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Seed Ergastic Substances Profiling and its Implications for the Amaranthaceae-Chenopodiaceae Complex

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ABSTRACT

The chemotaxonomic significance of ergastic substances that are aligned systematically to the Amaranthaceae-Chenopodiaceae group and their prospective applications, such as the use of its starch for food, health and industrial uses, were assessed in the present study employing species from four genera: *Amaranthus* (Amaranthaceae), *Chenopodium*, *Atriplex* and *Suaeda* (Chenopodiaceae). Alkaloids, fats, oils, inulin, protein and starch profiles of the taxa studied generated three groups using Principal Component Analysis (PCA) and four clusters using Cluster Analysis (CA). The resultant groups and clusters showed the species did not segregate across traditional lines but aligned with taxa outside genus and family borders. The species *Chenopodium botrys* and *Chenopodium polyspermum* were most divergent, constituting a separate group and clusters. The majority of the species segregated as a primary group/cluster, showing close affinities between members of both families; hence, the Amaranthaceae-Chenopodiaceae group can be regarded as a mono-paraphyletic group. Alkaloids were recorded only in Chenopodiaceae taxa and betalains only in Amaranthaceae which presupposes that taxonomic relevant ergastic substances demarcation lines may exist to delimit the families. In addition, these ergastics substances showcase the taxa potential food, health and industrial applications. The Amaranthaceae-Chenopodiaceae starch granule is small in size (0.7-5.4 μm), circular in shape (poorly irregular) and lacks hilum and striations. The small-size granule will be invaluable for a number of prospective food and health uses, principally for low glycemic load foods for diabetics, as well as numerous industrial uses, such as producing environmentally friendly biodegradable plastics as alternatives to petrochemicals.

Key words: Amaranthaceae, Chenopodiaceae, chemotaxonomic, ergastic substances, genetic diversity, starch, systematics

INTRODUCTION

Members of the Amaranthaceae and Chenopodiaceae are herbs, shrubs, or lianas with alternate or opposite, entire and exstipulate leaves. Fruit; a dry utricle or a fleshy capsule, indehiscent, irregularly bursting, or circumscissile. Seeds; lenticular, reniform, subglobose, or shortly cylindrical, smooth or veruculose (Muller and Borsch, 2005).

Though widespread and cosmopolitan, the Amaranthaceae are predominantly tropical (Bojian *et al.*, 2003). A number of species, like spinach (*Spinacia oleracea*), beet (*Beta vulgaris*) and green (*Amaranthus spinosa*) are used as vegetables; some forms of *Beta vulgaris* are fodder beet

and sugar beet, while seeds of Amaranth and Quinoa (*Chenopodium quinoa*) are edible as cereals even as late as the Incas civilization. Members of the genera; *Alternanthera*, *Achyranthes*, *Aerva*, *Celosia*, *Digera*, *Dysphania* and *Pupalia* are medicinal herbs (Asolkar *et al.*, 1992; Katewa *et al.*, 2003; Parveen and Kumar, 2007; Jain *et al.*, 2009). The *Atriplex* are generally halophytes, a number of species of the genera *Alternanthera*, *Amaranthus*, *Celosia* and *Iresine* make excellent ornamental plants and several species like *Amaranthus retroflexus*, *Amaranthus cruentus* and *Alternanthera philoxeroides* are considered weeds (Liu-Qing *et al.*, 2008; Mlakar *et al.*, 2012).

Ergastic substances (phytochemicals) studies are often good tools for analysis of the relationship between taxa at various levels. The similarity or difference in the profiling of these chemical constituents of plants can help in the understanding of the linkages that may exist between various species as well as the potential exploitation and applications of such species (Conrad and Idu, 2013).

There is a divide whether the Amaranthaceae and Chenopodiaceae are two distinct monophyletic or a polyphyletic group. Recent works points to the subfamily Polycnemoideae as a pivotal clade for resolving this. The Amaranthaceae is a monophyly group sometimes considered paraphyletic when grouped with the Chenopodiaceae (Kadereit *et al.*, 2003; Akhani *et al.*, 2007; Judd *et al.*, 2008; Kadereit and Freitag, 2011). The present study investigated the ergastic substances profile of the Amaranthaceae and Chenopodiaceae species and discussed its possible systematics, genetic diversity, starch characteristics, present and future food application and biodegradable plastics implications.

MATERIALS AND METHODS

Seeds were obtained from the Botanischer Garten und Botanisches Museum (BGBM) Berlin-Dahlem, Germany (1000 Berlin 33, Königin-Luise-Straße 6-8, 14195) and from seeds collection surveys across Southern Nigeria (2009-2010); were analyzed for the present study. Seeds vouchers are stored in the seed germplasm banks of the Department of Biological Sciences, Covenant University (CU), Ota and the Department of Plant Biology and Biotechnology, University of Benin (UNIBEN), Benin City, Nigeria (Table 1).

Seed ergastic analysis: Tests for various ergastic substances; fats and oils, protein, tannins, inulin and starch were analyzed according to Gill *et al.* (1991) and Idu and Onyibe (2011). Starch granule characteristics; granule shape, granule size, hilum striations and hilum size were recorded to the nearest decimal (0.00 µm). Starch granule sizes were as designated by Li *et al.* (2008); as A type (diameter>9.9 µm) and B-type granules (diameter<9.9 µm).

Table 1: Seed samples for the study (providing/donor institution, repository held, specimen no.)

