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REVIEW ARTICLE

Differential distribution of polyphenols in plants using multivariate techniques

Vinod Kumar[a,b,*,1], Anket Sharma[c,1], Sukhmeen Kaur Kohli[b], Shagun Bali[b], Manik Sharma[b], Rakesh Kumar[a], Renu Bhardwaj[b], Ashwani Kumar Thukral[b]

[a] *Department of Botany, DAV University, Sarmastpur, Jalandhar, Punjab, India*
[b] *Department of Botanical & Environmental Sciences, Guru Nanak Dev University, Amritsar, Punjab, India*
[c] *State Key Laboratory of Subtropical Silviculture, Zhejiang A & F University, Hangzhou, China*

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Abstract Plants form a substantive portion of human diet that contains a plethora of structurally diverse polyphenols. These polyphenols extend both nutritional as well as disease preventive benefits to the consumer. Many ancient medicinal systems like Ayurveda reiterate the consumption of particular polyphenol rich plant in specific medical condition. Therefore, it is necessary to create a database of the contents of different polyphenols in various plants. This study compiles a bibliographic review of polyphenol distribution in different plants along with their statistical analysis like Pearson's correlation matrix, cluster analysis, principal component and factor analysis, and non-metric multidimensional scaling. It was observed that caffeic acid and quercetin were the most abundant polyphenols in the plants. A significant positive correlation of umbelliferone was found with kaempferol and epicatechin. Species having close proximities on the basis of polyphenols were *Parthenium hysterophorus*, *Rumex dentatus*, *Achyranthus aspera*, *Chenopodium ambrosoides*, *Cannabis sativa*, *Rhododendron arboreum*, *Alternanthera philoxeroides*, *Debregeasia longifolia* and *C. album*. Factor analysis showed four underlying factors for polyphenols. Factor-1 had maximum loadings on epicatechin, umbelliferone and kaempferol. Gallic acid and catechin had maximum loadings on factor-2. Factor-3 had maximum loadings on chlorogenic acid and quercetin, and factor-4 had maximum loading on coumaric acid.

Introduction

Plants are important dietary constituents in human food. The dietary intake of polyphenols is one gram per day (Scalbert, Johnson, & Saltmarsh, 2005) which is more than other classes of phytochemicals and known as dietary

* Corresponding author.
E-mail: vinodverma507@gmail.com (V. Kumar).
[1] Contributed equally.

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antioxidants. Fruit and plant derived beverages, i.e., juices, red wine, tea and coffee are the major dietary sources in human food. Cereals, chocolate, dry legumes and vegetables are also an important source of total polyphenol intake (Scalbert et al., 2005). Polyphenols constitute the active substances found in various plants which modulate the activities of a wide variety of enzymes and cell receptors (Middleton, Kandaswami, & Theoharides, 2000). Thousands of molecules having a polyphenol structure have been found in plants. These molecules are the secondary metabolites which are involved in protection against ultraviolet radiation. These compounds may be categorized in different groups on the basis of the number of phenol rings that they contain and structural elements that bind these rings to one another (Manach, Scalbert, Morand, Rémésy, & Jiménez, 2004). Polyphenols especially flavonoids are shown to improve learning and memory processes and are studied for their potential to check age-related cognitive reduction in animals as well as humans (Haque et al., 2006; Kaur, Pathak, Pandhi, & Khanduja, 2008; Krikorian et al., 2010; Williams et al., 2008).

Polyphenols are abundant antioxidants in the human diet and the largest and best studied class of these compounds is flavonoids. Polyphenols are classified into four main categories based on their structure, i.e., flavonoids, phenolic acids, lignans and stilbenes. Flavonoids have a common structure consisting of 2 aromatic rings joined together by 3-C atoms to form an oxygenated heterocycle. Based on their hydroxylation standard of oxygenated heterocycle and hydroxyl group arrangement, polyphenols are further divided into 4 subclasses such as flavonols, chalcones, flavones and anthocyanins. Flavones are further classified into four subgroups. (a) flavanones found in citrus fruits, (b) flavanols abundantly found in red wine, chocolate and green tea, (c) flavones present in celery, olives and parsley, and (d) isoflavones found mainly in soy (Collin & Crouzet, 2011). Phenolic acids are further categorized into hydroxybenzoic acid, e.g., black tea, red wine, black berries etc., and hydroxycinnamic acid, e.g., red wine, olives and plums (Collin & Crouzet, 2011). Stilbenes consist of two aromatic rings joined together by methylene bridge and existed in cis and trans forms which have different biological and chemical characteristics. Stilbenes are present in cranberries and lingo berries (Collin & Crouzet, 2011). Lignans are characterized by 1,4-diarylbutane structure and it is a precursor of plant polymers that constitute factors of defense against pathogens (Collin & Crouzet, 2011).

The mode of action of flavonoids is not clear, but there are indications that they regulate the molecular and cellular processes that are involved in memory and learning (Spencer, Vauzour, & Rendeiro, 2009). Fruits, vegetables, tea and wine are the richest sources of flavonoids for humans (Kumar & Pandey, 2013). Flavonols are the most common flavonoids in the food. Flavonoids are responsible for colour, taste and prevention of fat oxidation (Yao et al., 2004). Isoflavones, flavonols and flavones are the major flavonoids which are found in the human diet. Catechin is present in most of the fruits and some legumes (Arts, van de Putte, & Hollman, 2000). Flavonoids influence the food quality by acting as antioxidants, flavorants and colourants (Craig, 1999; Kumar, Sharma, Sharma, & Pandey, 2012). Flavonoids found in berries may have positive effect against the Parkinson's disease and may also help to improve the memory of the elder people (Li et al., 2005). Various studies confirmed that these compounds have protective function on the human health and these are the key constituents of the balanced diet (Lima, Vianello, Corrêa, Campos, & Borguini, 2014). Natural polyphenols are found in various plants and food, i.e., fruits, tea, cereals, medicinal plants, microalgae, edible and wild flowers. Some of the wild and edible fruits that have been analyzed viz., blueberry, mango, citrus fruits, grape, olive and sweetsop contain high polyphenol contents (Deng et al., 2012, 2013; Fu et al., 2011; Guo et al., 2012; Li et al., 2012, 2013; Xia, Deng, Guo, & Li, 2010). Mediterranean diets are linked with deceased risk of cardiovascular disorders due to proper intake of olive oil and red wine, which contained high contents of polyphenols (Carluccio et al., 2003; Xia et al., 2011). Pigmented cereals, i.e., red rice, purple rice and black rice contained high contents of total phenols (Deng et al., 2013). Various techniques are used for the estimation of different polyphenols in the plants such as GC–MS, UHPLC etc. (Kumar et al., 2015; Sharma, Thakur, et al., 2016). Gonzales et al. (2015) used principal component analysis categorization and differentiation of polyphenols in red cabbage and Brussels sprout waste streams. Sârbu et al. (2012) also used cluster analysis and principal component analysis in classification of polyphenols in kiwi and pomelo fruits. Dorta et al. (2014) while working on phenolic compounds in *Mangifera indica* also applied cluster analysis and principal component analysis for classification of polyphenols. Santos Grasel et al. (2016) applied multivariate techniques in determination of polyphenols nature in Black wattle, Myrabolan, Chestnut, Quebracho, Tara and Valonea. Rodriguez Galdon et al. (2010) while working on onion varieties used cluster analysis for classification of polyphenols. The present review focuses on the contents of different polyphenols present in the methanolic extracts of plants. Fig. 1 shows the classification of different polyphenols.

