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Review Article

Role of *Brassica juncea* (Indian mustard) and *Brassica carinata* (Ethiopian mustard) plants in phytoremediation and their interaction with a *Potyvirus*

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Abstract: *Brassica juncea* (Indian mustard) and *Brassica carinata* (Ethiopian mustard), members of family *Cruciferae* (*Brassicaceae*) are the most important edible mustard oilseed crops in genera *Brassica*. Indian mustard and Ethiopian mustard are an important edible oilseed crops in the world used to produce mustard oil. Its leaves are used in African cooking and all plant parts are used in the Indian cuisine, particularly in the mountain regions of Nepal and northern India. Both plants are used in phytoremediation of heavy metals, because of their nature of heavy metal accumalation. *Turnip mosaic virus* (TuMV) is the main viral pathogen infecting Indian mustard and plant. The focus of the present review is to study the details of phytoremediation capacity of both plants and threat of TuMV in cultivation of Indian mustard and Ethiopian mustard plants.

Key words: Indian mustard, Ethiopian mustard, Heavy metals, phytoremediation and *Turnip mosaic virus*

Introduction

Brassica is one of the genus in the *Brassicaceae* family. The plant species of the *Brassica* genus are informally known as cruciferous mustard or vegetables and cabbages. The Brassica is one of the significant plant genus as they are most important agricultural and horticultural crops. *Brassica* species and cultivars are used as foods that include cabbage, cauliflower, broccoli, turnip, rutabaga. Some seeds are used in the production of edible mustard oil. Brassica has numerous varities of cultivars and among them, there are about 25-30 wild species and hybrids that are under cultivation. But most of them are annuals or biennials, seasonal plants and some are small shrubs.

The most Brassicas are native to temperate regions of Asia, Western Europe, the Mediterranean and some wild species grow as weeds, especially in Australia, North America and South America. Parts of plant species of brassica are consuming as main food in all over the world. All the parts of some brassicas are produced for food, some for oil from their seeds (all mustard seeds plant), leaves and flowers are used from cabbage, cauliflower, broccoli. Different Brassica plant species and their common names are represented in Table 1.

Some *Brassica* plants have been shown much scientific interest because of their agricultural importance. Especially, six particular species (*Brassica carinata, Brassica juncea, Brassica napus, Brassica nigra, Brassica oleracea and Brassica rapa*) evolved by the combining of chromosomes from three earlier species, asdescribed by the Triangle of U theory (U, 1935) (Figure 1).

Table 1. Different *Brassica* plant species and their common names

Scientific Name	Common Name
Edible crops	
Brassica balearica	Mallorca cabbage
Brassica carinata	Ethiopian mustard
Brassica elongata	Elongated mustard
Brassica fruticulosa	Mediterranean cabbage
Brassica hilarionis	St Hilarion cabbage
Brassica juncea	Indian mustard, brown and leaf mustards
Brassica napus	Rapeseed, canola, rutabaga, Swedish turnip
Brassica narinosa	Broad beaked mustard
Brassica nigra	Black mustard
Brassica oleracea	Cabbage, broccoli, cauliflower and Brussels sprouts
Brassica perviridis	Mustard spinach
Brassica rapa	Chinese cabbage, turnip and rapini
Brassica rupestris	Brown mustard
Brassica septiceps	Seven top turnip
Brassica tournefortii	Asian mustard

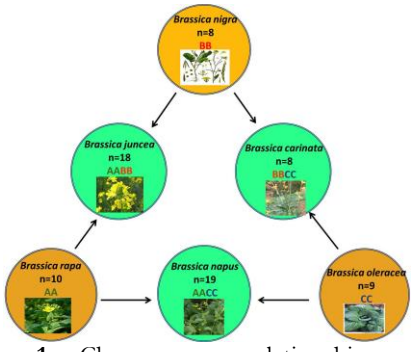

Figure 1. Chromosome relationships of six cultivated *Brassica* species as reported in U's triangle

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(U, 1935) and some other studies(Chang *et al.,* 2011). U's triangle provides the evolutionary relation between three cultivated primary species (*B. nigra, B. oleracea* and *B. rapa*) and other three amphiploid species (*B. carinata, B. juncea* and *B. napus*). Genome types of nuclear, numbers of chromosome, and mitotypes are shown in the figure.