Taxons	Specimen no.	Provider (Repository held)
<i>Amaranthus albus</i>	0035V-270-59-89-10	BGBM (UNIBEN)
<i>Amaranthus caudatus</i>	OAC-NSE-0101	CU (CU)
<i>Amaranthus retroflexus</i>	0036V-238-83-89-10	BGBM (UNIBEN)
<i>Celosia argentea</i>	0039V-068-02-87-34/OAC-NSE-0116	BGBM/CU (CU)
<i>Atriplex sagittata</i>	00291V-238-93-89-10	BGBM (UNIBEN)
<i>Atriplex prostrata</i>	00290V-255-59-10	BGBM (UNIBEN)
<i>Atriplex sibirica</i>	0292V-053-19-74-74/OAC-NSE-0093	BGBM/CU (CU)
<i>Atriplex tatarica</i>	0293V-238-73-89-10	BGBM (UNIBEN)
<i>Chenopodium album</i>	0296V-238-22-89-10/OAC-NSE-0124	BGBM/CU (CU)
<i>Chenopodium botrys</i>	0297-252-64-90-10	BGBM (UNIBEN)
<i>Chenopodium hybridum</i>	0298V-238-63-89-10	BGBM (UNIBEN)
<i>Chenopodium polyspermum</i>	0300-225-82-90-10	BGBM (UNIBEN)
<i>Suaeda maritima</i>	0302-255-79-90-10	Bgbm (UNIBEN)

Data analysis: Data matrix was analyzed to generate a relationship grouping following cluster analysis and Principal Component Analysis with SPSS 15.1 for Windows.

RESULTS

Ergastic substances profile: Amaranthaceae and Chenopodiaceae species were compared based on their ergastic substances profile (Table 2). Four Amaranthaceae and nine Chenopodiaceae species recorded similar ergastic profiles. The species showed the presence of inulin, proteins, fats, oil and starch. All members of the genus *Atriplex*, *C. album* and *C. botrys* (Chenopodiaceae) recorded alkaloids. Starch granules were generally circular, some species recorded irregular shaped granules and only starch from *Chenopodium hybridum* showed hilium striations.

Cluster analysis: The cluster analysis generated four clusters with the most distant cluster comprising of *Chenopodium botrys* and *Chenopodium polyspermum*.

Principal components analysis: The principal components analysis generated three groups showing the influences of the ergastic substances in separating the population (Fig. 1). The grouping did not follow traditional (morphological) demarcation lines. The first two components recorded very strong influence on the taxa, accounting for 90.89% of the total rotated cumulative percentage (Eigenvalue) of all the components (Table 3).

Table 2: Ergastic profile of some Amaranthaceae and Chenopodiaceae seeds

Taxons	Life form	AKD	Fats and oil	Inulin	Protein	Starch				Size μm (a)	Size m (b)	Type
						Starch	CIR	IRG	HLM and STRS			
<i>Amaranthus albus</i>	H	-	+	+	+	+	+	-	-	0.8	0.8	2
<i>Amaranthus caudatus</i>	H	-	+	+	+	+	+	+	-	1.0	0.8	2
<i>Amaranthus retroflexus</i>	H	-	+	+	+	+	+	-	-	0.8	1.0	2
<i>Celosia argentea</i>	H	-	+	+	+	+	+	+	-	2.0	2.0	1
<i>Atriplex sagittata</i>	H	+	+	+	+	+	+	+	-	4.4	1.0	1
<i>Atriplex prostrata</i>	H	+	+	+	+	+	+	+	-	3.7	3.7	1
<i>Atriplex sibirica</i>	H	+	+	+	+	+	+	-	-	0.7	0.7	2
<i>Atriplex tatarica</i>	H	+	+	+	+	+	+	-	-	0.8	0.8	2
<i>Chenopodium album</i>	H	+	+	+	+	+	+	+	-	4.0	1.0	1
<i>Chenopodium botrys</i>	H	+	+	+	+	+	-	+	-	5.4	1.3	1
<i>Chenopodium hybridum</i>	H	-	+	+	+	+	+	-	+	2.0	1.7	1
<i>Chenopodium polyspermum</i>	H	-	+	+	+	+	-	+	-	0.8	1.0	2
<i>Suaeda maritima</i>	H	-	+	+	+	+	+	+	-	4.4	1.3	1

AKD: Alkaloid, CIR: Circular, IRG: Irregular, HLM and STRS: Hilium and striations, -: Absence, +: Presence and H: Herb

Table 3: Component score coefficient matrix for 13 Amaranthaceae-Chenopodiaceae species

Variables	Principal component	
	1	2
<i>Amaranthus albus</i>	0.130*	-0.047
<i>Amaranthus caudatus</i>	0.114*	0.020
<i>Amaranthus retroflexus</i>	0.130*	-0.047
<i>Celosia argentea</i>	0.015	0.221*
<i>Atriplex sagittata</i>	0.120*	-0.015
<i>Atriplex prostrata</i>	0.084	0.093
<i>Atriplex sibirica</i>	0.131*	-0.053
<i>Atriplex tatarica</i>	0.130*	-0.048
<i>Chenopodium album</i>	0.010	0.231*
<i>Chenopodium botrys</i>	-0.078	0.276*
<i>Chenopodium hybridum</i>	0.116*	-0.067
<i>Chenopodium polyspermum</i>	-0.082	0.260*
<i>Suaeda maritima</i>	0.062	0.151*

*Members of the group (principal components 1 and 2) with significant strength for clumping observed

DISCUSSION

Systematics: The first publication on the family Amaranthaceae was by De Jussieu (1789) and the family Chenopodiaceae was published by Htienne Pierre Ventenat in 1789-99. Several works have discussed the closeness of the families Amaranthaceae and Chenopodiaceae, in some of such studies, as in the 2003 APG II system; the Amaranthaceae was considered as a sister-group of Chenopodiaceae and both families were placed in the order Caryophyllales (Borsch *et al.*, 2001; Angiosperm Phylogeny Group, 2003). Consequently, the new, broadly defined Amaranthaceae is strongly supported by morphological phylogenetic analyses as a monophyletic group (Judd *et al.*, 2008).