Materials and method

Collection of data

The data of 67 plant species for different classes of polyphenols were collected and presented in form of μg/g dw units. Further the data was statistical analyzed by using various techniques like Pearson's correlation analysis, cluster analysis, heatmap analysis, principal component analysis and non-metric multidimensional scaling. Fig. 2 depicts the collected of data from different countries. The maximum number of plant species collected for polyphenols were from Greece. The second dominant country for collection of plant species was Poland which was followed by India.

Results and discussion

Table 1 presents the contents of different polyphenols found in different plants. Table 2 shows the mean, maximum and minimum contents of different polyphenols found in different plants. *Vitis vinnifera* recorded maximum content of catechin, whereas minimum contents of catechin and epicatechin have been reported in *Achyranthus aspera*.

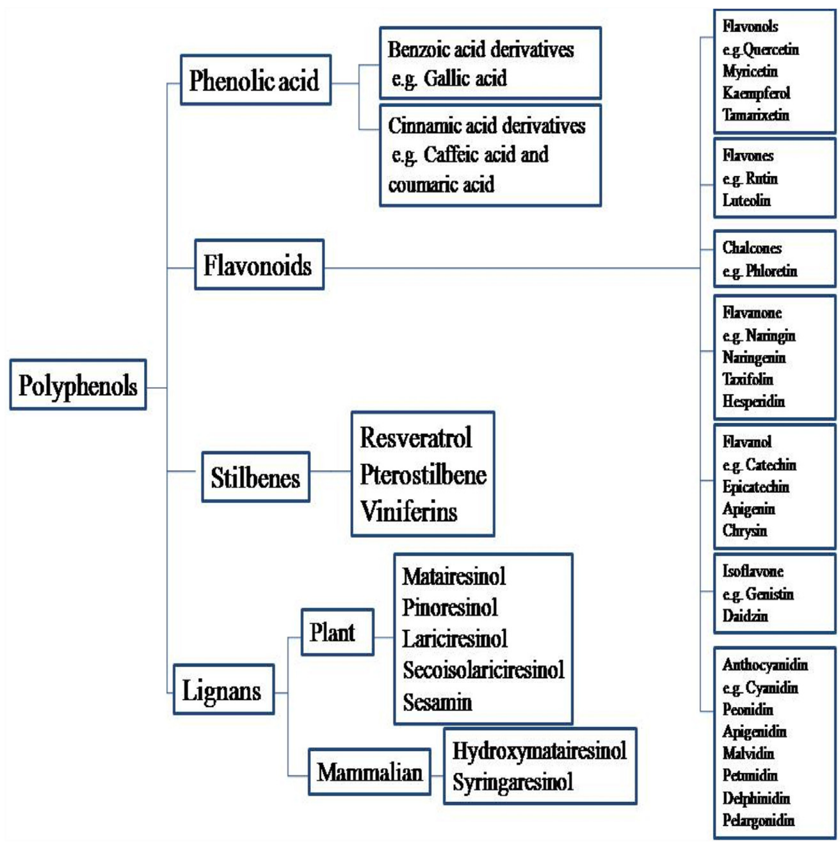

Figure 1 General classification of polyphenols.

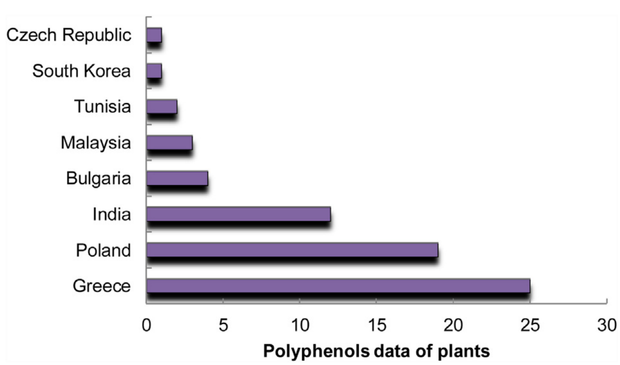

Figure 2 Polyphenols data of plants from different countries.

Maximum contents of kaempferol and coumaric acid occur in *Juglans regia*, whereas *Rhododendron arboretum* recorded the minimum contents of these polyphenols. *Tanacetum vulgare* recorded maximum contents of ferulic acid, caffeic acid, chlorogenic acid and apigenin.

Polyphenols extracted from some plants using the same extraction techniques and analyzed same equipment were used for Pearson's correlation analysis and multivariate statistical techniques. Pearson's correlation analysis was applied to the contents of different polyphenols by using R-programming software 3.1.3 in order to find correlation between different polyphenols (Fig. 3). Positive correlations of gallic acid were found with catechin and chlorogenic acid. Positive correlation of gallic acid with chlorogenic acid may be attributed to the fact that both are phenolic acids. Epicatechin shows positive correlation with umbelliferone and kaempferol. Positive correlation of epicatechin with kaempferol may be attributed to the fact that both are flavonoids. Positive correlation of chlorogenic acid was found with quercetin. Cluster analysis (CA) conducted to categorize different plant species on the basis of polyphenols content into clusters or groups, in such a way that one plant species is more closely associated with another plant species in the same cluster than to another plant species allocated to different clusters (Brereton, 2003). CA was applied by using Ward's method and Euclidean distance as a measure of similarity (Dorta et al., 2014) (Fig. 4). *Rumex dentatus*, *Achyranthus aspera*, *Chenopodium ambrosoides*, *Chenopodium album* and *Alternanthera philoxeroides* belong to the order Caryophyllales and had close proximity on the basis of polyphenol contents. Fernandes et al. (2016) applied CA for classification of different herbs like oregano, marjoram, lemon balm and rosemary on the basis of phenolic content.