However, these *Brassicas* are prone to numerous fungal, bacterial and viral diseases (Table 2). Various infections decrease the quality of the product which leads to huge loss of profit to brassica formers. Many viruses are known to infect *Brassicas* plants: namely, *Turnip mosaic potyvirus*, *Turnip crinkle carmovirus*, *Turnip yellow mosaic tymovirus, Beet western yellows luteovirus, Radish mosaic comovirus*, *Cucumber mosaic cucumovirus*, *Radish yellow edge alphacryptovirus*, *Cauliflower mosaic caulimovirus* and *Radish vein clearing potyvirus.*

Table 2. Different diseases and their causal agents of Brassica plants.

Disease	Causal Agent	Plant
Bacteria		
Black rot	Xanthomonas campestris	Cauliflower, Brussels sprouts
Soft rot	Erwinia and Pseudomonas species	Cauliflower and broccoli
Fungi		
Blackleg	*Leptosphaeria maculans*	Cauliflower
Clubroot	*Plasmodiophora brassicae*	Cauliflower, vegetable brassica
Damping off	*Fusarium or Pythium species*	Turnip, Chinese cabbage
Downy mildew	*Hyaloperonospora parasitica*	Cauliflower, Turnip and other Brassicas
Leaf spot/target spot	*Alternaria species*	Turnip, Chinese cabbage and
Powdery mildew	*Erysiphe cruciferarum*	Brussels sprouts, swedes and cabbages
Ring spot	*Mycosphaerella brassicicola*	Cauliflower and broccoli
White blister	*Albugo candida*	Broccoli and cauliflower
White leafspot	*Pseudocercosporella capsellae*	Chinese cabbage
White mould	Sclerotinia species	Cauliflower
Wirestem	Rhizoctonia solani	Cauliflower
Virus		
Beet western yellows virus	*Polerovirus*	Turnip and Radish
Cauliflower mosaic virus	*Caulimovirus*	Cauliflower, Turnip and other Brassicas
Cucumber mosaic virus	*Cucumovirus*	Turnip
Radish ilarvirus	*Ilarvirus*	Radish
Radish mosaic virus	*Comovirus*	Rape, mustards, cabbage and other cruciferous
Turnip crinkle virus	*Carmovirus*	*Brassica carnpestfis*
Turnip mosaic virus	*Potyvirus*	Cauliflower, Turnip and other *Brassicaceae*
Turnip yellow mosaic virus	*Tymovirus*	Cabbages, cauliflower and broccoli.

According to U's triangle *B. rapa* (Turnip) (2n=20), *B. nigra* (Black mustard) (2n=16), *B. oleracea* (Cabbage) (2n=18) and B. nigra (2n=16) are an ancient plant sps. Indian mustard (2n=36) was derived from the cross between Turnip and Black mustard. Ethiopian mustard (2n=34) was derived from the cross between Cabbage and Black mustard. Hybridization occurred at least a few thousand years ago because they were cultivated in India and Ethiopia at that time. (Alemayehu & Becker, 2002). The amphiploid mustard plant sps,. Indian mustard and Ethiopian mustard are an erect, branched, annual herbs and growing from 30 to 200 cm tall (Alemayehu & Becker, 2002).

Indian mustard is an important edible oilseed crop in the world used to produce mustard oil. It is grown throughout the South, East Asia, North America and Europe (Schippers, 2007). All plant parts of Indian mustard's are used in cooking of Indian cuisine, especially in some parts of Nepal and northern regions of India (Ghawi *et al.,* 2014, Grubben & Denton, 2004).

Ethiopian mustard likely originated in Ethiopia a few thousand years ago (Warwick *et al.,* 2006). In the last two decades, a considerable interest has been shown in the cultivation of Ethiopian mustard as an oilseed crop to produce the biofuels and some other significant uses (Babu *et al.,* 2013, Getinet *et al.,* 1996, Guerrero-Díaz *et al.,* 2013, Newson *et al.,* 2013, Warwick *et al.,* 2006).