Despite the interest in the taxonomy and classification of the family Amaranthaceae, there is still need to study its phylogeny. The present study shows that a considerable level of similarity exists amongst the taxa (Fig. 1 and 2). The Amaranthaceae genus; *Amaranthus* and the Chenopodiaceae genus; *Atriplex* alongside *C. hybridum* correlated strongly with the first component of the PCA. However, *Chenopodium botrys* and *Chenopodium polyspermum* were most strongly correlated with the second component and form the more divergence group, constituting an entirely Chenopodiaceae cluster. A third and middle group spreads between these extreme groups and shares members from both families; albeit a single Amaranthaceae species among three Chenopodiaceae species. However, with the cluster analysis (four clusters), the picture is rather that of a closely-knit Amaranthaceae and a diverse Chenopodiaceae group. The Amaranthaceae members clustered as one together with two *Atriplex* species and the three other clusters comprise members of the Chenopodiaceae at increasing distance with the species *Chenopodium botrys* and *Chenopodium polyspermum* most distant. One can suppose the Chenopodiaceae are more divergent from a common centre and responsible for the proposed separation of the families.

The similarity in ergastic substances in both families may indicate identical biochemical pathways in the families. This semblance in ergastic profiles underlines the closeness between both families and the Amaranthaceae-Chenopodiaceae complex can be termed a close-chemotaxonomic

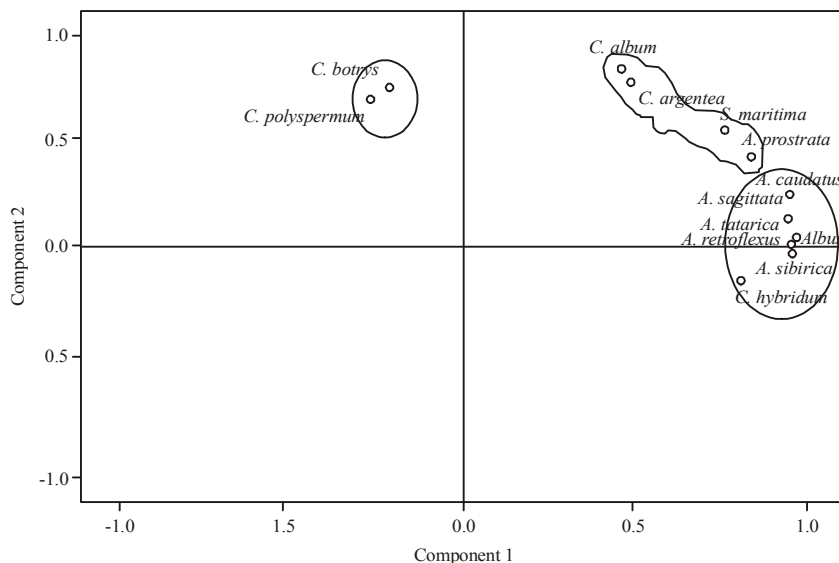


Fig. 1: Amaranthaceae-Chenopodiaceae taxa rotation in space based on seed ergastic substance profile (component score coefficient matrix normalization at $\alpha = 0.1$)

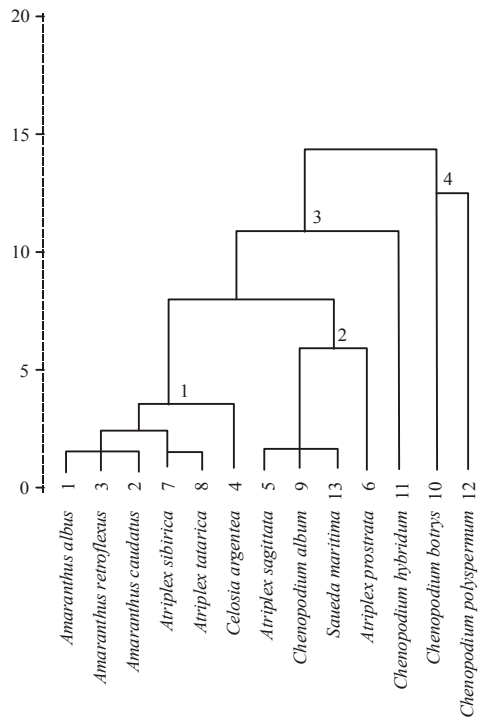


Fig. 2: Amaranthaceae-Chenopodiaceae taxa clustered into 4 clusters 1-4 (squared euclidean distance). All Amaranthaceae clustered in one with 2 Chenopodiaceae at (1) short distance, other clusters have only Chenopodiaceae at (2, 3, 4) longer distance)

group. Previously, Erdtman (1960) showed the families share a number of important but mostly derived features such as the prevalence of pollen grains, making them a stenopalynologic group and thus share a similar route of evolution.

Evidences from emerging molecular studies show the erstwhile phylogenetic constructions from morphological and anatomical data have not often reflected the relationship between the families. The former Amaranthaceae is segregated into two sub-families; Amaranthoideae and Gomphrenoideae. Some genera of the sub-family Gomphrenoideae and Amaranthoideae are polyphyletic, hence, a clearer circumscription of the group following some degree of taxonomical reviews are required (Del-Pino *et al.*, 2009). Whilst, there is similarity in the ergastic substance profiles in the present study, a point of divergence between both families emerges following the occurrence of alkaloids. This occurrence separates the Chenopodiaceae (with all species of the genus *Atriplex* and two of the *Chenopodium* recording alkaloids) from the family Amaranthaceae. However, the seed lot size for the study does not allow for a family-wide delimitation claim based on such occurrence. Nevertheless, where such trend (absence of alkaloid) is consistent across the family Amaranthaceae or in the genus *Amaranthus*; a chemotaxonomic point of divergence may have arisen for both families, although the possibility of such trend is not uncommon among these families. Earlier, betalains, betacyanins (amaranthine and isoamaranthine) have been isolated from species of *Amaranthus* (Amaranthaceae) and not from Chenopodiaceae (Francis, 1999; Raven *et al.*, 2004; Gandia-Herrero *et al.*, 2005; Bartoloni *et al.*, 2013) which affirms that some points of chemotaxonomic delimitation may exist between both families.

Several studies have considered and support the position that the Amaranthaceae-Chenopodiaceae alliance constitutes a monophyletic group together with the Achatocarpaceae and that Chenopodiaceae should be merged with Amaranthaceae (Rodman, 1994; Cuenoud *et al.*, 2002; Kadereit *et al.*, 2003; Pratt, 2003). Closer examinations of both existing and emerging evidences are required to generate a clearer circumscription of the Amaranthaceae-Chenopodiaceae complex.

