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CONTRIBUTION OF ENVIRONMENTAL AND SOIL PHYSICOCHEMICAL ATTRIBUTES IN INVASIVENESS OF *IPOMOEA CARNEA* JACQ. IN DIVERSE HABITATS ALONG ELEVATION AND SALINITY GRADIENTS

SYED MOHSAN RAZA SHAH, MANSOOR HAMEED* AND MUHAMMAD SAJID AQEEL AHMAD

Department of Botany, University of Agriculture, Faisalabad 38040, Pakistan
**Corresponding author's e-mail: hameedmansoor@yahoo.com*

Abstract

A study was conducted in Punjab and Azad Jammu and Kashmir (AJK) to evaluate invasion success of *Ipomoea carnea* in different ecological zones. The thirty selected habitats were grouped on the basis of salinity levels into non-saline (0.9-3.8 dS m-1), moderately saline (4.1-7.1 dS m-1) and highly saline (10-31.5 dS m-1). Data for weather attributes was obtained from meteorology station, Islamabad-, while soil physicochemical traits and ecological parameters were recorded. Importance value of *Ipomoea carnea* inhabiting non-saline habitats was the maximum at Puran (PRN). Among moderately saline habitats, *I. carnea* was the most abundant at Pasrur Pond (PPD), while at highly saline in populations growing at Gatwala (GWA). Importance value and relative density were associated with annual precipitation and maximum and minimum temperatures at non-saline sites. Relative cover as associated with soil physicochemical attributes like ECe, Na^+, Cl^-, K^+, Ca^{2+}. PO_4^{3-} and NO_3^-. Relative density was associated with soil moisture content and soil Ca^{2+} at moderately saline sites. The highly saline sites showed association of RF with climate factors like maximum and minimum temperatures and soil physicochemical traits like saturation percentage, ECe, Na^+, K^+, Ca^{2+} and PO_4^{3-}. Invasion success based on frequency, density and percent cover decreased with increase in elevation at non-saline, moderately saline and highly saline habitats. Invasive success decreased along salinity gradient at moderately saline habitats, while increased at non-saline and highly saline habitats.

Key words Salinity tolerance; Invasive success; Physicochemical traits; Elevation; Importance value.

Abbreviations: Ecological parameters: RD-Relative density; RF-Relative frequency; RC-Relative cover; IV-Importance value. **Weather attributes:** MAP-Annual precipitation; ELE-Elevation; MxT-Maximum temperature; MnT-Minimum temperature. **Soil physicochemical attributes:** EC (ECe); pH (pH); SOM-Organic matter; SCa-Ca^{2+}; SK-K^+; SNa-Na^+; SCl-Cl^-; SNO-NO_3^-; SPO-PO_4^{3-}; SSP-Saturation percentage; SMC-Moisture contents. **Populations:** KHA-Kohala; ISB-Islamabad; PNA-Pahari Nala; MWA-Manawala; NSF-Nerian Sharif; DKA-Daska; PRD-Phularwan road; NML-Namal; LJM-Lower Jhelum, PRN-Puran; MPO-Mong Depot; PPD-Pasrur Pond; LYH-Layyah; PKT-Pir Kot; DKT-Dhir Kot; KWA-Kharianwala; PWL-Phularwan Canal; RCI-Rasool Choki; MHN-Majuhan; SKT-Shah Kot; GJL-Gunjal; GWA-Gatwala; SPA-Skindar Pura; CSS-Choa Sadien Shah; PID-Phid; BCL-Buchal; KKR-Kallar Kahar; CDT-Cholistan Desert; SHL-Sangla Hills; SWA-Sahianwala.

Introduction

Pakistan is located in Southeast Asia between latitudes 24^o to 37^o North and longitudes 60^o to 75^o East. The country has distinctive geographical profile and climate as one region is totally different from the other. Environmental heterogeneity is an important feature of Pakistan that includes hot coastline of Arabian Sea in south to very cold hilly areas in the north. Therefore, climatic factors like rainfall, annual maximum and minimum temperatures, wind speed and humidity varies greatly throughout the country (Adnan *et al.*, 2019). Most regions are arid and semi-arid with average annual rainfall more than 240 mm, but arid areas have very low rainfall about 125 mm (Ashraf *et al.*, 2008). Pakistan receives maximum rainfall during monsoon in the months from June to September. Temperature of plain areas ranges from 35-40^{o}C and deserts have even higher (52^{o}C) temperature. In winter, temperature of northern mountainous regions remains very low, commonly below freezing point (Körner & Paulsen, 2004).

The introduction of alien plant species by human interference is rapidly increasing around the globe often with limiting effects on functions of natural biodiversity (Sax & Gaines, 2008). Determining the processes of successful invasion of alien species and finding the strategies to control new invasions is an important step for attenuate their influence on biodiversity. There are three key assembly mechanisms to influence the successful invasion of an alien species are 1) environment 2) biotic 3) dispersal filtering (Theoharides & Dukes, 2007). First, native environment of the new range filters species from the pool of alien species based on their ecological niches and adaptations (environmental filtering). Another mechanism is competition from the native species among the alien species that can coexist within native communities through utilization of unexploited resources (biotic filtering). Third, dispersal by human or natural mechanism determines which species will compete with native communities (dispersal filtering). Finally the interaction of these three mechanisms determines which species invade the enormous bio-geographical scale (Richardson & Pyšek, 2012).

Invasion is introduction, colonization and spread of a plant species in a new area were it was absent earlier. The progression is different from of colonization on the basis of biogeographical origin of invasive species and the harmful effects its spread will impose on the flora of new area (Falk-Petersen *et al.*, 2006). Invasion by a new plant species causes serious problem around the globe. Invasive plant species can change the native communities by competing and replacing them that causes serious threat to natural biodiversity (Pimentel *et al.*, 2000). The successful invasion of an alien species to new areas mainly depends on its adaptive strategies in those areas. Environmental attributes like soil disturbance, soil transport and deposition determine the invasive success of an alien species (Woitke & Dietz, 2002).