This species has great potential in brassica genera as a commercial crop due to higher ability to compete with weeds, less crop destruction, great tolerance to drought and higher disease resistance than other brassicas (Marillia *et al.,* 2014). A few years ago jets were flown using biofuel produced from Ethiopian mustard in Western Canada (McMillan, 2012).

The *Brassica nigra* (black mustard) is an annual herbaceous plant, created by dispersion of the seeds, which are used as a species. Today it is less frequent than brown mustard, but it is still grown, especially in India, as a source of oil and ingredient garnishes. Their leaves are used in cooking.

It is an annual herb, erect, with a slightly pubescent stem and little branched, which can reach almost 250 cm in height. It presents alternate leaves; the lower ones are pinatifid, with a terminal lobe well pronounced as well as some laterals, and between 10 and 20 cm long, while the upper ones are sessile

and reduced. It has been reported recently that the mustard plant species has a great potential to accumulate high concentrations of elements, highly toxic traces and that it can be used for phytoremediation.

Brassicas applications in environments

The mustard plants have a significant and great tolerance to heavy metals and store these substances in their cells. There have been a large number of studies on tolerance to heavy metal and uptake in in these brassica plants (Ebbs *et al.,* 1997, Gisbert *et al.,* 2006, Irtelli & Navari-Izzo, 2008, Irtelli *et al.,* 2009, Quartacci *et al.,* 2009, Zhu *et al.,* 1999). They grow rapidly and produce a large amount of aerial and terrestrial biomass. Due to these characteristics, these species have been objective to evaluate their phytoremediation potential on several occasions (Ebbs *et al.,* 1997, Gisbert *et al.,* 2006, Irtelli & Navari-Izzo, 2008, Irtelli *et al.,* 2009, Marchiol *et al.,* 2004, Quartacci *et al.,* 2007, Quartacci *et al.,* 2009, Zhu *et al.,* 1999). Thus, they have been used for several times in phytoremediation.

Phytoremediation

Phytoremediation (phyto = plant and remediation = bad to correct), is a modern technology that exploits the ability of some plants to remove, absorb, accumulate, metabolize, volatilize or stabilize and concentrate pollutants(organic and inorganic) that are present in soil, sludge, industrial streams and sediments.

These compounds represent a threat to living beings, so a series of methods have been developed to amend the impact caused. Conventional methods are usually expensive and can irreversibly affect the properties of soil, water and the living beings that inhabit them (Padmavathiamma & Li, 2007). The increase in costs and the limited effectiveness of physicochemical treatments have stimulated the development of new technologies. Therefore, phytoremediation represents a sustainable and low-cost alternative for the rehabilitation of environments affected by natural and anthropogenic pollutants (Reichenauer & Germida, 2008, Singh & Jain, 2003). The mechanisms of phytoremediation include phytoextraction, phytodegradation and phytostabilization.

A wide diversity of plant species are used for this purpose. Some of them, due to their greater capacity to accumulate heavy metals can be called hyperaccumulators. By definition, these plants must accumulate at least 100 µg / g (0.01% dry weight) of Cd and As; 1000 µg / g (0.1% dry weight) of Co, Cu, Cr, Ni and Pb; and 10 000 µg/g (1.0% dry weight) of Mn (Kamal *et al.,* 2004, McGrath *et al.,* 2001, Padmavathiamma & Li, 2007, Reeves, 2006, Reeves *et al.,* 1999, Watanabe, 1997, Yang *et al.,* 2004).

The Phytoremediation technology is made more effective through genetic manipulation, which improves the remediation capacity of plants, which improves the remediation capacity of plants (Cherian & Oliveira, 2005). Some plant species have been designed with a greater capacity for degradation of organic pollutants or heavy metal accumulation. These genetically modified (GM) plants are specifically adapted for the phytoremediation of Cd, Hg or polychlorinated biphenyls (PCB's) (Eapen *et al.,* 2007, Macek *et al.,* 2008, Meagher, 2000, Pilon-Smits & Pilon, 2002, Raskin, 1996).