Ecology and cultivation: Phytochemicals are integral to the ecological adaptations and successful interactions of plants. Thus ergastic substances profiles of plants species are valid tools for assessing the ecological disposition, colonization and distributions. Similar ecological niches and distribution patterns are often shared by plants with identical ergastic substances profiles (Ahmad, 1986; Nishida, 2002; Agrawal and Fishbein, 2006).

The identical ergastic substances profile for species from both families particularly the *Amaranthus* and *Chenopodium* reflects the distribution pattern for the genera. The survival in similar habitats, sea level, valley and sub-tropical systems of this group of plants and pseudo-grains can be linked to their phytochemical composition (Valencia-Chamorro, 2003; NRC., 2005).

Whether in pre-Columbian times; Quinoa (Incans) and Amaranth (Mayans and Aztecs) or in present day, the ergastic substance profiles of key species of both families as with the colonization of identical ecological settings and have enjoyed cultivation and emerged as prime crops in various human settlements in the different eco-geographical zones they have survived or are introduced (Valencia-Chamorro, 2003).

Genetic diversity: The Amaranthaceae-Chenopodiaceae complex comprises of an array of plants across several ecological zones with identical ergastic substances profiles. Nevertheless, the presence of alkaloids for example, in only *Chenopodium* species, the diverse ecological setting within which these taxa thrives (Valencia-Chamorro, 2003); the various forms of adaptations and uses (Grubben and Denton, 2004), are bound to generate a diversity of forms.

The genus *Amaranthus* for example, have a multitude of forms (varieties and species) that cross easily with one another and been wind-pollinated, an array of hybrids and subspecies are generated. With such a wide assortment of morphological and thus genetic diversity, species classification is hard to ascertain due to hybridization hence, the genus have been regarded as a “difficult” genus by systematists (Costea and DeMason, 2001; Juan *et al.*, 2007). The genus *Atriplex* are polyploid plants with high hybridization among perennial forms and a complex evolution (Sampson and Byrne, 2012). The result is a versatile group of plants with unique adaptation for marginal and extreme ecological settings. The genus *Chenopodium* are most likely allotetraploid (Maughan *et al.*, 2004), forming a diverse group of plants following years of cultivation across varied ecological settings and hybridization between the cultivated and wild species. Diverse morphological features characterize the genus and *Chenopodium quinoa* in particular is bifurcated into coastal and highland ecotypes across the Andean regions (Fuentes *et al.*, 2009).

The degree of genetic variation, ecological adaptation, high level of hybridization, various cultivation and uses of the Amaranthaceae-Chenopodiaceae plants offer a considerable diversity of genetic forms for improvements and developmental programmes for the species and related crops.

Ancient crops, future foods: Species of *Amaranthus* and *Chenopodium* flourished for over 3000-7000 years amongst the Incans, Aztecs and Mayan civilizations together with other important

crops emerging as some of the most important crops in the Americas before the advent of the Spanish colonialists. The Aztecs and Mayans considered amaranth a “superfood” cultivated with other staples like maize and beans. The ancient Incans regarded Quinoa as “mother of cereals” cropped alongside beans and corn on the Peruvian-Bolivian alpine plains (Popenoe, 1989; Lehmann, 1994; Keen and Haynes, 2004; Keppel, 2012).

The cultivation of these species and their relatives evolved into a highly developed agricultural system ultimately relegated and destroyed by the Spanish invaders. Nonetheless, several *Amaranthus* and *Chenopodium* species spread throughout the world as important grain and/or vegetable crop during the 17, 18 and 19th century, reaching Indo-China and Africa continents, following the initial introduction of Amaranth for example as an ornamental plant in the 16th century. The upbeat on *Amaranthus* and *Chenopodium* following the awareness resurgence on the species probably started with sudden increase in the knowledge on the high nutritional value of quinoa and amaranth at the beginning of the 20th century as well as the food security concerns driven by the hidden harvest programme of the Food and Agricultural Organization (FAO) (Cauda *et al.*, 2013). Amaranth and Quinoa presently enjoys sizeable cultivation in some parts of Africa, China, Czech Republic, India, Russia, South America and the USA (Van Rensburg *et al.*, 2007; James, 2009).

Amaranthus and *Chenopodium* species have been identified for their nutritional potentials with such species as *Amaranthus caudatus*, *Amaranthus retroflexus*, *Chenopodium quinoa* and *Chenopodium alba* (Cole, 1979; Kelly and Martin, 1983). Amaranth grains have shown considerable protein content (12-17%) with high lysine level, an amino acid often found in low quantities in other grain crops. Similarly, the grain also showed high fibre and low saturated fats content. These factors have contributed to the high degree of patronage of Amaranth grain by the health food market. It is an exceptionally rich source of calcium, iron and vitamin C, a very rich source of potassium, vitamin A and riboflavin, rich source of niacin and an above-average source of protein. Quinoa in comparison is very high in protein (14% by mass) and a source of complete protein. It has excellent level of dietary fibre, iron, magnesium, phosphorus and calcium and is gluten-free (USDA., 2013). The interest of the food and related industry on the species extends to the presence of betalains in Amaranth grains. Identified as antioxidants and betanin as natural food dyes, similar to the 'Hopi Red Dye' amaranth rich in betacyanins used by Hopi Amerindians as the source of a deep red dye; the prospective use of these antioxidants and dyes in food and health products is promising (Goncalves *et al.*, 2013).