Ipomoea carnea Jacq. is a native plant species of Tropical South America. It is introduced to sub-continent in late 19th century. Nowadays, this plant is expanding quickly in several deserts, terrestrial and aquatic habitats, establishing large population throughout Indo-Pak region (Al-Sodany *et al.*, 2009). This species has rapid growth and spreading rate, and invades in xeric to aquatic habitats and causes major problems for irrigation, navigation, cultivation and fisheries. It can vegetative propagate by stem parts and have ability of rooting within few days. Farmer uses this species as hedge and ornamental plant along water channels. These uses along with ability to reproduce by multiple means lead to inhabitation into new areas (Shaltout *et al.*, 2010). It is hypothesized that environmental conditions and soil physicochemical attributes may have significant impact on invasiveness of the species in Pakistan. Therefore, the present study was conducted to evaluate the invasive success of *Ipomoea carnea* Jacq. in different environmental conditions in Pakistan.

Material and Methods

This vegetation study was conducted at 30 sites of Punjab and Azad Jammu and Kashmir comprising desert, plains and mountainous regions (Table 1). The sampling was done at three distinct habitats (non-saline (Fig. 1), moderately saline (Fig. 2) and highly saline (Fig. 3). Each habitat was isolated by a distance of at least 60 km. Three transect lines (100 m) were selected at each study site and 5 quadrats (10 x 10) were set along each transect line. High-pixel photography of *I. carnea* habitats was taken. Plant samples were preserved and submitted to the herbarium collection, Department of Botany, University of Agriculture Faisalabad. Data for density, frequency and cover were recorded according to Greig-Smith (1983).

Table 1. Meteorological data and coordinates of *Ipomoea carnea* Jacq. collection sites from Punjab and Azad Jammu and Kashmir, Pakistan.

Non saline	Regions/District	Habitats	Longitude (N)	Latitude (S)
KHA-Kohala	Muzaffarabad	High mountainous slope	34° 05' 19"	73° 30' 34"
ISB-Islamabad	Islamabad	Urban area (mountains)	33° 41' 21"	73° 02' 50"
PNA-Pahari Nala	Sialkot	Water stream from mountains	32° 30' 28"	74° 31' 38"
MWA-Mana Wala	Faisalabad	Agricultural fields along roadside	31° 27' 43"	73° 08' 18"
NSF-Nerian Sharif	Sudhnoti	High mountainous slope	33° 55' 34"	73° 46' 50"
DKA-Daska	Sialkot	Agricultural fields away from road	32° 20' 22"	74° 22' 02"
PRD-Phularwan road	Sargodha	Roadside	32° 18' 42"	72° 57' 51"
NML-Namal	Mianwali	Top of mountain	32° 40' 10"	71° 48' 45"
LJM-Lower Jhelum-	Mandi Bahauddin	Wetland near link canal	31° 23' 10"	71° 50' 48"
PRN-Puran	Gujrat	Bank of main canal	32° 46' 07"	73° 37' 56"
Moderately saline				
MPO-Mong Depot	Mandi Bahauddin	Water channel	32° 17' 49"	71° 52' 55"
PPD-Pasrur Pond	Sialkot	Water pond	32° 15' 53"	74° 39' 17"
LYH-Layyah	Layyah	Thal desert	30° 55' 30"	70° 54' 11"
PKT-Pir Kot	Poonch	Mountains	32° 19' 30"	73° 59' 21"
DKT-Dhir Kot	Bagh	Mountains	34° 02' 26"	74° 34' 22"
KWA-Kharian Wala	Sheikhupura	Agricultural fields	31° 39' 24"	73° 56' 00"
PWL-Phularwan Canal	Sargodha	Canal	32° 21' 10"	73° 00' 45"
RCI-Rasool Choki	Mandi Bahauddin	River bank	32° 41' 37"	73° 33' 43"
MHN-Majuhan	Mirpur	Mountains	34° 12' 39"	73° 28' 48"
SKT-Shah Kot	Nankana Sahib	Agricultural fields	31° 33' 34"	73° 28' 40"
Highly saline				
GJL-Gunjal	Khushab	Agricultural fields	32° 17' 49"	71° 52' 55"
GWA-Gatwala	Faisalabad	Waste water pond	31° 28' 39"	73° 12' 38"
SPA-Skindar Pura	Faisalabad	Canal	31° 28' 39"	73° 12' 38"
CSS-Choa Sadien Shah	Chakwal	Residential area in mountains	32°43′00″	72° 59′ 00″
PID-Phid	Chakwal	Along road side in mountains	32° 39' 08"	72° 59' 30"
BCL-Buchal	Chakwal	Road side near the fields (mountains)	32°40′47″	72° 38′ 02″
KKR-Kallar Kahar	Chakwal	Near Kalar Kahar lake	32°46′46″	72° 42′ 24″
CDT-Cholistan Desert	Rahim Yar Khan	Sandy and saline desert	28° 30' 22"	71° 34' 20"
SHL-Sangla Hills	Faisalabad	Railway track and roadside	31° 42' 41"	73° 23' 28"
SWA-Sahianwala	Faisalabad	Near saline wetlands	31° 38' 21"	73° 13' 51"