PCA is an unsupervised algorithm of pattern identification to assess, categorize and decrease the dimensions of data sets (Costache et al., 2009). We conducted PCA to classify the different types of polyphenols on the basis of their content in different studied plant species. The first three components of PCA explained 93.4% of the total variance (43.3%, 31.2% and 18.9% respectively). Factor analysis revealed mainly four underlying factors for polyphenols

Table 1 Content of different polyphenols found in different plants.

Family	Species name	Extract used	Location	Analyzed part	Polyphenols	Content (μg/g dw)	References
Amaranthaceae	*Achyranthes aspera*[a]	Methanol	Punjab, India	Leaves	Gallic acid	0.13	Kumar, Sharma, Thukral, and Bhardwaj (2015)
					Catechin	0.08	
					Chlorogenic acid	0.97	
					Epicatechin	0.41	
					Caffeic acid	1.46	
					Umbelliferone	0.85	
					Coumaric acid	3.12	
					Kaempferol	4.92	
					Ellagic acid	38.18	
Amaranthaceae	*Alternanthera philoxeroides*[a]	Methanol	Punjab, India	Leaves	Chlorogenic acid	2.72	Kumar et al. (2015)
					Epicatechin	2.01	
					Caffeic acid	0.27	
					Umbelliferone	7.45	
					Rutin	0.16	
					Quercetin	18.86	
					Kaempferol	9.12	
Apiaceae	*Lagoecia cuminoides*	Methanol	Greece	Fruit	Gallic acid	10	Proestos, Chorianopoulos, Nychas, and Komaitis (2005)
					Caffeic acid	66	
					Vanillic acid	13	
					Ferulic acid	42	
Araceae	*Acorus calamus*	Methanol	Poland	Rhizome	Caffeic acid	23.1	Wojdyło, Oszmiański, and Czemerys (2007)
					Coumaric acid	43.1	
					Ferulic acid	3	
					Quercetin	50	
					Kaempferol	15.7	

Table 1 (*Continued*)

Family	Species name	Extract used	Location	Analyzed part	Polyphenols	Content (μg/g dw)	References
Asteraceae	*Achillea millefolium*	Methanol	Poland	Herbal	Caffeic acid	4290	Wojdyło et al. (2007)
					Chlorogenic acid	1180	
					Ferulic acid	350	
					Luteolin	1030	
					Apigenin	843	
Asteraceae	*Ageratum conyzoides*[a]	Methanol	Punjab, India	Leaves	Gallic acid	0.95	Kumar et al. (2015)
					Catechin	127.56	
					Chlorogenic acid	0.04	
					Epicatechin	46.26	
					Caffeic acid	0.38	
					Umbelliferone	0.17	
					Coumaric acid	0.6	
					Quercetin	2.28	
					Ellagic acid	7.07	
Asteraceae	*Artemisia absinthium*	Methanol	South Korea	Leaves	Quercetin	30.9	Lee, Thiruvengadam, Chung, and Nagella (2013)
					Kaempferol	12.95	
					Caffeic acid	80.6	
					Coumaric acid	9.1	
					Ferulic acid	53.55	
					Gallic acid	63.99	
					Rutin	44	
					Vanillin	12.55	
Asteraceae	*Artemisia arborescens*	Methanol	Greece	Herb	Gallic acid	11	Proestos et al. (2005)
					Caffeic acid	384	
					Vanillic acid	13	
					Ferulic acid	308	
Asteraceae	*Artemisia vulgaris*	Methanol	Poland	Herbal	Caffeic acid	3040	Wojdyło et al. (2007)
					Chlorogenic acid	544	
					Ferulic acid	138	
Asteraceae	*Echinacea purpurea*	Methanol	Poland	Leaves	Caffeic acid	6200	Wojdyło et al. (2007)
					Chlorogenic acid	1150	
					Coumaric acid	195	
					Ferulic acid	179	
					Quercetin	123	

Table 1 (*Continued*)

Family	Species name	Extract used	Location	Analyzed part	Polyphenols	Content (μg/g dw)	References
Asteraceae	*Erigeron bonariensis*[a]	Methanol	Punjab, India	Leaves	Gallic acid	0.26	Kumar et al. (2015)
					Catechin	19.68	
					Epicatechin	9.41	
					Caffeic acid	0.04	
					Umbelliferone	34.24	
					Coumaric acid	0.72	
					Rutin	0.78	
					Quercetin	4.13	
					Kaempferol	38.64	
					Ellagic acid	34.64	
Asteraceae	*Inulahelenium*	Methanol	Poland	Root	Caffeic acid	1830	Wojdyło et al. (2007)
					Chlorogenic acid	630	
					Ferulic acid	245	
Asteraceae	*Parthenium hysterophorus*[a]	Methanol	Punjab, India	Leaves	Gallic acid	2.68	Kumar et al. (2015)
					Catechin	25.37	
					Chlorogenic acid	4.25	
					Epicatechin	49.97	
					Caffeic acid	0.05	
					Umbelliferone	2.83	
					Coumaric acid	1.53	
					Ellagic acid	3.72	
Asteraceae	*Silybum marianum*	Methanol	Poland	Seed	Caffeic acid	928	Wojdyło et al. (2007)
					Coumaric acid	536	
					Ferulic acid	207	
					Quercetin	23.9	
Asteraceae	*Tanacetum vulgare*	Methanol	Poland	Leaf	Caffeic acid	8940	Wojdyło et al. (2007)
					Chlorogenic acid	3350	
					Ferulic acid	4710	
					Luteolin	8480	
					Apigenin	1650	
Asteraceae	*Taraxacum officinale*	Methanol	Greece	Leaves	Caffeic acid	30	Proestos et al. (2005)
					Ferulic acid	20	
					Epicatechin	4	

Table 1 (*Continued*)

Family	Species name	Extract used	Location	Analyzed part	Polyphenols	Content (μg/g dw)	References
Brassicaceae	*Brassica juncea*[a]	Methanol	Amritsar, India	Leaves	Catechin	57.94	Sharma, Kumar, Thukral, and Bhardwaj (2016)
					Chlorogenic acid	12.39	
					Caffeic acid	34.32	
					Ellagic acid	3.95	
					Kaempferol	87.79	
Brassicaceae	*Brassica juncea*[a]	Methanol	Amritsar, India	Seedlings	Catechin	16.86	Sharma, Kumar, et al. (2016)
					Caffeic acid	50.05	
					Rutin	11.39	
					Ellagic acid	1.7	
					Quercetin	1.77	
					Kaempferol	97.8	
Cannabaceae	*Cannabis sativa*[a]	Methanol	Punjab, India	Leaves	Gallic acid	3.32	Kumar et al. (2015)
					Catechin	0.19	
					Chlorogenic acid	3.27	
					Epicatechin	1.3	
					Caffeic acid	0.37	
					Umbelliferone	0.6	
					Coumaric acid	2.04	
					Quercetin	1.31	
					Kaempferol	1.89	
					Ellagic acid	3.73	
Cannabaceae	*Humulus lupulus*	Methanol	Poland	Cone	Caffeic acid	381	Wojdyło et al. (2007)
					Coumaric acid	228	
					Ferulic acid	143	
					Quercetin	472	
					Kaempferol	453	
Caryophyllaceae	*Herniaria glabra*	Methanol	Poland	Herbal	Caffeic acid	781	Wojdyło et al. (2007)
					Coumaric acid	233	
					Ferulic acid	369	