Currently, over 40 grain amaranth products exist in the market, a good picture about the level of utilization of grain amaranth by humans and has earned it "the crop of the future" status (Marx, 1977). NASA considers the *Chenopodium*-Quinoa as “superfood” for its long-duration human occupied spaceflight programme-Controlled Ecological Life Support System (Schlick and Bubenheim, 1993; Cauda *et al.*, 2013). A number of Amaranthaceae and Chenopodiaceae species, some of which are analysed in the present study; have been identified as multipurpose agro-industrial crops by FAO and documented in ancient records for several uses amongst present day uses as cereal (Bermejo and Leon, 1995). The properties and importance of these pseudo-cereals to the global food economy is of major concern, so much that the United Nations General Assembly declared 2013 as the "International Year of Quinoa" in recognition of ancestral practices of the Andean people. The purpose is to draw the world's attention to the role that such pseudo-cereals will play in the drive towards attaining food security, nutrition and poverty eradication and thus achieving the Millennium Development Goals (FAO., 2013).

The genus *Atriplex* saltbush is cosmopolitan in distribution (McArthur and Sanderson, 1984). Though a number of *Atriplex* are halophytes, some like the shrubby saltbush species are important plants for livestock, wildlife and for stabilization of drastically disturbed land in arid and semiarid regions (Goodall, 1982). One area of great possibility is the use of the drought and validity of members of the sister genus *Atriplex* for resistance in crops in future improvement programmes.

Comparing chemo-constituents with grain cereals: Taxa of the Chenopodiaceae and Amaranthaceae share identical ergastic profiles ranging from important nutritional biomolecules to anti-nutritional factors. The study taxa recorded the anti-nutritional compounds alkaloids (only Chenopodiaceae) and inulin (known to be non bio-available to humans). Quinoa is reported to contain anti-nutritional factors like saponins, phytic acid, tannins and trypsin inhibitors (Chauhan *et al.*, 1992; Improta and Kellems, 2001). Similarly, saponins, phytic acid, phenolics, phytohemagglutinins, tannins, polyphenols, protease inhibitors, oxalates and nitrates have been reported for grain amaranth (Institute for the Development of Amaranth Products Inc., 1992).

Protein and fats were present in all the taxa studied. Protein (mostly albumins and globulins) content of Quinoa and Amaranth seeds is 8-22%, higher and the fat content 17-70% higher on average than that in common cereals (Valencia-Chamorro, 2003). *Amaranthus* and *Chenopodium* cereals amongst other properties are gluten-free (low or no prolamin). Quinoa and amaranth grains boast of complete essential amino acid profiles, although amaranth grains lack the amino acids leucine and threonine (Garcia *et al.*, 1972; Bressani *et al.*, 1989). The amino acids lysine, methionine, histidine and isoleucine limited in grain cereals are present in quinoa and amaranth grains (Koziol, 1992; Vilche *et al.*, 2003). The studied taxa recorded starch and reports show the quinoa and amaranth grains have comparable carbohydrate content with grain cereals (Valencia-Chamorro, 2003; USDA., 2013).

Starch characteristics: The genera *Amaranthus*, *Chenopodium*, *Atriplex* and *Seaua* offer alternatives to present sources for industrial starch and carbohydrate diet. The *Chenopodium* species profile suggests the genera present a considerable amount of seed starch to qualify for consideration for food as well as industrial uses. *Celosia argentea* and the Amaranth species are known vegetables and like the *Chenopodium* species, *Amaranthus* species have been employed as grains over a long time and the present profile suggest this position is valid.

In the present study, the starch grains were generally circular, devoid of hilum and striations, with a few irregular shaped granules. The granule size ranged 0.7-5.4 μm (Table 2). One major attribute of starch from these genera, particularly, *Chenopodium* and *Amaranthus* are the small granule sized of less than 1 μm (Caussette *et al.*, 1997). The diameter of quinoa and amaranth starch granules is smaller than reported for maize (1-23 μm), wheat (2-40 μm), cassava (3-28 μm) and potato (10-70 μm). Small-granule starches exhibit a higher gelatinization temperature; for quinoa, the temperature range is 57-64°C, for amaranth grain - 68.3°C (Valencia-Chamorro, 2003; Resio *et al.*, 2000; Comai *et al.*, 2007).

Food application of Amaranthaceae-Chenopodiaceae starch: Application of starch in food depends mainly on the functional characteristics of the starch granules which ultimately determines the product performance. This is critical to the food industry and it reflects how industry practitioners view starch. The specific application will thus depend on a set of established functional physico-chemical properties. The most basic physical property of starch is the granule size. Amaranthaceae and Chenopodiaceae have small granule-sized starch which implies that the

starch has low amylase content in the amylose/amylopectin ratio. This ratio determines the viscosity, shear resistance, gelatinization, textures, solubility, tackiness, gel stability, cold swelling and retrogradation functions of starch. Larger granule-sized starches tend to have higher amylose content than small granule-sized starches such as rice starch granules with little or no amylase content (Satin, 2000). This attribute offers both food and industrial potentials for Amaranthaceae-Chenopodiaceae starch.

Flour made from Amaranth seed has been proposed as food additives to wheat flour (Ayo, 2001), where the anti-nutritional content is reduced or eliminated; *Amaranthus* and *Chenopodium* starch will make good additives as thickeners, absorbents and hypoallergenic. These starches can find uses in the broader spectrum of foods due to insulin and high protein contents, making a better substitute for low glycemic load foods for diabetics (Gargari *et al.*, 2013). The applications could extend to meat binding, canning, cereals, snacks, bakery, batters and breading, frozen foods, flavours and beverage clouds, confectionery, dairy products, dressings, soups and sauces (Satin, 2000; Bender, 2005).

Non-food potential for Amaranthaceae-Chenopodiaceae starch: Industrial applications of starch are an ever-growing one encompassing all ranges of starches. However, small granule-sized starches have peculiar relevance in the pharmaceutical, skin cosmetics, laundry and printing sector of the industry, requiring a great deal of value-added applications before specific features with particular functional characteristics are attained (Satin, 2000). Amaranthaceae and Chenopodiaceae starch will help augment the increasing demand for fine granule starch in various areas. The fineness of the granules predisposes such starch to improve recycling process, saving pristine resources and reducing biodiversity loss.