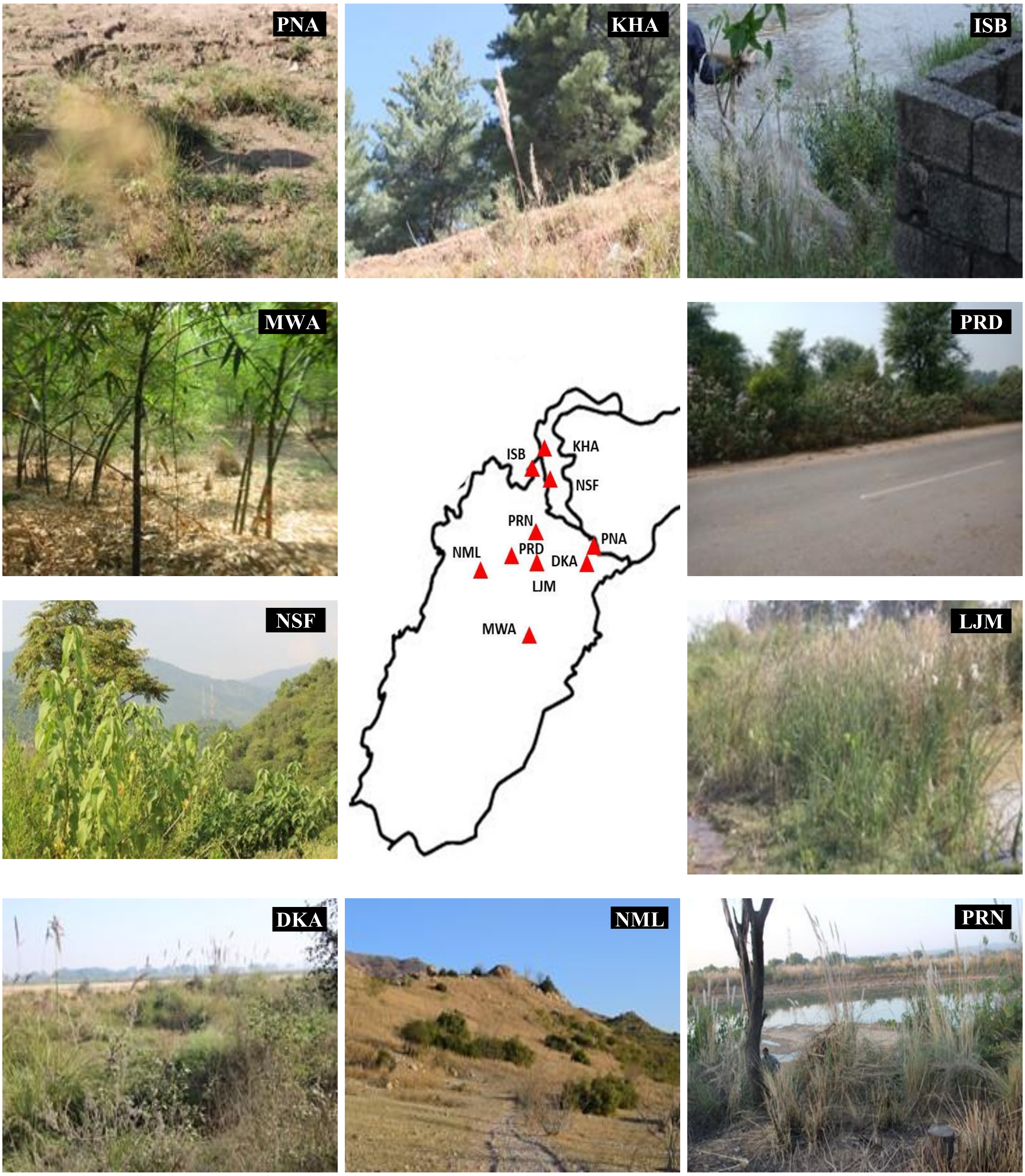


Fig. 1. Map and habitats details of *Ipomoea carnea* Jacq. non-saline collection sites from Punjab and Azad Jammu and Kashmir, Pakistan.
Legends: KHA-Kohala; ISB-Islamabad; PNA-Pahari Nala; MWA-Manawala; NSF-Nerian Sharif; DKA-Daska; PRD-Phularwan road; NML-Namal; LJM-Lower Jhelum, PRN-Puran

Meteorological data: Meteorological data (annual precipitation and maximum and minimum temperature range) were obtained from the World Wildlife Fund (WWF) for the Nature and Meteorological Station, Islamabad. This meteorological station maintains records for all sub-stations in collaboration with other organization in the country and is regulated by the Government of Pakistan.

Statistical analysis

The response of various ecological attributes was concluded by running a redundancy analysis (RDA) in Canoco software (version 4.5). The triplots were constructed in CanoDraw (version 4.14). For this purpose, the ecological attributes were considered as dependent variable (factor 1), influenced by soil factors response variables (factor 2) of different sites as fixed effects (factor 3). The response curves were then plotted separately for non-saline, moderately saline and highly saline sites against the soil salinity and elevation gradients with CanoDraw (version 4.14) by fitting a GLM - Generalized Linear Model.

Results

Weather: Among non-saline sites, the NSF site located at the highest elevation (1898 m a.s.l.) received the maximum annual precipitation (1380 mm year^{-1}). The PRD site located at the lowest elevation (195 m a.s.l.) received the minimum precipitation (350 mm year^{-1}). Mean annual temperature was the highest at MWA site (48^{o}C), while the lowest (-10.3^{o}C) was recorded at NSF site (Table 2). In moderately saline habitats LYH site located at the lowest elevation (145 m a.s.l.) received the minimum annual precipitation (210 mm year^{-1}) with maximum temperature (49^{o}C). The PKT site located at the highest elevation (2025 m a.s.l.) received the maximum annual precipitation (1170 mm year^{-1}) with the lowest (-12^{o}C) temperature (Table 2). Among highly saline habitats, CSS, PID, BCL and KKR received the maximum annual precipitation (around 595 mm year^{-1}), while the CDT site received the minimum precipitation (180 mm year^{-1}). The CSS site located at the highest elevation (676 m a.s.l.) had the least maximum (34.1^{o}C) and minimum (-2.6^{o}C) mean annual temperatures while the CDT site located at the lowest elevation (180 m a.s.l) had the highest maximum (51.1^{o}C) and minimum (8.6^{o}C) mean annual temperatures (Table 2).

