lactones of Sagebrush - constituents of Artemisia-tripartita. Phytochemistry 13, 669–670. http://dx.doi.org/10.1016/ S0031-9422(00)91383-9.

Shaw, J., Noble, T., Epstein, W., 1975. Methyl (2r), (3s)-2,5-dimethyl-3-vinylhex-4- enoate (methyl santolinate) a new irregular monoterpene constituent of Artemesia-tridentada-tridentada. J. Chem. Soc., Chem. Commun. 590–591. http://dx.doi.org/10.1039/c39750000590.

Shultz, L.M., 2006. Artemisia. In: Flora of North America Editorial Committee (Ed.), 1993+. Flora of North America North of Mexico. 16+ vols, vol. 19–21. Oxford, New York.

Shultz, L.M., 2009. Monograph for Artemisia. The American Society of Plant Taxonomists, USA.

Stanton, D.J., McArthur, E.D., Freeman, D.C., Golenberg, E.M., 2002. No genetic substructuring in Artemisia subgenus Tridentatae despite strong ecotypic subspecies selection. Biochem. Syst. Ecol. 30, 579–593. http://dx.doi.org/ 10.1016/S0305-1978(01)00118-1.

Tamma, R.V., Miller, G.C., Everett, R., 1985. High-performance liquid chromatographic analysis of coumarins and flavonoids from section Tridentatae of Artemisia. J. Chromatogr. 322, 236–239. http://dx.doi.org/ 10.1016/S0021-9673(01)97678-2.

Tan, R., Zheng, W., Tang, H., 1998. Biologically active substances from the genus Artemisia. Planta Med. 64, 295–302. http://dx.doi.org/10.1055/s-2006-957438. Tiwari, B.K., Valdramidis, V.P., O’Donnell, C.P., Muthukumarappan, K., Bourke, P., Cullen, P.J., 2009. Application of natural antimicrobials for food preservation. J. Agric. Food Chem. 57, 5987–6000. http://dx.doi.org/10.1021/jf900668n. Turner, N.J., 2009. Plantes aromatiques dans l’alimentation et la médecine des régions Nord-Ouest de l’Amérique du Nord. Phytothérapie 7, 136–146. Turner, N., Bouchard, R., Kennedy, D., 1980. Ethnobotany of the Okanagan-Colville Indians of British Columbia and Washington. British Columbia Provincial Museum, Victoria, BC.

Valles, J., Garcia, S., Hidalgo, O., Martin, J., Pellicer, J., Sanz, M., Garnatje, T., 2011. Biology, genome evolution, biotechnological issues and research including applied perspectives in Artemisia (Asteraceae). Adv. Bot. Res. 60 (60), 349–419. http://dx.doi.org/10.1016/B978-0-12-385851-1.00015-9.

Weaver, D.K., Phillips, T.W., Dunke, F.V., Weaver, T., Grubb, R.T., Nance, E.L., 1995. Dried leaves from rocky-mountain plants decrease infestation by stored-product beetles. J. Chem. Ecol. 21, 127–142. http://dx.doi.org/10.1007/BF02036647.

Welch, B.L., McArthur, D.E., 1981. Variation of monoterpenoid content among subspecies and accessions of Artemisia-tridentata grown in a uniform garden. J. Range Manage. 34, 380–384. http://dx.doi.org/10.2307/3897909.

White, S.M., Flinders, J.T., Welch, B.L., 1982. Preference of Pygmy Rabbits (Brachylagus-idahoensis for various populations of Big Sagebrush (Artemisia tridentata). J. Range Manage. 35, 724–726. http://dx.doi.org/10.2307/3898249.

Wilt, F.M., Miller, G.C., 1992. Seasonal-variation of coumarin and flavonoid concentrations in persistent leaves of Wyoming Big Sagebrush (Artemisia tridentata ssp wyomingensis, Asteraceae). Biochem. Syst. Ecol. 20, 53–67. http:// dx.doi.org/10.1016/0305-1978(92)90072-L.

Wilt, F.M., Geddes, J.D., Tamma, R.V., Miller, G.C., Everett, R.L., 1992. Interspecific variation of phenolic concentrations in persistent leaves among 6 Taxa from subgenus Tridentatae of Artemisia (Asteraceae). Biochem. Syst. Ecol. 20, 41–52. http://dx.doi.org/10.1016/0305-1978(92)90071-K.

Wu, H., Guo, J., Chen, S., Liu, X., Zhou, Y., Zhang, X., Xu, X., 2013. Recent developments in qualitative and quantitative analysis of phytochemical constituents and their metabolites using liquid chromatography-mass spectrometry. J. Pharm. Biomed. Anal. 72, 267–291. http://dx.doi.org/10.1016/ j.jpba.2012.09.004.

Xie, G., Schepetkin, I.A., Siemsen, D.W., Kirpotina, L.N., Wiley, J.A., Quinn, M.T., 2008. Fractionation and characterization of biologically-active polysaccharides from Artemisia tripartita. Phytochemistry 69, 1359–1371. http://dx.doi.org/10.1016/ j.phytochem.2008.01.009.

Christina Turi obtained her B.Sc in Plant Biology from 

the University of British Columbia (Canada) and her

M.Sc in Ethnobotany at the University of Kent (UK). She

is currently a PhD candidate investigating spiritual and

ceremonial uses of North American plants and their

potential as sources for novel neurologically active

constituents. Her research interest include: metabolo

mics, conservation of medicinal plants, and ethnobot

any.

26 C.E. Turi et al. / Phytochemistry 98 (2014) 9–26

Paul Shipley obtained his Ph.D. in chemistry from the 

University of Washington where he studied the bio

synthesis of antibiotics in actinomycete bacteria. His

research at the University of British Columbia’s Okana

gan campus is on the secondary metabolism of phar

macologically active plants and bacteria, with a focus on

metabolomic profiling of these species using nuclear

magnetic resonance spectrometry. He is currently an

associate professor in the chemistry department at the

University of British Columbia’s Okanagan campus.

Susan Murch received her PhD from the University of Guelph specializing in plant biochemistry and biotech nology. Her thesis described the discovery and physio logical roles of the human neurohormone melatonin in plants. She is currently an associate professor in chem istry at UBC’s Okanagan Campus and a Canada Research Chair in Natural Products Chemistry.