The mustard plants are used to remove heavy metals, such as cadmium and lead from soil in hazardous waste streams and sites. Particularly, Indian mustard is effective in removing cadmium from the streams and contaminated soils (Schneider *et al.,* 1999). The process of heavy metal removal will end when the plant is harvested. Indian mustard showed that phytoremediation by this plant is cheaper and easier than traditional methods for the reduction of heavy metals from metal contamination sites.

Heavy metals are soft, metals that normally occur as a minor component in their ores. Heavy metals have many industrial applications, for example Cadmium is used in electroplating, batteries industries, as a barrier to control nuclear fission and other heavy metals are using plastics, painting industries and also using in educational laboratories to emit the luminescence after excitation of some heavy metals

Increasing of industrialization causes environmental pollution and contaminates water and soil throughout the world. The release of industrial wastes and its derivatives in high doses resulted in the pollution of surface water, groundwater. Depending on the type of pollutant, the conditions of the site and the level of cleanliness is acquired; Phytoremediation technologies can be made as a means of containment rhizofiltration, under hydroponic culture conditions. The rhizofiltration uses the roots of plants to eliminate contaminants from the water medium (Dushenkov *et al.,* 1995). In the rhizofiltration these plants are cultivated in a hydroponic manner. When the root system is well developed, the plants are introduced into the water contaminated with metals, where the roots absorb and accumulate them. As the roots become saturated, the plants are harvested and disposed for their final use (Cherian & Oliveira, 2005, Eapen *et al.,* 2003, Nedelkoska & Doran, 2000). There are reports related to the accumulation of pollutants of various aquatic plants, some examples of which are: *Azolla caroliniana* (Hg, Cr Sr, Cu, Cd, Zn, Ni, Pb, Au, Pt) (Antunes *et al.,* 2001, Bennicelli *et al.,* 2004, Cohen-Shoel *et al.,* 2002, Fogarty *et al.,* 1999, Pandey, 2012, Zhao & Duncan, 1998), *Lemna gibba*

(Pb, As, Cu, Cd, Ni, Cr, Al, Fe, Zn, Mn) (Boniardi *et al.,* 1999, Dilek, 2007, Maleva *et al.,* 2004, Mkandawire *et al.,* 2005, Verma & Suthar, 2015) *Ludwigina palustris*, *Mentha aquatic* and *Myriophyllum aquaticum,* and (Cu, Zn, Mn, Fe, Ni) (Kamal *et al.,* 2004), *Scirpus lacustris* (Cd, Cu, Pb, Mg, Fe, Se, Cr) (Groudeva *et al.,* 2001, Suseela *et al.,* 2002), *Elatine sps* (As) (Zheng *et al.,* 2003), *Polygonum punctatum* (Cu, Cd, Pb, Se, As, Hg, Cr, Mn, and Zn), (Lin & Terry, 2003, Núñez *et al.,* 2011), *Eichhornia crassipes*, *Ludwigia helminthorriza*, and *Polygonum punctatum* (Hg, Cu, Pb, Cd, and Zn) *(Núñez et al., 2011)*, *olffia globosa* (Cd) (Upatham *et al.,* 2002, Xie *et al.,* 2013), *Spartina alterniflora* (Hg; Pb; Zn; Cu; Cr;) (Chen *et al.,* 2017, Lacerda *et al.,* 1997, Pang *et al.,* 2017, Weis & Weis, 2004, Weis *et al.,* 2003), *Phragmites australis* (Hg; Pb; Zn; Cu; Cr; Ni) (Bonanno & Lo Giudice, 2010, Bragato *et al.,* 2006, Esmaeilzadeh *et al.,* 2016, Ganjali *et al.,* 2014, Hou *et al.,* 2012, Jastrzębska *et al.,* 2010, Nikolaidis *et al.,* 1996, Vymazal & Březinová, 2016, Wang & Jia, 2009, Ye *et al.,* 1997).