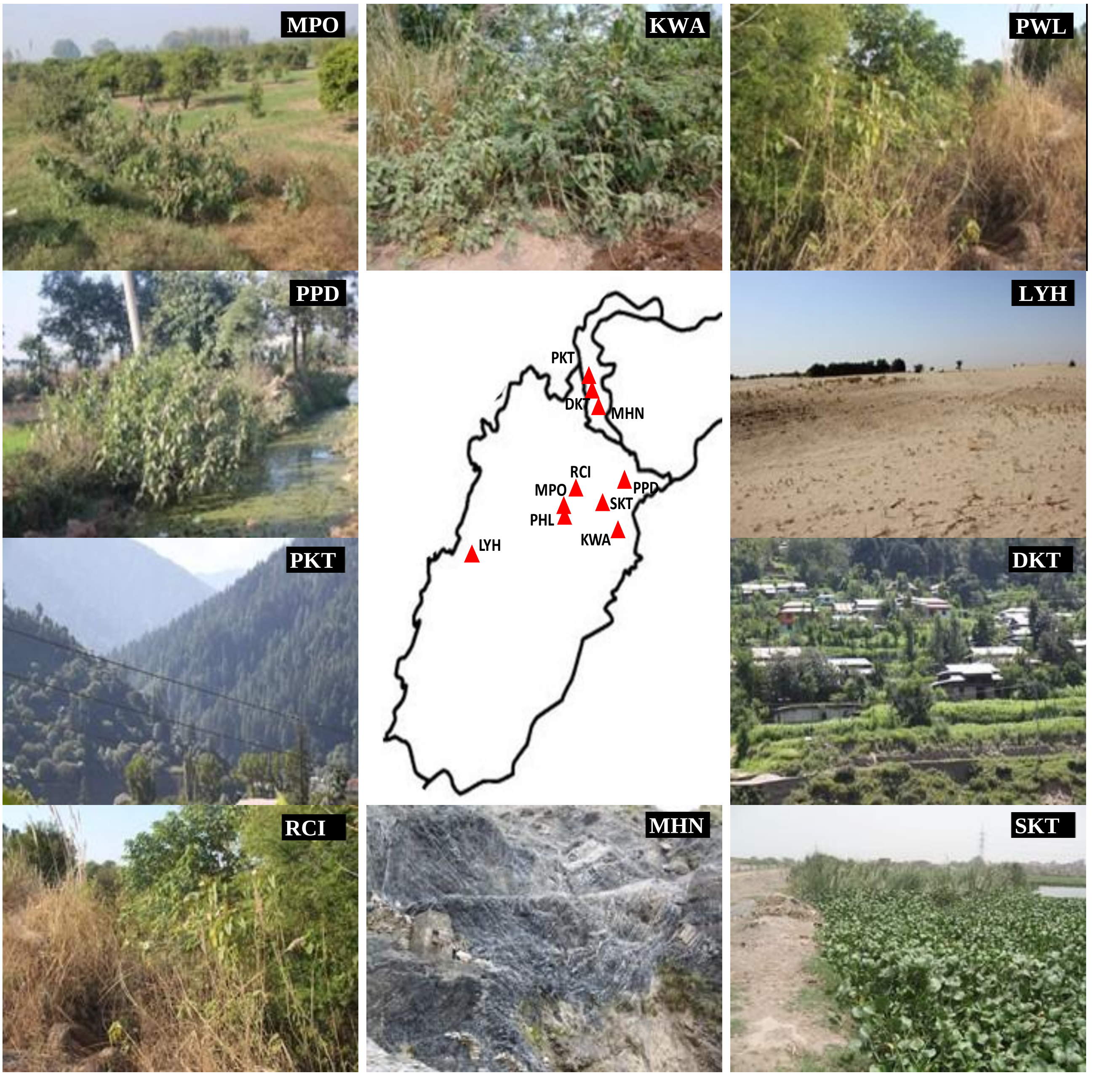


Fig. 2. Map and habitats details of *Ipomoea carnea* Jacq. moderately saline collection sites from Punjab and Azad Jammu and Kashmir, Pakistan.

Legends: MPO-Mong Depo; PPD-Pasrur Pond; LYH-Layyah; PKT-Pir Kot; DKT-Dhir Kot; KWA-Kharianwala; PWL-Phularwan Canal; RCI-Rasool Choki; MHN-Majuhan; SKT-Shah Kot