Biodegradable plastics: There has been an increase in the demand for starch use in the production of biodegradable plastics. Biodegradable plastics are probably one of the most innovative materials being developed in the packaging industry at present and its usage and volume proposes to increase drastically (Mohanty *et al.*, 2000). The small-sized granule starch characteristics of the Amaranthaceae-Chenopodiaceae species will influence their applications, particularly in the manufacture of biodegradable plastics. The attention towards biodegradable plastics for natural fibre formulations and related products as new and replacement materials is drawn from the increased awareness of the harm posed by non-biodegradable plastics. This will eventually upstage the tonnage of starch required to meet the demand for starch in the adhesives, explosives industry, paper industry, construction industry, metals industry, textile industry, cosmetic industry, pharmaceutical industry, mining industry and now biodegradable plastics targeted areas of the industry (Berkesch, 2005; Sriroth and Sangseethong, 2006).

CONCLUSION

The similarity in ergastic substances profile between the Amaranthaceae and Chenopodiaceae families may support the demand to merge both families as one monophyletic group and hence can be considered a mono-paraphyletic group. However, the present study and earlier reports reveal that certain ergastic substances such as alkaloids (Chenopodiaceae) and betalains (Amaranthaceae) are restricted to one family. Such trends if fully established, constitutes chemotaxonomic as well as numerous prospective food and industrial applications for the taxa. With quinoa and amaranth grains gaining respectable global attention and the myriad of vegetable crops from these families,

the present study shows, there is a sizeable genetic resource for improvement efforts targeting such key as well as evolving Amaranthaceae and Chenopodiaceae species. Such improvement efforts can increase seed size and yield, flour quality, reduce anti-nutritional content, in these pseudo-grains as well as improved resistance to drought and salinity and thus extends cultivation range of these grains to marginal lands and arid regions. The small-sized starch granules, high lipids, protein and inulin content of Amaranthaceae-Chenopodiaceae grains endears them for several food and health applications, including improved glycemic rating in diabetics diets. In addition, Amaranthaceae-Chenopodiaceae starches can become a good complement for meeting the ever-increasing global demand for starch in the industry as well as contribute immensely to the drive for biodegradable plastics as an environmentally friendly alternative to petrochemicals.

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REFERENCES

- Agrawal, A.A. and M. Fishbein, 2006. Plant defense syndromes. *Ecology*, 87: S132-S149.
- Ahmad, S., 1986. Enzymatic adaptations of herbivorous insects and mites to phytochemicals. *J. Chem. Ecol.*, 12: 533-560.
- Akhani, H., G. Edwards and E.H. Roalson, 2007. Diversification of the old world salsoleae s.l. (Chenopodiaceae): Molecular phylogenetic analysis of nuclear and chloroplast data sets and a revised classification. *Int. J. Plant Sci.*, 168: 931-956.
- Angiosperm Phylogeny Group, 2003. An update of the angiosperm phylogeny group classification for the orders and families of flowering plants: APG II. *Bot. J. Linn. Soc.*, 141: 399-436.
- Asolkar, L.V., K.K. Kakkar and O.J. Chakre, 1992. Second Supplement to Glossary of Indian Medicinal Plants with Active Principles. Publications and Information Directorate, CSIR, New Delhi, India, ISBN-13: 9788172360481, Pages: 414.
- Ayo, J.A., 2001. The effect of amaranth grain flour on the quality of bread. *Int. J. Food Properties*, 4: 341-351.
- Bartoloni, F.H., L.C.P. Goncalves, A.C.B. Rodrigues, F.A. Dorr, E. Pinto and E.L. Bastos, 2013. Photophysics and hydrolytic stability of betalains in aqueous trifluoroethanol. *Monatshefte fur Chemie-Chemical Monthly*, 144: 567-571.
- Bender, D.A., 2005. Starch, pregelatinized. *A Dictionary of Food and Nutrition*. <http://www.encyclopedia.com/doc/1O39-starchpregelatinized.html>.
- Berkesch, S., 2005. Biodegradable polymers: A rebirth of plastic. Michigan State University, Michigan.
- Bermejo, J.E.H. and J. Leon, 1995. Neglected Crops: 1492 from A Different Perspective (FAO Plant Production and Protection Series). FAO, Rome, ISBN-13: 978-9251032176, Pages: 365.
- Bojian, B., E. Steven, S. Clemants and T. Borsch, 2003. Amaranthaceae. *Flora China*, 9: 415-429.
- Borsch, T., S. Clemants and S. Mosyakin, 2001. Symposium: Biology of the amaranthaceae-chenopodiaceae alliance. *J. Tor. Bot. Soc.*, 128: 234-235.
- Bressani, R., L.G. Elias and A. Garcia-Soto, 1989. Limiting amino acids in raw and processed amaranth grain protein from biological tests. *Plant Foods Hum. Nutr.*, 39: 223-234.
- Cauda, C., C. Micheletti, B. Minerdo, C. Scaffidi and E. Signoroni, 2013. Quinoa in the Kitchen. In: *Quinoa Cultivation and Faqs*, Food and Agriculture Organization, Slow Food Editore, Rome, pp: 12-31.