Table 1 (*Continued*)

Family	Species name	Extract used	Location	Analyzed part	Polyphenols	Content (μg/g dw)	References
Caprifoliaceae	*Sambucus nigra*	Methanol	Greece	Flower	Gentisic acid	15	Proestos et al. (2005)
					Caffeic acid	375	
					Vanillic acid	8	
					Ferulic acid	398	
					Naringenin	6	
Ericaceae	*Rhododendron arboretum*[a]	Methanol	Amritsar, India	Leaves	Gallic acid	0.37	Proestos and Komaitis (2013)
					Catechin	3.25	
					Chlorogenic acid	0.11	
					Epicatechin	1.41	
					Caffeic acid	0.2	
					Umbelliferone	0.58	
					Coumaric acid	0.14	
					Rutin	2.05	
					Ellagic acid	9.8	
					Kaempferol	0.16	
Fabaceae	*Debregeasia longifolia*[a]	Methanol	Punjab, India	Leaves	Gallic acid	8.3	Kumar et al. (2015)
					Catechin	74.93	
					Chlorogenic acid	1.52	
					Caffeic acid	49.98	
					Umbelliferone	44.34	
					Coumaric acid	0.69	
					Rutin	27.73	
					Kaempferol	12.38	
					Ellagic acid	70.01	
Fabaceae	*Glycyrrhiza glabra*	Methanol	Poland	Herbal	Caffeic acid	153	Wojdyło et al. (2007)
					Coumaric acid	119	
					Ferulic acid	197	
					Apigenin	858	
Lamiaceae	*Hyssopus officinalis*	Methanol	Greece	Herb	Gentisic acid	12	Proestos et al. (2005)
					Caffeic acid	65	
					p-hydroxybenzoic acid	12	
					Apigenin	12	
					Catechin	57	
Hypericaceae	*Hypericum perforatum*	Methanol	Poland	Herbal	Caffeic acid	2290	Wojdyło et al. (2007)
					Coumaric acid	323	
					Ferulic acid	93.8	
					Quercetin	497	
					Kaempferol	58.9	

Table 1 (*Continued*)

Family	Species name	Extract used	Location	Analyzed part	Polyphenols	Content (μg/g dw)	References
Juglandaceae	*Juglans regia*	Methanol	Poland	Leaves	Caffeic acid	1480	Wojdyło et al. (2007)
					Chlorogenic acid	947	
					Coumaric acid	1250	
					Ferulic acid	352	
					Kaempferol	880	
Lamiaceae	*Lavandula vera*	Methanol	Greece	Flower	Gallic acid	5	Proestos et al. (2005)
					Caffeic acid	4	
					Vanillic acid	6	
					Ferulic acid	13	
					p-hydroxybenzoic acid	16	
					Catechin	24	
Lamiaceae	*Mentha pulegium*	Methanol	Greece	Leaves	Caffeic acid	600	Proestos et al. (2005)
					Vanillic acid	8	
					Luteolin	150	
					Catechin	260	
Lamiaceae	*Melissa officinalis*	Methanol	Greece	Leaves	Gentisic acid	21	Proestos and Komaitis (2013)
					Caffeic acid	138	
					Ferulic acid	48	
					Hydroxybenzoic acid	23	
					Eriodictyol	11	
					Catechin	210	
Lamiaceae	*Melissa officinalis*	Methanol	Greece	Leaves	Gentisic acid	21	Proestos et al. (2005)
					Caffeic acid	138	
					Ferulic acid	480	
					p-hydroxybenzoic acid	23	
					Catechin	210	
Lamiaceae	*Mentha viridis*	Methanol	Greece	Leaves	Gallic acid	9	Proestos et al. (2005)
					Caffeic acid	60	
					Vanillic acid	7	
					Ferulic acid	56	
					Apigenin	7	
					Rutin	14	
					Catechin	20	

Table 1 (*Continued*)

Family	Species name	Extract used	Location	Analyzed part	Polyphenols	Content (μg/g dw)	References
Lamiaceae	*Ocimum basilicum*	Methanol	Greece	Leaves	Gentisic acid	15	Proestos et al. (2005)
					Caffeic acid	28	
					Ferulic acid	40	
					p-hydroxybenzoic acid	13	
					Catechin	12	
Lamiaceae	*Origanum majorana*	Methanol	Greece	Herb	Gentisic acid	14	Proestos et al. (2005)
					Caffeic acid	42	
					Ferulic acid	92	
					p-hydroxybenzoic acid	12	
					Apigenin	8	
					Catechin	26	
Lamiaceae	*Origanum dictamnus*	Methanol	Greece	Leaves	Coumaric acid	139	Proestos and Komaitis (2013)
					Ferulic acid	3.4	
					Catechin	5	
Lamiaceae	*Origanum vulgare*	Methanol	Greece	Leaves	Caffeic acid	10	Proestos and Komaitis (2013)
					Vanillic acid	10	
					Ferulic acid	32	
					Eriodictyol	7	
					Rutin	10	
					Catechin	177	
					Epicatechin	18	
Lamiaceae	*Salvia officinalis*	Methanol	Poland	Herbal	Chlorogenic acid	531	Wojdyło et al. (2007)
					Coumaric acid	103	
					Ferulic acid	135	
					Luteolin	496	
					Apigenin	221	
Lamiaceae	*Salvia officinalis*	Methanol	Greece	Leaves	Gentisic acid	24	Proestos et al. (2005)
					Ferulic acid	49	
					p-hydroxybenzoic acid	12	
					Apigenin	3	
					Catechin	25	

Table 1 (*Continued*)