Some of the representative results were presented in Table 3 about heavy metal accumulation in different species of *Brassica* under hydroponic experimental conditions. In Table 4 heavy metal accumulation results are represented by some sps of brassica under soil experimental conditions.

Table 3. Reported results on the uptake of heavy metals in different *Brassica* species in hydroponic experimental conditions.

Plant	Metal	DAT	DAT	Concentration	Uptake (mg/g DW)			Ref
					Root	Stem	leaf/shoot	
				3 mg/L	0.33	-	0.27	
		29	$Cd(NO_3)_2$	9 mg/L	0.83	-	0.57	(Armas *et al.,* 2015)
				30 mg/L	1.67	-	0.36	
			$Cd(NO_3)_2$	2 mg/L	0.268	-	-	(Dushenkov *et al.,* 1995)
		28	$CdCl_2$	120 µM	1.2	-	0.6	(Seth *et al.,* 2012)
	Cd	56			2.0	-	1.1	
		28	$CdCl_2$	1 µM		-	0.004	(Ebbs *et al.,* 1997)
		45	$CdSO_4$	0.5 mg/L	0.8	-	0.7	(Rahman *et al.,* 2016)
				1.0 mg/L	3.1	-	0.7	
				5 ppm	2.2		0.34	
			Contaminated river Soil	10 ppm	6.0		0.7	(Singh & Fulekar, 2012)
				20 ppm	13.9		2.0	
				50ppm	18.4		3.3	
			$K_2Cr_2O_7$	4 mg/L	0.76			(Dushenkov *et al.,* 1995)
	Cr	29	$CrCl_2$	120 µM	0.4		0.15	(Seth *et al.,* 2012)
		56			1.5		0.62	
	Co	0	07	100 mg/L	-	-	224	(Cuypers *et al.,* 2011)
		28	$CuCl_2$	0.32 mg/L	1.2		0.33	(Seth *et al.,* 2012)
		58			2.0		0.8	
B. juncea	**Cu**	9	7	50 µM	3667	-	88.3	(Grispen *et al.,* 2006)
		13	8	8 µM	*835*			(Zaier *et al.,* 2010)
		14	$Cu(NO_3)_2$	0.32 mg/L	4.9		2.1	(Ebbs & Kochian, 1997)
		0	7	100 mg/L	-	-	235	(Cuypers *et al.,* 2011)
			$Cu(NO_3)_2$	6 mg/L	3.0			(Dushenkov *et al.,* 1995)
		7	56	120 µM	1.5	-	0.002	(Ebbs & Kochian, 1997)
	Hg	25	$HgNO_3$	10 mg/L	1.08	-	0.003	(Moreno *et al.,* 2008)
	As	45	$NaAsO_2$	0.5 mg/L	0.4	-	-	(Rahman *et al.,* 2016)
				1.0 mg/L	1.0	-	-	
	Mn	0	7	100 mg/L	-	-	445	(Cuypers *et al.,* 2011)
			$Ni(NO_3)_2$	10 mg/L	1.1			(Dushenkov *et al.,* 1995)-
	Ni	0	7	100 mg/L	-	-	135	(Cuypers *et al.,* 2011)
			$Pb(NO_3)_2$	2 mg/L	1.1			(Dushenkov *et al.,* 1995)
				4.14 mg/L	3.21	0.07	0.04	
		21	$Pb(NO_3)_2$	41.4 mg/L	16.0	0.73	0.06	(Liu *et al.,* 2000)
				414 mg/L	0.54	0.21	0.13	
	Pb	29	$PbCl_2$	120 µM	1.3		0.24	(Seth *et al.,* 2012)
		58			2.0		0.41	
				5 ppm	1.3		0.25	
			Contaminated river Soil	10 ppm	4.9		0.25	(Singh & Fulekar, 2012)
				20 ppm	7.1		1.0	
				50ppm	12.3		2.5	
		45	$Pb(NO_3)_2$	0.5 mg/L	1.7		0.03	(Rahman *et al.,* 2016)
				1.0 mg/L	2.5		0.08	
			$Pb(NO_3)_2$	600 mg/L	10.5			(Takeda *et al.,* 2010)
	Zn		$Zn(NO_3)_2$	100 mg/L	13.15			(Dushenkov *et al.,* 1995)