- Caussette, M., J.L. Kershaw and D.R. Shelton, 1997. Survey of enzyme activities in desaponified quinoa *Chenopodium quinoa* Willd. *Food Chem.*, 60: 587-592.
- Chauhan, G.S., N.A.M. Eskin and R. Tkachuk, 1992. Nutrients and anti-nutrients in quinoa seed. *Cereal Chem.*, 69: 85-88.
- Cole, J.N., 1979. *Amaranth: From the Past, for the Future*. Rodale Press, Emmaus, PA., ISBN: 9780878572403, Pages: 311.
- Comai, S., A. Bertazzo, L. Bailoni, M. Zancato, C.V. Costa and G. Allegri, 2007. The content of proteic and nonproteic (free and protein-bound) tryptophan in quinoa and cereal flours. *Food Chem.*, 100: 1350-1355.
- Conrad, O.A. and M. Idu, 2013. Implications of seed ergastic substance-based diversity in some polygonaceae taxa. *Acad. J. Agric. Res.*, 1: 180-186.
- Costea, M. and D.A. DeMason, 2001. Stem morphology and anatomy in *Amaranthus* L. (*Amaranthaceae*): Taxonomic significance. *J. Torrey Bot. Soc.*, 128: 254-281.
- Cuenoud, P., V. Savolainen, L.W. Chatrou, M. Powell, R.J. Grayer and M.W. Chase, 2002. Molecular phylogenetics of caryophyllales based on nuclear 18S rDNA and plastid *rbcL*, *atpB* and *matK* DNA sequences. *Am. J. Bot.*, 89: 132-144.
- De Jussieu, A.L., 1789. *Genera Plantarum Secundum Ordines Naturales Disposita, Juxta Methodum in Horto Regio Parisiensi Exaratam, Anno 1774* (Google eBo). Herissant, Paris, Pages: 498.
- Del-Pino, I.S., T. Borsch and T.J. Motley, 2009. *trnL-F* and *rpl16* sequence data and dense taxon sampling reveal monophyly of unilocular anthered Gomphrenoideae (*Amaranthaceae*) and an improved picture of their internal relationships. *Syst. Bot.*, 34: 57-67.
- Erdtman, G., 1960. The acetolysis method: A revised description. *Svenok. Bot. Tidskr.*, 54: 561-564.
- FAO., 2013. *International year of quinoa*. Food and Agriculture Organization of the United Nations, Rome.
- Francis, F.J., 1999. *Colorants*. Egan Press, St. Paul, MN.
- Fuentes, F.F., E.A. Martinez, P.V. Hinrichsen, E.N. Jellen and P.J. Maughan, 2009. Assessment of genetic diversity patterns in chilean quinoa (*Chenopodium quinoa* Willd.) germplasm using multiplex fluorescent microsatellite markers. *Conserv. Genet.*, 10: 369-377.
- Gandia-Herrero, F., F. Garcia-Carmona and J. Escribano, 2005. Botany: Floral fluorescence effect. *Nature*, 437: 334-334.
- Garcia, W.J., H.W. Gardner, J.F. Cavins, A.C. Stringfellow, C.W. Blessin and G.E. Inglett, 1972. Composition of air-classified defatted corn and wheat-germ flours. *Cereal Chem.*, 49: 499-507.
- Gargari, B.P., P. Dehghan, A. Aliasgharzadeh and M.A. Jafar-Abadi, 2013. Effects of high performance inulin supplementation on glycemic control and antioxidant status in women with type 2 diabetes. *Diabetes Metab. J.*, 37: 140-148.
- Gill, L.S., H.G.K. Nyawuame, M.I. Aibangbee and D.A. Agho, 1991. Nature of ergastic substances in some Mediterranean angiospermous seeds-VI. *Fed. Rep.*, 102: 613-628.
- Goncalves, L.C.P., B.M. Di Genova, F.A. Dorr, E. Pinto and E.L. Bastos, 2013. Effect of dielectric microwave heating on the color and antiradical capacity of betanin. *J. Food Eng.*, 118: 49-55.
- Goodall, D.W., 1982. Chenopod shrubland communities: A global perspective. *Int. J. Ecol. Environ. Sci.*, 9: 85-99.
- Grubben, G.J.H. and O.A. Denton, 2004. *Plant Resources of Tropical Africa 2. Vegetables*. PROTA Foundation/Backhuys Publishers/CTA, Wageningen, The Netherlands, ISBN-13: 9057821486, Pages: 667.

- Idu, M. and N.I. Onyibe, 2011. Nature of ergastic substances in some Poaceae seeds. *Afr. J. Biotechnol.*, 10: 9800-9803.
- Improta, F. and R.O. Kellems, 2001. Comparison of raw, washed and polished Quinoa (*Chenopodium quinoa* Willd.) to wheat, sorghum or maize based diets on growth and survival of broiler chicks. *Livestock Res. Rural Dev.*, Vol. 13, Institute for the Development of Amaranth Products Inc., 1992. Amaranth and the currents of history amaranth and the current of history. *Legacy Official New Amaranth Inst.*, 5: 6-9.
- Jain, S.C., R. Jain and R. Singh, 2009. Ethnobotanical survey of Sariska and Siliserh regions from Alwar district of Rajasthan, India. *Ethnobotanical Leaflets*, 13: 171-188.
- James, L.E.A., 2009. Quinoa (*Chenopodium quinoa* Willd.): Composition, chemistry, nutritional and functional properties. *Adv. Food Nutr. Res.*, 58: 1-31.
- Juan, R., J. Pastor, M. Alaiz and J. Vioque, 2007. Electrophoretic characterization of Amaranthus L. seed proteins and its systematic implication. *Bot. J. Linn. Soc.*, 155: 57-63.
- Judd, W.S., C.S. Campbell, E.A. Kellog, P.F. Stevens and M.J. Donoghue, 2008. *Plant Systematics: A Phylogenetic Approach*. Sinauer Associates Inc., Sunderland, MA.
- Kadereit, G., T. Borsch, K. Weising and H. Freitag, 2003. Phylogeny of amaranthaceae and chenopodiaceae and the evolution of C4 photosynthesis. *Int. J. Plant Sci.*, 164: 959-986.
- Kadereit, G. and H. Freitag, 2011. Molecular phylogeny of Camphorosmeae (Camphorosmoideae, Chenopodiaceae): Implications for biogeography, evolution of C₄ photosynthesis and taxonomy. *Taxon*, 60: 51-78.
- Katewa, S.S., B.L. Chaudhary, A. Jain and P.K. Galav, 2003. Traditional uses of plant biodiversity from Aravalli hills of Rajasthan. *Indian J. Trad. Knowl.*, 2: 27-39.
- Keen, B. and S.K. Haynes, 2004. *A History of Latin America: Volume 1: Ancient America to 1910*. 7th Edn., Wadsworth Publishing, USA., ISBN-13: 978-0618318520, Pages: 266.
- Kelly, G.O. and L.P. Martin, 1983. Amaranth: Grain and vegetable types. *Echo Technical Note*, pp: 1-14. <http://static1.squarespace.com/static/53596c97e4b095832d6a11aa/t/5507df8fe4b0a98d7320e087/1426579343616/Amaranth+Grain+%26+Vegetable+Types.pdf>.
- Keppel, S., 2012. The Quinoa boom is a lesson in the global economy. ABC Univision, March 4, 2012.
- Koziol, M.J., 1992. Chemical composition and nutritional evaluation of quinoa (*Chenopodium quinoa* Willd.). *J. Food Compos. Anal.*, 5: 35-68.
- Lehmann, J.W., 1994. Amaranth: Commercialization and Industrialization. In: *Amaranth Biology, Chemistry and Technology*, Paredes-Lopez, O. (Ed.). CRC Press, Boca Raton FL., pp: 207-217.
- Li, W.Y., S.H. Yan, Y.P. Yin, L.I. Yong and T.B. Liang *et al.*, 2008. Comparison of starch granule size distribution between hard and soft wheat cultivars in eastern China. *Agric. Sci. China*, 7: 907-914.
- Liu-Qing, Y., F. Yoshiharu, Z. Yong-Jun, Z. Jian-Ping, L. Yong-Liang and X. Song-Nan, 2008. Comparison of allelopathy potential between an exotic invasive weed *Alternanthera philoxeroides* and a local weed *A. sessilis*. *Proceedings of the 5th World Congress on Allelopathy Growing Awareness of the Role of Allelopathy in Ecological, Agricultural and Environmental Processes*, September 21-25, 2008, New York.
- Marx, J.L., 1977. Speaking of science: Amaranth: A comeback for the food of the Aztecs? *Science*, 198: 40-40.
- Maughan, P.J., A. Bonifacio, E.N. Jellen, M.R. Stevens and C.E. Coleman *et al.*, 2004. A genetic linkage map of quinoa (*Chenopodium quinoa*) based on AFLP, RAPD and SSR markers. *Theor. Applied Genet.*, 109: 1188-1195.