Family	Species name	Extract used	Location	Analyzed part	Polyphenols	Content (µg/g dw)	References
Lamiaceae	*Sideritis cretica*	Methanol	Greece	Leaves	Gallic acid	26	Proestos and Komaitis (2013)
					Coumaric acid	41	
					Syringic acid	11	
					Ferulic acid	69.5	
					Quercetin	16	
					Luteolin	91	
					Catechin	221	
					Epicatechin	69	
Lamiaceae	*Rosmarinus officinalis*	Methanol	Greece	Leaves	Gentisic acid	32	Proestos et al. (2005)
					Caffeic acid	20	
					Vanillic acid	20	
					Ferulic acid	52	
					p-hydroxybenzoic acid	14	
					Catechin	15	
Lamiaceae	*Rosmarinus officinalis*	Methanol	Poland	Herbal	Caffeic acid	4060	Wojdyło et al. (2007)
					Ferulic acid	362	
					Luteolin	6160	
					Apigenin	438	
Lamiaceae	*Teucrium chamaedrys*	Methanol	Greece	Herb	Gallic acid	6	Proestos et al. (2005)
					Caffeic acid	7	
					Ferulic acid	11	
					Quercetin	2	
					Apigenin	9	
Lamiaceae	*Thymus vulgaris*	Methanol	Greece	Herb	Gentisic acid	28	Proestos et al. (2005)
					Caffeic acid	58	
					Coumaric acid	12	
					Syringic acid	50	
					p-hydroxybenzoic acid	14	
					Epicatechin	3	
Myrtaceae	*Eucalyptus globulus*	Methanol	Greece	Leaves	Gallic acid	15	Proestos and Komaitis (2013)
					Coumaric acid	66	
					Quercetin	25	
					Rutin	18	

Table 1 (*Continued*)

Family	Species name	Extract used	Location	Analyzed part	Polyphenols	Content (μg/g dw)	References
Malvaceae	*Malva sylvestris*	Methanol	Greece	Herb	Gallic acid	11	Proestos et al. (2005)
					Ferulic acid	43	
					p-hydroxybenzoic acid	14	
Malvaceae	*Sida acuta*[a]	Methanol	Punjab, India	Leaves	Gallic acid	2.9	Kumar et al. (2015)
					Catechin	0.18	
					Chlorogenic acid	2.22	
					Epicatechin	118.98	
					Caffeic acid	1.16	
					Umbelliferone	668.7	
					Rutin	0.19	
					Quercetin	19.62	
					Kaempferol	733.62	
Oleaceae	*Olea europaea*	Methanol	Plovdiv, Bulgaria	Leaves	3,4-Dihydroxy benzoic acid	1699.4	Yancheva, Mavromatis, and Georgieva (2016)
					Ferulic acid	216.9	
					Quercetin	205.2	
					Luteolin	439.1	
Oleaceae	*Olea europaea*	Methanol	Plovdiv, Bulgaria	Leaves	3,4-Dyhydroxy benzoic acid	976.6	Yancheva et al. (2016)
					Caffeic acid	49.3	
					Coumaric acid	64	
					Ferulic acid	77.1	
					Quercetin	104.5	
					Rutin	19.1	
Oleaceae	*Olea europaea*	Methanol	Plovdiv, Bulgaria	Leaves	3,4-Dihydroxy benzoic acid	434.1	Yancheva et al. (2016)
					Sinapic acid	37.8	
					Ferulic acid	59.5	
					Quercetin	130.8	
					Hesperidin	50.2	
					Luteolin	300.6	
					Rutin	18.1	
Oleaceae	*Olea europaea*	Methanol	Plovdiv, Bulgaria	Leaves	3,4-Dihydroxy benzoic acid	104.5	Yancheva et al. (2016)
					Ferulic acid	555.3	
					Quercetin	26.4	
					Hesperidin	51.9	
					Luteolin	88	

Table 1 (*Continued*)

Family	Species name	Extract used	Location	Analyzed part	Polyphenols	Content (μg/g dw)	References
Papaveraceae	*Chelidonium majus*	Methanol	Poland	Herbal	Caffeic acid	1860	Wojdyło et al. (2007)
					Coumaric acid	717	
					Kaempferol	116.5	
					Apigenin	200	
Primulaceae	*Labisia pumila*	Methanol	Malaysia	Leaves	Apigenin	94.72	Karimi and Jaafar (2011)
					Kaempferol	217.6	
					Myricetin	103.2	
					Rutin	116.8	
					Caffeic acid	62.13	
Primulaceae	*Labisia pumila*	Methanol	Malaysia	Leaves	Apigenin	152	Karimi and Jaafar (2011)
					Kaempferol	541.7	
					Myricetin	147.7	
					Quercetin	210	
					Rutin	51.6	
					Gallic acid	312	
					Caffeic acid	151	
Primulaceae	*Labisia pumila*	Methanol	Malaysia	Leaves	Apigenin	53.92	Karimi and Jaafar (2011)
					Kaempferol	157.5	
					Myricetin	116.6	
					Quercetin	71.2	
					Rutin	28.9	
					Genistein	107	
					Gallic acid	508	
					Caffeic acid	147	
Rubiaceae	*Asperula odorata*	Methanol	Greece	Leaves	Gallic acid	12	Proestos et al. (2005)
					Caffeic acid	346	
					Ferulic acid	840	
					Rutin	15	
					Catechin	6	
					Epicatechin	13	

Table 1 (*Continued*)

Family	Species name	Extract used	Location	Analyzed part	Polyphenols	Content (μg/g dw)	References
Tamaricaceace	*Tamarix aphylla*	Ehtyl acetate	Tunisia	Leaves	Gallic acid	120.6	Mahfoudhi, Prencipe, Mighri, and Pellati (2014)
					Caffeic acid	8.2	
					Coumaric acid	34.3	
					Ellagic acid	211.4	
					Quercetin	125.7	
					Apigenin	26.5	
					Kaempferol	90.3	
					Quercetin	51	
Tamaricaceace	*Tamarix aphylla*	Ehtyl acetate	Tunisia	Stem	Gallic acid	24.3	Mahfoudhi et al. (2014)
					Coumaric acid	7.2	
					Ellagic acid	44.4	
					Kaempferol	16.3	
Utricaceae	*Debregeasia longifolia*[a]	Methanol	Punjab, India	Leaves	Gallic acid	0.02	Kumar et al. (2015)
					Catechin	0.39	
					Chlorogenic acid	6.29	
					Epicatechin	1.99	
					Caffeic acid	3.09	
					Umbelliferone	0.8	
					Coumaric acid	0.29	
					Rutin	46.91	
					Kaempferol	16.07	
					Ellagic acid	0.93	
Umbelliferae	*Archangelica officinalis*	Methanol	Poland	Leaves	Caffeic acid	853	Wojdyło et al. (2007)
					Chlorogenic acid	253	
					Ferulic acid	256	
					Quercetin	486	
					Luteolin	968	
					Apigenin	69.1	
Umbelliferae	*Anethum graveolens*	Methanol	Greece	Herb	Vanillic acid	16	Proestos et al. (2005)
					Quercetin	360	
					Epicatechin	45	
Umbelliferae	*Carum carvi*	Methanol	Poland	Fruit	Caffeic acid	3320	Wojdyło et al. (2007)
					Chlorogenic acid	968	
					Ferulic acid	383	