		28	$ZnSO_4$	100 µM			1.9	(Ebbs *et al.,* 1997)
		14	$Zn(NO_3)_2$	6.5 mg/L	9.5		1.5	(Ebbs & Kochian, 1997)
				5 ppm	2.3		0.5	
			Contaminated river Soil	10 ppm	4.5		1.0	(Singh & Fulekar, 2012)
				20 ppm	12.5		1.3	
				50ppm	26.5		2.6	
		12	14	6.5 mg/L	*6075*	-	*870*	(Nagajyoti *et al.,* 2010)
	Cd		$CdCl_2$	1 µM			0.003	(Ebbs *et al.,* 1997)
		0	28	20 µM	-	-	60	
B. carinata	**Cu**	0	28	75 µM	-	-	60	(Parveen *et al.,* 2014)
	Pb	0	28	100 µM	-	-	280	
	Zn	0	28	750 µM	-	-	333	
			$ZnSO_4$	100 µM	-	-	0.17	(Ebbs *et al.,* 1997)

Table 4. Reported results on the uptake of heavy metals in different *Brassica* species in soil experimental conditions.

Plant	Metal	Age	DAT	Concentration	Uptake (mg/g DW)			Reference
					Root	Stem	leaf/shoot	
		25	90	300 mg/L	38.1		20.8	(Neilson & Rajakaruna, 2012)
				100 mg/kg	*300*		*62*	(Cuypers *et al.,* 2010)
		22	4	200 µM	15970	665	722	(Pinto *et al.,* 2009)
		0	37	200 mg/kg	-	-	225	(Park *et al.,* 2012)
		3	22	150 µM	-	-	92	(Sankaran & Ebbs, 2008)
	Cd			5 mg/kg	1.0	0.00002	0.02	
		90	$Cd(NO_3)_2$	15 mg/kg	1.3	0.0005	0.06	(Pinto *et al.,* 2009)
B. juncea				35 mg/kg	2.5	0.0003	0.2	
		0	90	35 mg/kg	255	-	183	(Baryla *et al.,* 2001)
			$Cd(NO_3)_2$	5 mg/kg	0.11	-	0.03	(Armas *et al.,* 2015)
				35 mg/kg	0.25	-	0.18	
		42	Contaminated Soil	-	-	-	0.003	(Ebbs *et al.,* 1997)
	Cu		Sewage irrigated soil	-	0.052	-	0.022	(Purakayastha *et al.,* 2008)
	Ni			-	0.006	-	0.006	
	Pb			-	0.018	-	0.057	
	Zn	42	Contaminated Soil	-	-	-	0.6	(Ebbs *et al.,* 1997)
	As		Contaminated Soil	639 mg/kg			0.01	
	Cd	80	Contaminated Soil	61 mg/kg			0.08	(Quartacci *et al.,* 2009)
	Cu		Contaminated sites	1.85			0.17	
				-	0.046	-	0.009	
	Ni		Sewage irrigated soil	-	0.006	-	0.02	(Purakayastha *et al.,* 2008)
B. carinata				-	0.012	-	0.066	
	Pb	80	Contaminated sites	246 mg/kg			0.06	(Quartacci *et al.,* 2009)
	Zn		Sewage irrigated soil	-	0.08	-	0.145	(Purakayastha *et al.,* 2008)
		80	Contaminated sites	1.14 g/kg			0.11	(Quartacci *et al.,* 2009)

It is clear that the concentrations of metal accumulations (Table 3 and table 4) in plants are in different range with in the same species for the same metal. The only reason behind this different range of concentrations is that of experimental condition conditions approaches. Compering in the both plants, Indian mustard is the great heavy metal accumulator as it proved for their higher rate of metal accumulations in all the experimental conditions.