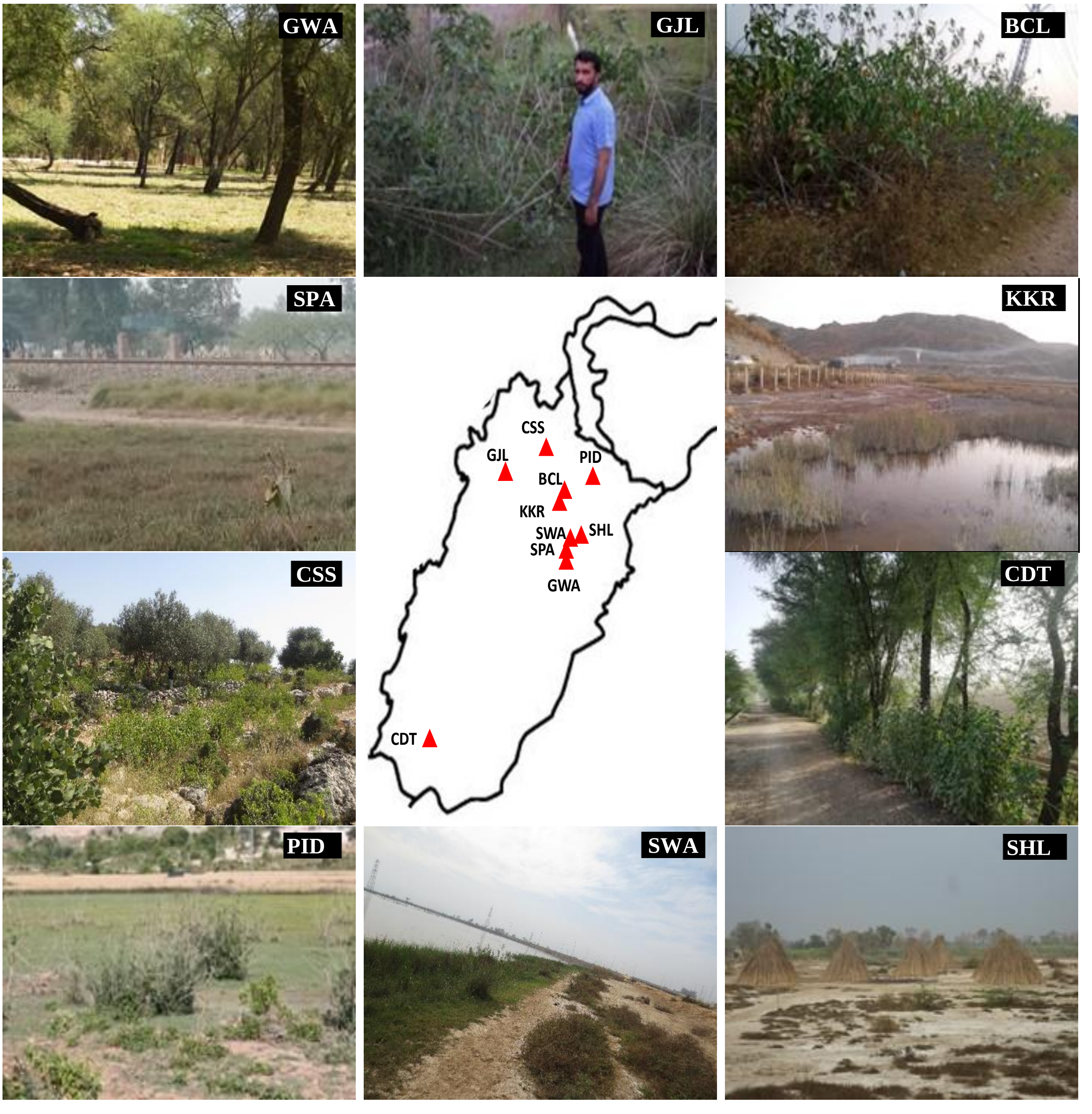


Fig. 3. Map and habitats details of *Ipomoea carnea* Jacq. highly saline collection sites from Punjab, Pakistan
Legends: GJL-Gunjal; GWA-Gatwala; SPA-Skindar Pura; CSS-Choa Sadien Shah; PID-Phid; BCL-Buchal; KKR-Kallar Kahar; CDT-Cholistan Desert; SHL-Sangla Hills; SWA-Sahianwal

Soil analysis: In non-saline habitats, the pH ranged from 7.8 (PNA) to 8.5 (NML), ECe from 0.9 (KHA) to 3.8 dS m^{-1} (PRN), Na^+ from 21.1 (KHA) to 34.5 mg Kg^{-1} (PRN), K^+ from 7.9 (KHA) to 15.6 mg Kg^{-1} (PRN), Cl^- from 18.1 (KHA) to 78.4 mg Kg^{-1} (PRN), NO_3^- from 1.6 (PNA) to 3.5 mg Kg^{-1} (DKA and PRN), PO_4^{3-} from 3.2 (PNA) to 16.8 mg Kg^{-1} (PRD), saturation from 28.1 (KHA) to 34.7 percent (PNA), moisture contents from 17.1 (KHA) to 26.1 percent (LJM) and organic matter from 0.5 (NML) to 1.3 percent (LJM). Among moderately habitats, the pH ranged from 7.8 (MPO and PWL) to 8.4 (KWA), ECe from 4.1 (MPO) to 7.1 dS m^{-1} (SKT), Na^+ from 360.4 (MPO) to 723.4 (SKT), K^+ from 107.2 (MPO) to 164.7 mg Kg^{-1} (SKT), Cl^- from 563 (MPO) to 2267.8 mg Kg^{-1} (SKT), NO_3^- from 3.8 (MPO) to 9.7 mg Kg^{-1} (PWL), PO_4^{3-} from 3.2 (KWA) to 17.5 mg Kg^{-1} (PKT), saturation from 28.4 (PKT and DKT) to 36.4 percent (PWL), moisture contents from 17.9 (DKT) to 25.3 (PWL) and organic matter from 0.5 (PKT) to 1.3 percent (DKT). Among highly saline habitats, the pH ranged from 7.8 (KKR) to 8.6 (CDT), ECe from 10.0 (GJL) to 31.5 dS m^{-1} (SWA), Na^+ from 1017.1 (GJL) to 2091.1 dS m^{-1} (SWA), K^+ from 51.4 (GJL) to 165.4 mg Kg^{-1} (SWA), Cl^- from 35.8 (GJL) to 95.4 mg Kg^{-1} (SWA), NO_3^- from 1.9 (GWA) to 5.6 mg Kg^{-1} (GJL), PO_4^{3-} from 4.9 (GJL) to 10.9 (SHL), saturation from 28.3 (CDT) to 34.4 percent (SWA and KKR), moisture contents from 15.8 (SPA) to 24.0 (SWA) and organic matter from 0.7 (SPA) to 1.3 percent (GWA and BCL) (Table 2).

Table 2. Soil physicochemical characteristics of the *Ipomoea carnea* Jacq. collection sites from the Punjab and Azad Jammu and Kashmir, Pakistan.