Table 1 (*Continued*)

Family	Species name	Extract used	Location	Analyzed part	Polyphenols	Content (μg/g dw)	References
Umbelliferae	*Levisticum officinale*	Methanol	Poland	Leaves	Caffeic acid	3900	Wojdyło et al. (2007)
					Chlorogenic acid	1640	
					Ferulic acid	762	
					Quercetin	9230	
Umbelliferae	*Petroselinum sativum*	Methanol	Poland	Root	Caffeic acid	144	Wojdyło et al. (2007)
					Coumaric acid	112	
					Ferulic acid	186	
					Apigenin	811	
Umbelliferae	*Petroselinum sativum*	Methanol	Greece	Leaves	Gallic acid	7	Proestos et al. (2005)
					Gentisic acid	16	
					Coumaric acid	4	
					Vanillic acid	6	
					p-hydroxybenzoic acid	13	
					Quercetin	13	
					Luteolin	21	
Umbelliferae	*Pimpinella anisum*	Methanol	Greece	Herb	Gallic acid	11	Proestos et al. (2005)
					Caffeic acid	8	
					Ferulic acid	12	
Vitaceace	*Vitis vinifera*	Methanol	Czech Republic	Berries	Catechin	118	Balik et al. (2008)
					Epicatechin	63.5	
					Trans-reveratrol	2.3	
					Trans-piceid	2.9	
				Stem	Catechin	867	
					Epicatechin	81.4	
					Trans-reveratrol	276.1	
					Trans-piceid	18.6	
				Leaves	Trans-reveratrol	8.5	
					Trans-piceid	32.9	
					Caftaric acid	618	
				Leaves	Trans-reveratrol	8.1	
					Trans-piceid	25.6	
					Caftaric acid	694	

[a] Data of plants used for Pearson's correlation, principal component and factor analysis.

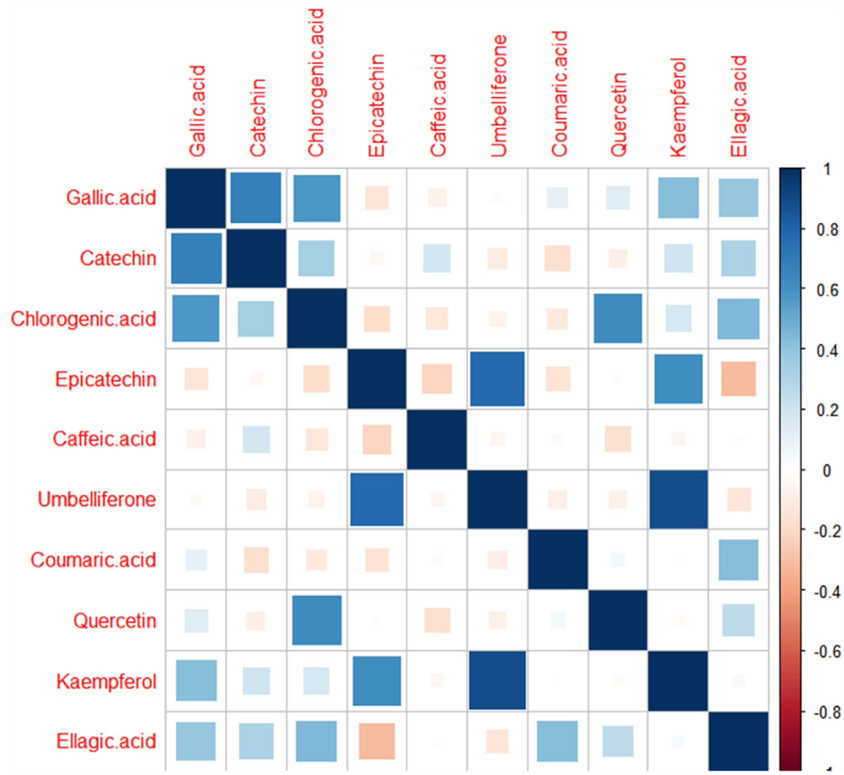

Figure 3 Pearson's correlation analysis of polyphenols.

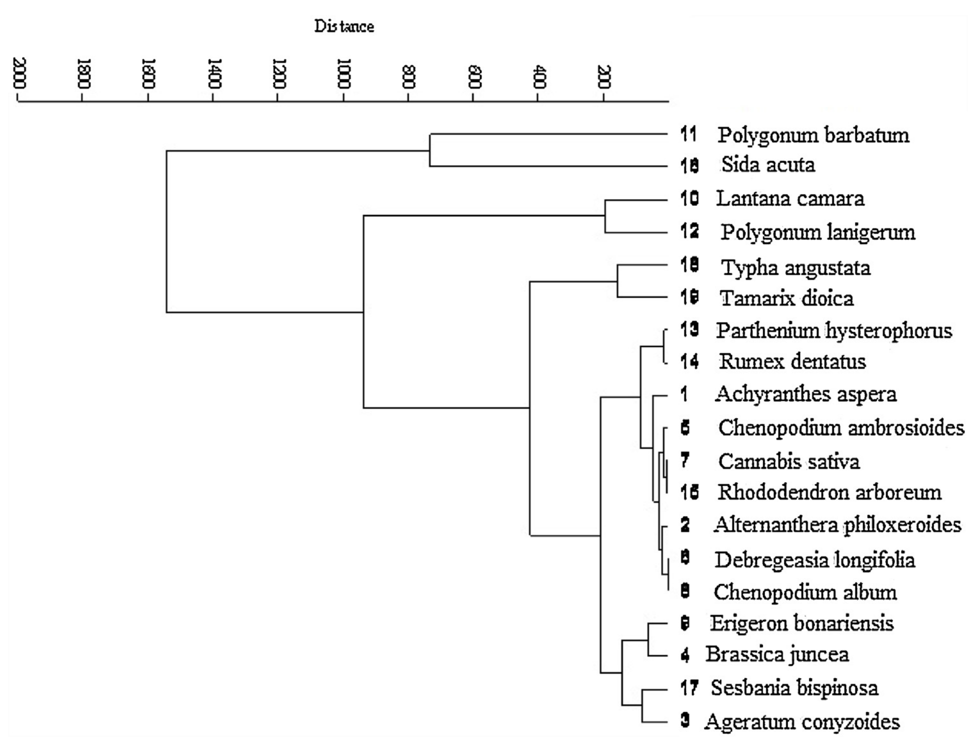

Figure 4 Cluster analysis of different plants on the basis of different polyphenols.