- McArthur, E.D. and S.C. Sanderson, 1984. Distribution, systematics and evolution of Chenopodiaceae: An overview. Proceedings of the Symposium on the Biology of Atriplex and Related Chenopods, May 4-6, 1984, Ogden, pp: 14-23.
- Mlakar, S.G., M. Jakop, M. Bavec and F. Bavec, 2012. Allelopathic effects of *Amaranthus retroflexus* and *Amaranthus cruentus* extracts on germination of garden cress. *Afr. J. Agric. Res.*, 7: 1492-1497.
- Mohanty, A.K., M. Misra and G. Hinrichsen, 2000. Biofibres, biodegradable polymers and biocomposites: An overview. *Macromol. Mater. Eng.*, 276-277: 1-24.
- Muller, K. and T. Borsch, 2005. Phylogenetics of Amaranthaceae based on matK/trnK sequence data: Evidence from parsimony, likelihood and Bayesian analyses. *Ann. Missouri Bot. Garden*, 92: 66-102.
- NRC., 2005. The Lost Crops of the Incas: Little-Known Plants of the Andes with Promise for Worldwide Cultivation. Books for Business, USA., ISBN-13: 978-0894991974, Pages: 436.
- Nishida, R., 2002. Sequestration of defensive substances from plants by Lepidoptera. *Ann. Rev. Entomol.*, 47: 57-92.
- Parveen, S.R. and A. Kumar, 2007. Traditional use of medicinal plants among the rural communities of Churu District in the Thar Desert, India. *J. Ethnopharmacol.*, 113: 387-399.
- Popenoe, H., 1989. Lost Crops of the Incas: Little-Known Plants of the Andes with Promise for Worldwide Cultivation. National Academy Press, Washington, DC.
- Pratt, D.B., 2003. Phylogeny and Morphological Evolution of Chenopodiaceae-Amaranthaceae Alliance. Iowa State University, Iowa, Pages: 232.
- Raven, P.H., F.E. Ray and S.E. Eichhorn, 2004. Biology of Plants. WH Freeman and Co., New York.
- Resio, A.C., M.P. Tolaba and C. Suarez, 2000. Some physical and thermal characteristics of amaranth starch. *Food Sci. Technol. Int.*, 6: 371-378.
- Rodman, J.E., 1994. Cladistic and Phenetic Studies. In: Caryophyllales: Evolution and Systematics, Behnke, H.D. and T.J. Mabry (Eds.). Springer-Verlag, Berlin, pp: 279-301.
- Sampson, J.F. and M. Byrne, 2012. Genetic diversity and multiple origins of polyploid *Atriplex nummularia* Lindl. (Chenopodiaceae). *Biol. J. Linnean Soc.*, 105: 218-230.
- Satin, M., 2000. Functional properties of starches. FAO Agricultural and Food Engineering Technologies Service. <http://www.fao.org/ag/magazine/pdf/starches.pdf>.
- Schlick, G. and D.L. Bubenheim, 1993. Quinoa: An emerging new crop with potential for CELSS. NASA Technical Paper 3422, November 1993.
- Sriroth, K. and K. Sangseethong, 2006. Biodegradable plastics from cassava starch. *Acta Hort.*, 703: 145-152.
- USDA., 2013. National nutrient database for standard reference release 26. U.S. Department of Agriculture, Agricultural Research Service.
- Valencia-Chamorro, S.A., 2003. Quinoa. In: Encyclopedia of Food Science and Nutrition, Caballero, B. (Ed.). Vol. 8. Academic Press, Amsterdam, pp: 4895-4902.
- Van Rensburg, W.S.J., W. van Averbeke, R. Slabbert, M. Faber and P. van Jaarsveld *et al.*, 2007. African leafy vegetables in South Africa. *Water SA*, 33: 317-326.
- Vilche, C., M. Gely and E. Santalla, 2003. Physical properties of Quinoa seeds. *Biosyst. Eng.*, 86: 59-65.