Non saline sites	KHA	ISB	PNA	MWA	NSF	DKA	PRD	NML	LJM	PRN
					Weather data					
Annual precipitation (mm)	1206	1142	957	375	1380	957	350	1290	399	1016
ELE (m a.s.l.)	715	562	253	185	1898	234	195	1522	258	237
MxT	30.2	40	41.8	48	22	41	45	27	41.2	39
MnT	-7.1	-3.9	1	4.1	-10.3	1	1	-8.3	1	1
					Soil analysis					
pH	8.3	8.3	7.8	7.9	8.3	7.8	7.9	8.5	8.0	7.9
EC (dS m^{-1})	0.9	1.2	1.3	1.4	2.5	2.6	3.41	3.5	2.6	3.8
SNa (mg Kg^{-1})	21.1	22.4	23.1	27.2	28.1	29.9	30.1	31.5	33.6	34.5
SK (mg Kg^{-1})	7.9	8.4	10.0	12.0	12.1	12.5	13.5	14.7	15.2	15.6
SCa (mg Kg^{-1})	29.3	31.1	37.1	55.6	57.6	59.3	60.2	62.1	63.8	64.0
SCl (mg Kg^{-1})	18.1	23.8	24.3	29.1	51.3	53.1	54.5	70.4	72.2	78.4
SNO (mg Kg^{-1})	2.5	1.7	1.6	2.0	3.4	3.5	3.6	3.2	3.3	3.5
SPO (mg Kg^{-1})	6.4	6.4	3.2	4.1	15.8	16.3	16.8	12.8	13.2	14.3
SSP (%)	28.1	30.4	34.7	32.3	29.2	32.0	32.8	30.5	34.3	34.2
SMC (%)	17.1	18.9	24.1	23.8	21.2	24.0	20.1	24.2	26.1	25.3
SOM (%)	0.6	0.6	1.0	0.8	0.6	1.0	1.3	0.5	1.3	0.6
Moderately saline sites	**MPO**	**PPD**	**LYH**	**PKT**	**DKT**	**KWA**	**PWL**	**RCI**	**MHN**	**SKT**
					Weather data					
Annual precipitation (mm)	503	957	210	1170	1150	488	350	399	1133	255
ELE (m a.s.l.)	195	239	145	2025	1551	208	205	219	1066	195
MxT	40	41	49	21	27	47	45	44	35	47
MnT	1.3	1	0	-12	-6	1	1	1.5	-4.5	1
					Soil analysis					
pH	7.8	7.9	8.3	8.2	8.2	8.4	7.8	7.9	8.3	8.0
EC (dS m^{-1})	4.1	4.2	4.2	4.5	4.6	5.3	5.9	6.3	6.4	7.1
SNa (mg Kg^{-1})	360.7	362.5	364.2	394.9	403.7	562.4	579.4	661.4	667.3	723.4
SK (mg Kg^{-1})	107.2	117.2	119.4	129.4	147.2	148.7	148.8	150.0	161.2	164.8
SCa (mg Kg^{-1})	51.8	52.8	80.4	88.1	116.3	126.1	128.9	115.2	115.7	85.8
SCl (mg Kg^{-1})	563.3	566.4	568.7	616.7	630.4	668.9	736.5	1839.4	1874.5	2267.8
SNO (mg Kg^{-1})	3.8	3.9	3.9	4.2	4.3	8.8	9.7	4.2	4.1	4.6
SPO (mg Kg^{-1})	3.9	15.6	15.7	17.5	17.4	3.2	3.5	15.6	15.9	15.5
SSP (%)	36.3	38.1	30.5	28.4	28.4	35.4	36.4	34.3	35.3	34.0
SMC (%)	25.1	24.7	19.9	18.3	17.9	23.4	25.3	22.8	23.3	22.6
SOM (%)	0.7	0.7	0.7	0.5	0.7	0.5	1.1	1.0	0.6	1.3
Highly saline sites	**GJL**	**GWA**	**SPA**	**CSS**	**PID**	**BCL**	**KKR**	**CDT**	**SHL**	**SWA**
					Weather					
Annual precipitation (mm)	401	375.92	376	596.9	597.1	595.4	594.1	180	380	375.92
ELE (m a.s.l.)	195	191	190	676	467	843	640.6	114	194.7	192.3
MxT	43	48	48	34.1	35.2	34.7	35.2	51.1	48	48
MnT	0	3.9	3.9	-2.6	-2.4	-2.3	-2.1	8.6	4.1	4.1
					Soil analysis					
pH	8.1	8	8.3	8.1	8.2	7.9	7.8	8.6	8.4	8.2
EC (dS m^{-1})	10.0	11.0	11.1	11.4	11.6	11.8	12.2	16.0	22.3	31.5
SNa (mg Kg^{-1})	1017.1	1151.7	1166.1	1203	1321.2	1490.8	1550.5	1654.1	1834.1	2091.1
SK (mg Kg^{-1})	51.4	52.7	53.2	53.5	56.9	58.7	77.4	155.1	160.1	165.4
SCa (mg Kg^{-1})	35.8	36.1	38.7	39.9	40.2	45.3	52.3	69.6	84.3	95.1
SCl (mg Kg^{-1})	1611.1	1442.1	1454.4	1521.3	1545.7	1951.4	1605.3	1398.5	1955.1	2551.4
SNO (mg Kg^{-1})	5.6	1.9	2.4	2.1	2.2	2.1	2.2	2.8	3.2	3.0
SPO (mg Kg^{-1})	4.9	6.6	6.7	7.3	7.2	7.1	7.4	9.6	10.9	10.1
SSP (%)	34.3	34.4	33.9	30.1	30.3	30.5	30.4	28.3	32.3	34.3
SMC (%)	16.1	17.9	15.8	19.6	18.7	16.4	17.5	15.9	20.1	24.0
SOM (%)	1.2	1.3	0.8	1.1	1.0	1.3	0.8	0.7	0.9	0.9

Abbreviations: MAP-Annual precipitation; ELE-Elevation; MxT-Maximum temperature; MnT-Minimum temperature; EC- Soil ECe; pH - SoilpH; SOM-Soil organic matter; SCa- Soil Ca^{2+}; SK- Soil K^{+}; SNa- Soil Na^{+};SCl- Soil Cl^{-}; SNO- Soil NO_3^{-}; SPO- Soil PO_4^{3-}; SSP-Soil saturation percentage; SMC-Soil moisture contents; KHA-Kohala; ISB-Islamabad; PNA-Pahari Nala; MWA-Manawala; NSF-Nerian Sharif; DKA-Daska; PRD-Phularwan road; NML-Namal; LJM-Lower Jhelum, PRN-Puran; MPO-Mong Depot; PPD-Pasrur Pond; LYH-Layyah; PKT-Pir Kot; DKT-Dhir Kot; KWA-Kharianwala; PWL-Phularwan Canal; RCI-Rasool Choki; MHN-Majuhan; SKT-Shah Kot; GJL-Gunjal; GWA-Gatwala; SPA-Skindar Pura; CSS-Choa Sadien Shah; PID-Phid; BCL-Buchal; KKR-Kallar Kahar; CDT-Cholistan Desert; SHL-Sangla Hills; SWA-Sahianwala