(Table 3 and Fig. S1). Factor-1 explained 25.6% of the total variance and had maximum loadings on epicatechin (flavanol), umbelliferone (cinnamic acid derivative) and kaempferol (flavonol). Factor-2 accounted for 23.6% of the total variance and had maximum loadings on gallic acid (benzoic acid derivative) and catechin (flavanol). 16.4% of the total variance was explained by factor-3 which had maximum loadings on chlorogenic acid and quercetin (flavonol).

Table 2 Mean, maximum and minimum contents of different polyphenols found in different plants.

Polyphenols	Mean (μg/g dw)	Max (μg/g dw)	Part analyzed	Min (μg/g dw)	Part analyzed
Gallic acid	28.2	508 *Labisiapumila*	Leaves	0.02 *Debregeasialongifolia*	Leaves
Epicatechin	16.9	118 *Sidaacuta*	Leaves	0.41 *Achyranthesaspera*	Leaves
Catechin	28.93	867 *Vitisvinifera*	Stem	0.08 *Achyranthesaspera*	Leaves
Chlorogenic acid	2.6	3350 *Tanacetumvulgare*	Leaves	0.04 *Ageratum conyzoides*	Leaves
Caffeic acid	219.3	8940 *Tanacetumvulgare*	Leaves	0.04 *Erigeron bonariensis*	Leaves
Umbelliferone	100.1	668.7 *Sidaacuta*	Leaves	0.17 *Ageratum conyzoides*	Leaves
Quercetin	220	9230 *Levisticumofficinale*	Leaves	1.31 *Cannabis sativa*	Leaves
Rutin	13.9	116.8 *Labisiapumila*	Leaves	0.16 *Alternantheraphiloxeroides*	Leaves
Coumaric acid	44	1250 *Juglansregia*	Leaves	0.14 *Rhododendron arboreum*	Leaves
Kaempferol	132.9	880 *Juglansregia*	Leaves	0.16 *Rhododendron arboreum*	Leaves
Ellagic acid	25.3	211.4 *Tamarixaphylla*	Leaves	0.93 *Debregeasialongifolia*	Leaves
Vanillic acid	4.9	20 *Rosmarinusofficinalis*	Leaves	6.0 *Lavandulavera*	Flower
Ferulic acid	186	4710 *Tanacetumvulgare*	Leaves	3.0 *Acoruscalamus*	Rhizome
Apigenin	142	1650 *Tanacetumvulgare*	Leaves	3.0 *Salvia officinalis*	Leaves

Table 3 Factor analysis of different polyphenols of plants.

Variable	Factor-1	Factor-2	Factor-3	Factor-4	Communality
Gallic acid	−0.100	−0.870	0.124	0.172	0.812
Catechin	0.016	−0.881	−0.223	−0.112	0.840
Chlorogenic acid	0.075	−0.634	0.674	0.011	0.862
Epicatechin	−0.861	0.177	0.061	−0.202	0.817
Caffeic acid	0.156	−0.188	−0.588	0.038	0.407
Umbelliferone	−0.961	0.050	−0.011	−0.021	0.927
Coumaric acid	0.021	0.126	−0.063	0.936	0.897
Quercetin	0.088	−0.104	0.850	0.094	0.750
Kaempferol	−0.909	−0.338	0.012	0.076	0.947
Ellagic acid	0.156	−0.465	0.213	0.675	0.742
%Var	25.6%	23.6%	16.4%	14.3%	80%

Factor-4 explained 14.3% of the total variance and had maximum loading on coumaric acid (cinnamic acid derivatives). Brenna and Pagliarini (2001) applied PCA to subtract the non-significant polyphenols, i.e., caffeic acid, epicatechin, procyanidin, quercetin, quercetin-3-glucuronide, rutin, isorhamnetin, kaempferol and cyanidin-3-glucosid in wines. Csomós et al. (2002) reported loadings of spermidine, tyramine and resveratrol on PC 1 while working on polyphenols of Hungarian wines. Guo et al. (2017) while working on different polyphenols in kiwifruit juices and reported loadings of epicatechin, flavan-3-ols and caffeic acid on PC1.

Non-metric multidimensional scaling (NMDS) is a multivariate technique that reduces data sets. In NMDS ranked distinction among the points in multidimensional space are maintained in a 2- or 3-dimensional space using a similarity measure (Kaur et al., 2018). NDMS scatter plot indicate two points (point # 11 = *P. barbatum* and point # 16 = *S. acuta*) separated to the mail group (Figs. 5 and 6). The polyphenols content of these plants might be segregating them

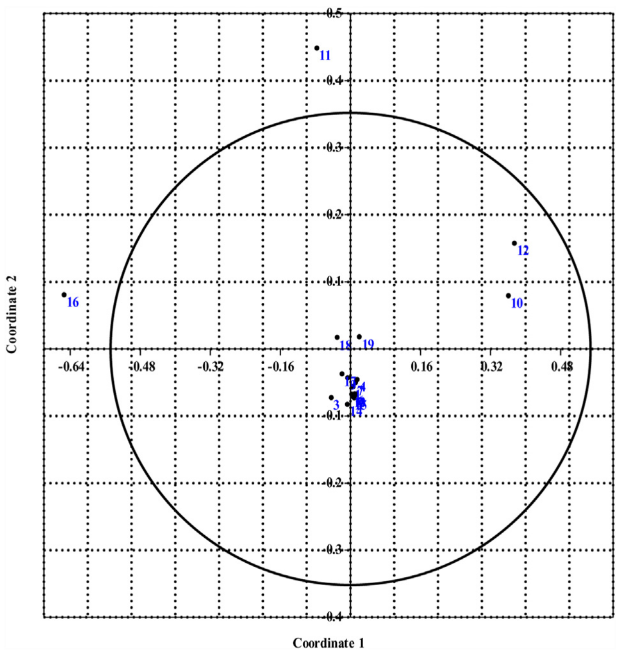

Figure 5 NMDS scatter plot (95% ecclipse) of different polyphenols in plants using correlation as a similarity measure.