Turnip mosaic virus (TuMV) is one of the most important plant viruses from the economic point of view throughout the world (Tomlinson, 1987) and it causes a detrimental disease in the Brassica crops (Babu *et al.,* 2013, Green & Deng, 1985, Hardwick *et al.,* 1994, Kehoe *et al.,* 2010, Shattuck & Stobbs, 1987, Spence *et al.,* 2007, Walsh, 1989, Walsh & Tomlinson, 1985). TuMV is not only a devastating virus in agriculture; it also has some relevance in environmental science, as shown by the effect of Ni accumulation on TuMV-infected serpentine plants (Davis *et al.,* 2001).

Due to the considerable biological variation in terms of the interaction with different host plants and from different geographical regions, TuMV has several isolates. It infects a wide range of plant species, covering over 318 plant species in 156 genera of 43 plant families, including many important crops and weed plants, mostly from the family *Brassicaceae* (Walsh & Jenner, 2002).

Indian mustard and Ethiopian mustard are infected by TuMV virus naturally and show symptoms such as chlorotic local lesions, mosaic, mottling, puckering and vein clearing in leaves (Babu *et al.,* 2013, Haq *et al.,* 1994, Mingochi & Jensen, 1988). Some of the viral strains of this virus are specialized in infecting the Brassica plants. Recently, the same

scenario has been reported with the full length clones of TuMV isolate UK 1 (a British isolate) and isolate JPN 1 (a Japanese isolate) on Indian mustard, Turnip and Ethiopian mustard plants (López-González *et al.,* 2017).

This systemic infection of plants occurs when a virus amplifies and disperses its genome and the virus isolates may have evolved mechanisms such as presence of a viral host pathogenic determinant that enables it to overcome host resistance and produce systemic infections. The determinants can be studied using recombinants constructed from different isolates of same virus.

Turnip mosaic virus

Turnip mosaic virus (TuMV) is a quite relevant and widespread agricultural virus. It infects a wide range of plant species, covering over 318 plant species in 156 genera of 43 plant families, including many important crops and weed plants, mostly from the family *Brassicaceae* (Walsh & Jenner, 2002) belongs to the genus Potyvirus family *Potyviridae*. *Potyvirus* is the largest genus to infect many plant sps. It is well-considered as one of the most important viruses of *Brassicaceae* family in the world including the temperate and tropical regions of Africa, Asia, Europe, Oceania and North and South America that infect field-grown vegetables and displays a large natural as well as experimental host range (Provvidenti, 1996).

Among the plant viruses, TuMV has been reported to infect a wide range of crop and weed plant species and has been ranked second among the five most damaging vegetable viruses (Tomlinson, 1987, Walsh & Jenner, 2002). It is transmitted by several stylet-borne aphid vectors in the non-persistent manner (Hamlyn, 1953). In many parts of the world, horticultural and cultivar Brassica crops are grown in close proximity and often there is year-round crop cultivation which results in reservoirs of TuMV infected plants providing constant inoculum source for aphid vectors (Walsh, 1986, Walsh *et al.,* 2002).

The virions are flexuous rods approx. 720*15nm (Walsh & Jenner, 2002). The encapsidated genome is a single-stranded, positive-sense RNA of 9833 nucleotides, characterized by a single large open reading frame (ORF), encoding a polyprotein of 3164 amino acids (aa) (Ohshima *et al.,* 1996) and characterized by a 5´ untranslated region (UTR), a single large open reading frame (ORF) and a 3´ UTR which has a polyadenylated (polyA) tail (Figure 2). The ORF is processed by three virus-encoded proteinases to yield at least ten mature viral proteins (P1–HcPro–P3–6K1–CI–6K2–VPg–NIaPro–NIb–CP) (Revers & García, 2015, Riechmann *et al.,* 1992, Urcuqui-Inchima *et al.,* 2001) Two further proteins (P3N-PIPO and P3N-ALT) have been discovered in the form of fusion proteins with the N-terminal region of the viral protein P3 (Figure 2) (Chung *et al.,* 2008, Hagiwara-Komoda *et al.,* 2016). Another fusion protein (P1N-PISPO) has been described for some members of the *Potyviridae* family (Mingot *et al.,* 2016), but its presence in TuMV has not been reported so far.