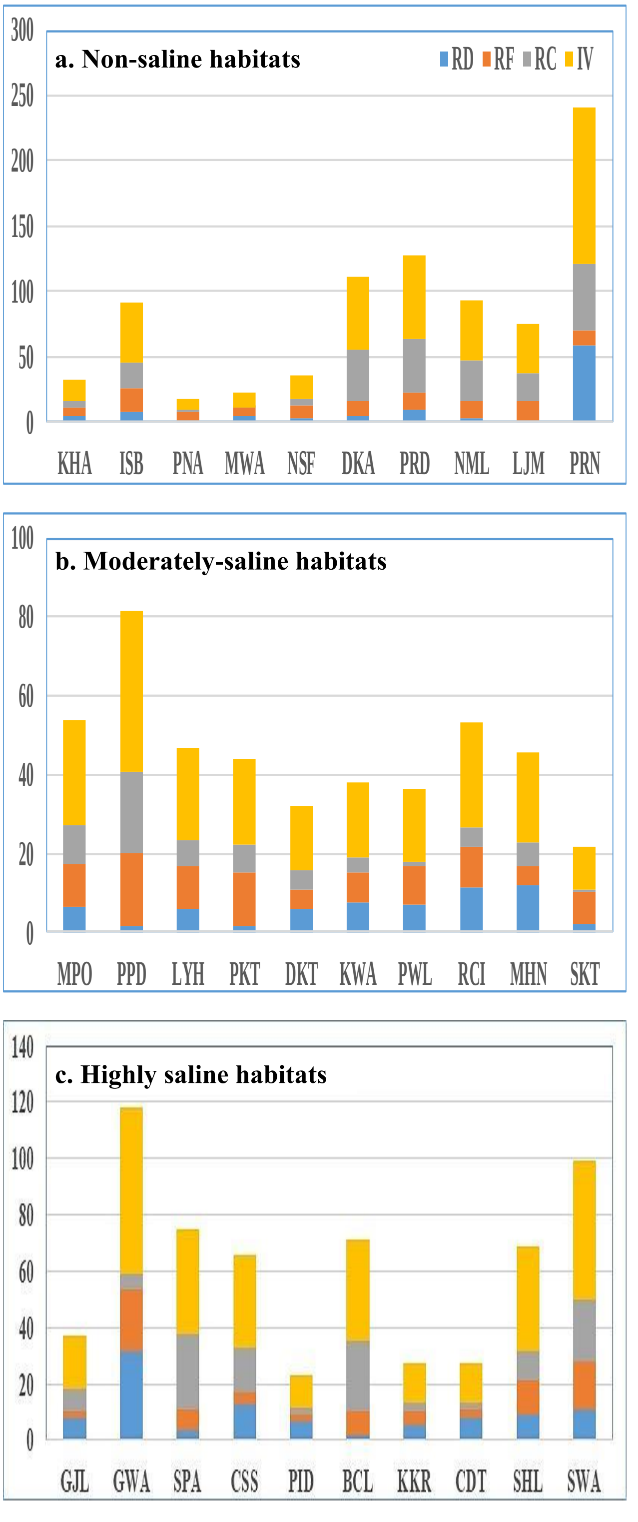


Fig. 4. Ecological parameters of *Ipomoea carnea* Jacq. collected from different habitats of Punjab and Azad Jammu and Kashmir, Pakistan.

Legends: RD-Relative density; RF-Relative frequency; RC-Relative cover; IV-Importance value; KHA-Kohala; ISB-Islamabad; PNA-Pahari Nala; MWA-Manawala; NSF-Nerian Sharif; DKA-Daska; PRD-Phularwan road; NML-Namal; LJM-Lower Jhelum, PRN-Puran; MPO-Mong Depo; PPD-Pasrur Pond; LYH-Layyah; PKT-Pir Kot; DKT-Dhir Kot; KWA-Kharianwala; PWL-Phularwan Canal; RCI-Rasool Choki; MHN-Majuhan; SKT-Shah Kot; GJL-Gunjal; GWA-Gatwala; SPA-Skindar Pura; CSS-Choa Sadien Shah; PID-Phid; BCL-Buchal; KKR-Kallar Kahar; CDT-Cholistan Desert; SHL-Sangla Hills; SWA-Sahianwala

Ecological parameters: In non-saline habitats, the relative density was the maximum (58.8) in PRN site, while all other population showed the minimum relative density values. Relative frequency was the highest (16.6) in ISB site, while the lowest in MWA and KHA sites. PRN site showed the maximum relative cover, while the MWA and PNA sites showed the minimum relative cover. Importance value was the maximum (120.4) in PRN site, while the minimum at PNA and MWA sites (Fig. 4a). In moderately saline habitats, relative density was the maximum in RCI and MHN sites, while the minimum in was recorded at PPD and PKT sites. PPD site showed the maximum relative frequency, while the PKT and MHN sites showed the minimum. PPD site showed the maximum relative cover, while the SKT site showed the minimum. Importance value was the highest in PPD site, while was the importance at the SKT site (Fig. 4b).

Among highly saline habitats, GWA site showed the highest relative density, while BCL site showed the lowest. Relative frequency was the maximum in GWA site, while the minimum was at PID site (Table 3). SPA and BCL sites showed the maximum relative cover, while PID and KKR sites showed the minimum relative cover. Importance value was the maximum at the GWA site, while the minimum in the PID site (Fig. 4c).

Redundancy analysis: In non-saline habitats, ecological parameter like RD and IV showed a strong association with MAP site, MxT and MnT with KHA and MWA sites. RC was associated with SOM and pH of PRD, ISB, DKA, NML and LJM sites, while RF was associated with ELE in NSF and PNA sites. The soil attributes EC, SNa, SCl, SK, SNO, SPO, SSP and SMC were linked to PRN site but did not showed any association with ecological parameters (Fig. 5a). In moderately saline habitats, RC was in close association with ELE, SPO and MAP of LYH, MPO and PPD sites, while IV was closely associated with SSP and pH in DKT and MHN sites. RD was in close association with EC, SNa, SCl, SK, SCa, SNO, SMC, MxT and MnT of PWL, KWA and RCI sites, while RF was closely associated with SOM in SKT and PKT sites (Fig. 4b).

In highly saline habitats, RD was in close association with pH in CDT and PID sites, while RC was closely associated SNO, SOM, ELE and MAP of SPA, GJL and CSS sites. RF and IV were closely associated with MxT, MnT, SK, SPO and SCa of GWA and KKR sites. The soil parameter like SSP, SMC, SNa, EC and SMC showed no association with ecological parameters of any of the highly saline habitats (Fig. 5c).

Response curves: In non-saline habitats RC, RD and IV showed negative slope in response to elevation, while the RF showed linear response against the elevation gradient (Fig. 6a). In moderately saline habitats, all ecological parameters (RD, RF, RC and IV) showed negative slope in response to elevation (Fig. 6b). In highly saline habitats RD, RF and IV showed negative slope in response to elevation, while RC showed positive slope in response to elevation (Fig. 6c). In non-saline habitats all ecological parameters (RD, RF, RC and IV) showed positive slope with increase in salinity (Fig. 6d). In moderately saline habitats, RC, RF and IV showed negative slope with increasing salinity, while RD showed a positive slope along increasing salinity (Fig. 6e). In highly saline habitats, RC, RF and IV showed the positive slope with increase in salinity, while RD showed the linear response with increase in salinity (Fig. 6f).