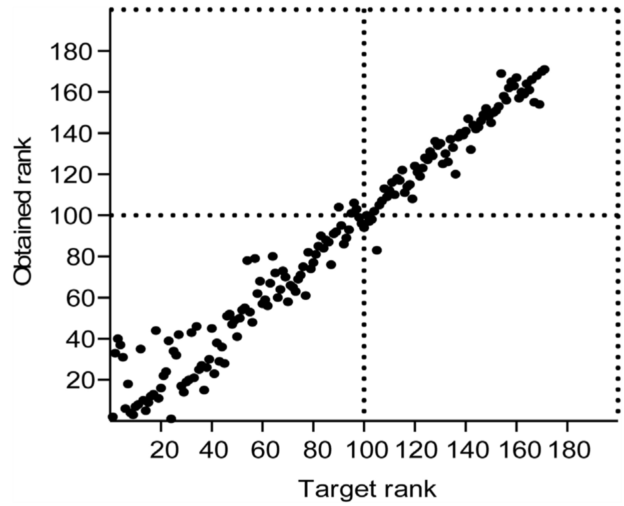

Figure 6 NMDS Shepard 2-D plot of polyphenols in plants (Stress = 0.09511, R^2 for Axis 1 = 0.6892, Axis 2 = 0.5115).

from the other plants. Heatmap is the graphical depiction of data present in 2-D matrix, indicates each value as colour (Sun and Li, 2013). The same colour of a parameter indicates similar abundance or content of particular parameter.

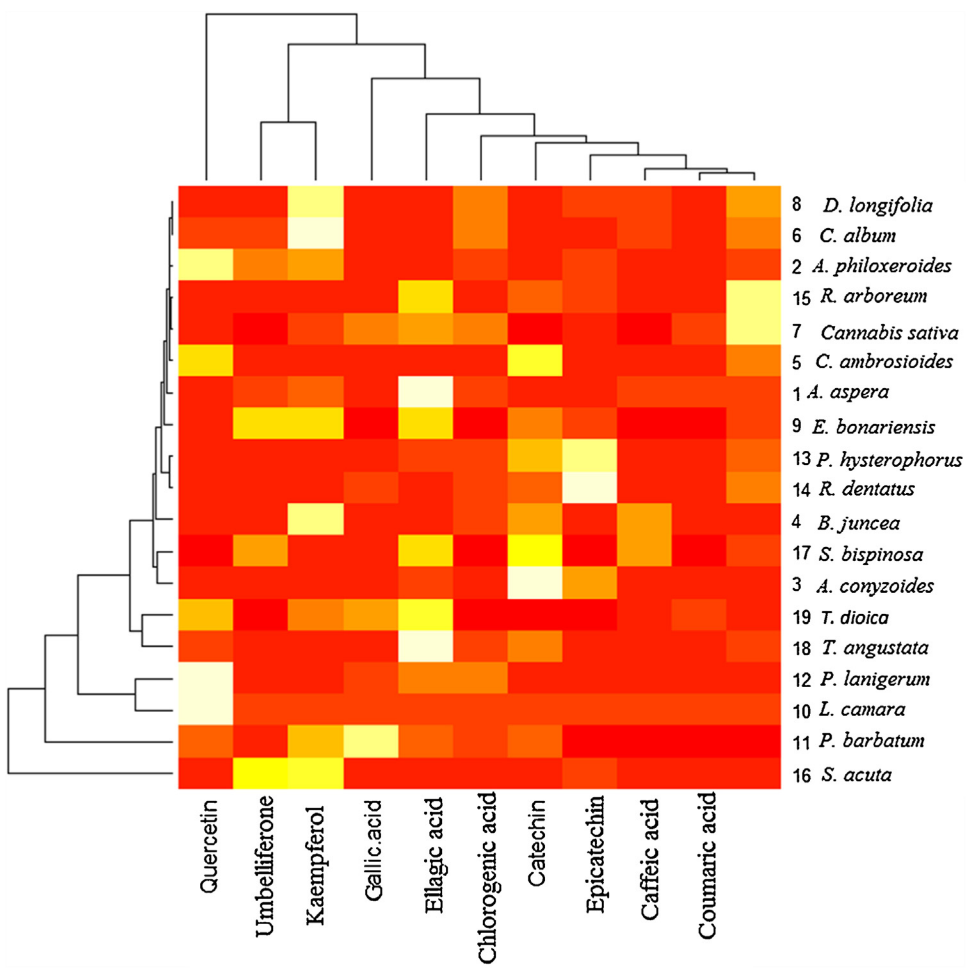

Figure 7 Heatmap analysis of different polyphenols and plant species.

However, the heatmap provides classification of all the studied parameters by the use of CA and also gives overview of parameters with higher content more directly (Tian et al., 2018). Heatmap was also prepared to different polyphenols and plant species (Fig. 7). Umbelliferone and kaempferol are associated with each other. Catechin, epicatechin, caffeic acid and coumaric acid also related with each other. The results of heatmap are supported by Pearson's correlation analysis. *L. camara* and *P. lanigerum* are also associated with each other. *T. angustata* and *T. dioica* are also included in the same group. Tian et al. (2018) while working on polyphenols in apple juice also reported that catechin and epicatechin showed associations with each other.

Conclusions and future prospects

There is increasing attention in plant polyphenols because of their antioxidant, anticancer and various other human health advantages and industrial applications. Regarding their significance in health effects, the identification of polyphenols in different plant species permits a great attention in analytical science. Multivariate techniques are vital tools in metabolite analysis and metabolomics has been represented as important technique in assessment of food quality, food processing, food component analysis etc. (Cevallos-Cevallos et al., 2009; Wishart, 2008). In addition to the application of multivariate techniques in environmental biology, and in this review we have explored their application in plant analysis which may be helpful in classification of polyphenols or other metabolites in plants. Antioxidants provide protection against harm mediated by free radicals. Plants are rich sources of antioxidants, and their link with free radicals, and functioning of diverse organs and organ systems is complicated and finding of redox signalling is key step regarding their association. By exploring such plants that are rich in metabolites with antioxidant properties may be helpful for human health (Devasagayam et al., 2004). Polyphenols form an important component of the plant based diet. They being antioxidant in their function, assuage the chances of disease establishment in humans. In the present review, we have observed that in most of the plants caffeic acid and quercetin were present in the maximum amounts. The positive correlation of epicatechin existed with umbelliferone and kaempferol. Epicatechin and kaempferol also showed positive correlation with each other which may be attributed to the fact that both are flavonoids. Catechin, epicatechin, caffeic acid and coumaric acid also showed associations with each other as indicated by heatmap analysis further supported by correlation analysis findings. CA showed that *Rumex dentatus*, *Achyranthus aspera*, *Chenopodium ambrosoides*, *Chenopodium album* and *Alternanthera philoxeroides* had close proximity with each other. The first three components of PCA accounted for 93.4% of the total variance. So, most of the medicinal benefits exerted by eating medicinal plants may be due to their consumption. Mechanistic studies are required which may suggest their mode of action in various diseased conditions.

Conflict of interest

All authors declared that there is no conflict of interest.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.biori.2019.03.001.

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