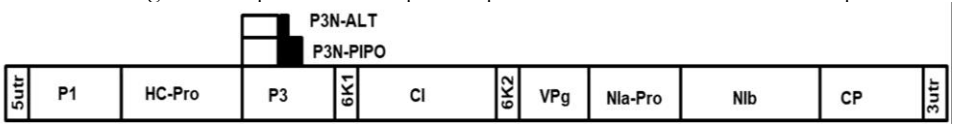

Figure 2. Genome organization of *Turnip mosaic virus.*

TuMV infects most Brassicaceae plants, that too particularly damaging to mustard, turnip, Chinese cabbage and radish. The most common symptom in the infected crops are mosaic and vein clearing with dark green colors in the leaves. Necrotic spots are the primary symptom and are common in cabbage.

It has been observed that TuMV infects Indian mustard, Ethiopian mustard and Turnip inducing mosaic, vein clearing, stunting (Babu *et al.,* 2013, Jenner & Walsh, 1996, López-González *et al.,* 2017, Mingochi & Jensen, 1988, Ohshima *et al.,* 2002, Sánchez *et al.,* 2007, Sánchez *et al.,* 2003, Suehiro *et al.,* 2004, Tomimura *et al.,* 2003, Walsh, 1989).

TuMV is a highly diverse potyvirus. Among the published sequences of TuMV are presently available in public databases, some were covered the whole viral genome (Nguyen *et al.,* 2013, Ohshima *et al.,* 2007, Tomimura *et al.,* 2003) and most of them focus on partial genome stretches especially the coat protein (CP) gene. The CP gene is a highly variable region in *potyvirus* genome and has been widely accepted for classification of isolates in this species (Sánchez *et al.,* 2007, Sánchez *et al.,* 2003). There are many reports in terms of biological and serological variations in TuMV on the basis of its interaction with different host plants from different places around the world and many attempts have been made in the past to analyze TuMV variation at the nucleotide and amino acid levels (López-González *et al.,* 2017, Nguyen *et al.,* 2013, Ohshima *et al.,* 2002, Sánchez *et al.,* 2007, Sánchez *et al.,* 2003, Tomimura *et al.,* 2003).

Among TuMV, there is similarity in P3 proteins compared to other proteins as symptom determinant. Even within the limited literature available, we understood that P3 is an important factor in the process of TuMV infections, since TuMV-P3 has been implicated in several instances in the outcome of the interaction to *Brassicaceae* hosts (Jenner *et al.,* 2002, Sánchez *et al.,* 2015,

Suehiro *et al.,* 2004, Tan *et al.,* 2005) and identified as a symptom and avirulence determinant in brassicas (Jenner *et al.,* 2003). In *Arabidopsis thaliana* TuMV-P3 is responsible to cause a systemic hypersensitive reaction via gene-for-gene interaction (Kim *et al.,* 2010). Recently, studies using viral infectious clones of TuMV showed differential phenotypes of the infections in *A. thaliana* (Sánchez *et al.,* 2015). The isolate TuMV-JPN 1 were also reported in differential infections among *Brassicas* (López-González *et al.,* 2017).

Focusing on the plant species on differential infectivity from two strains of same virus TuMV and their chimeric derivatives can be exploited to pathogenicity determinant of objectives through *virus*-host interactions as similarly, C-terminal region of the P3 protein as responsible for the differential phenotypes of the infections in *A. thaliana* (Sánchez *et al.,* 2015).

Conclusion

Infection of TuMV in plants affected metal accumulation instead of offending the plants (Davis *et al.,* 2001) and A hexa histidine peptide fused onto the external surface of *Tomato mosaic virus* (ToMV) (Shingu *et al.,* 2006) and *Tobacco mosaic virus* (TMV) (Kadri *et al.,* 2011) particles showed an increased heavy metals tolerance to plants. Having to conclude this review we are proposing the virus infected plants can also be used in phytoremediation to see the enhanced metal accumulation.

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