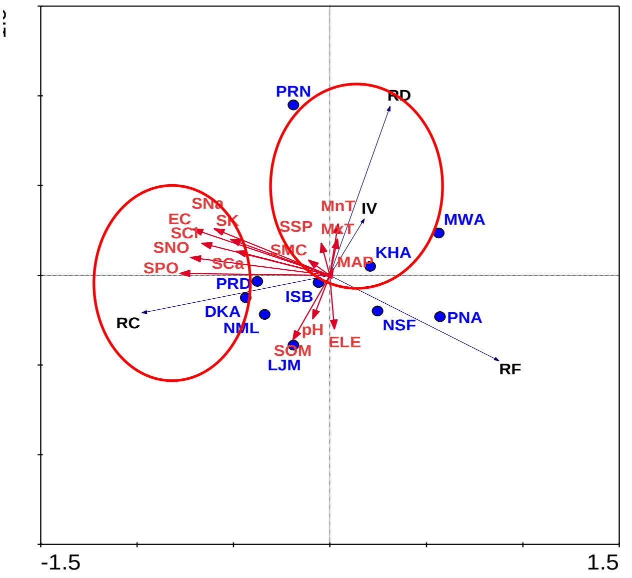
Discussion

Species associated at each study site were different not only with elevation but also with salinity gradient. The associated species with *I. carnea* at Khola were *Oplismenus compositus*, *Myrsine africana*, *Pinus roxburghii* and *Carex diandra*, which are species of temperate mountains (Khan *et al.*, 2019). Islamabad was dominated by 4 associated species along with *I. carnea* including one grass (*Apluda mutica*) and three shurbs/trees (*Olea europaea* L. subsp. *cuspidata*, *Myrsine africana* and *Carissa spinarum*). The most dominated species was *Apluda mutica*, the forest grass used as fodder in mountainous regions (Ali & Kauser, 2006). Pahar Nala, a wetland site in the vicinity of Pasrur, was completely invaded by *I. carnea*, however, the other associated species included *Saccharum spontaneum*, *Phragmites karka* and *Cynodon dactylon* that provide shelter and breeding spot to several aquatic wildlife species (Zereen *et al*., 2018).

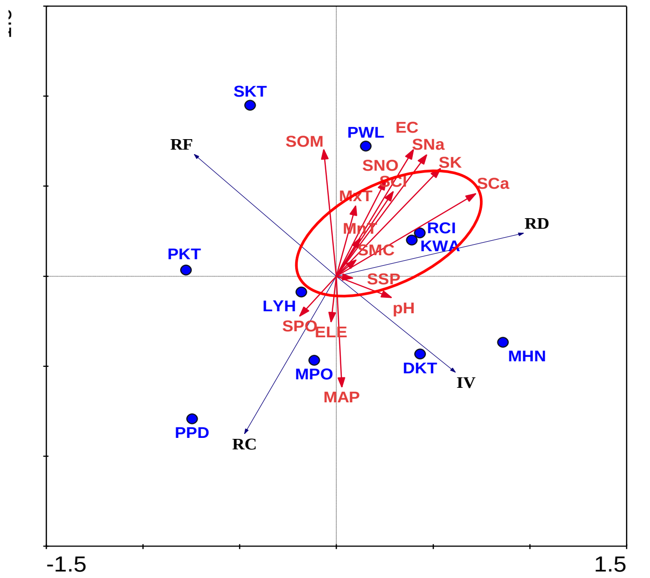
In Manawala (Punjab), the most associated species with *I. carnea* dominating in agricultural fields was *Cynodon dactylon.* The other colonizing species included *Oxalis corniculata*, *Melilotus indicus* and *Achyranthes aspera*, as also reported by Malik *et al*., (2013). Nerian Sharif (District Sudhnoti) is contiguous to Poonch Valley and located at the 1898 m elevation in Azad Jammu and Kashmir. The vegetation of Nerian Sharif was distinct from the vegetation of other districts that was patchy and dense with high alpine trees. However, shrubs and small bushes inhabited high mountainous region that was invaded by *I. carnea* along with associated species like *Themeda anathera, Cynodon dactylon, Dichanthium annulatum* and *Pinus roxburghii* (Shabir *et al.*, 2017). Daska site was dominated by three grasses, *Cynodon dactylon, Tripidium bengalense* and *Desmostachya bipinnata* and, two herbs *Abutilon indicum* and *Malvastrum coromandelianum. Cynodon dactylon* was the dominating grass of agricultural fields (Ikram *et al.*, 2014).

Table 3. Ecological characteristics of *Ipomoea carnea* Jacq. from different regions of Punjab and Azad Jammu and Kashmir, Pakistan.

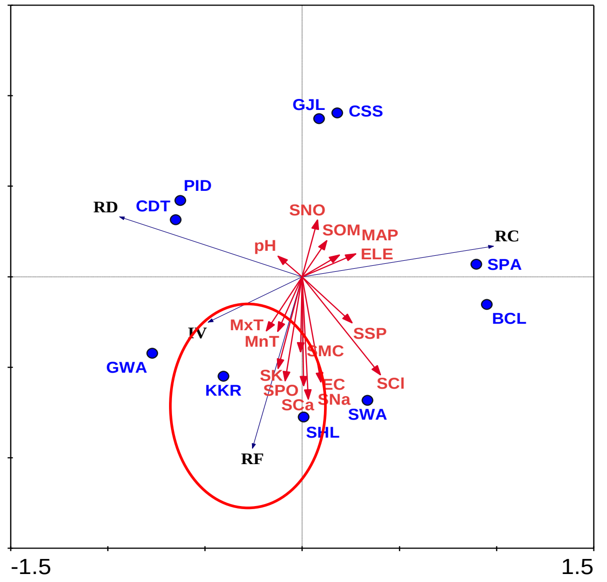
Collection site	Associated plant species
Non-saline	
Kohala	*Oplismenus compositus, Myrsine africana, Pinus roxburghii* and *Carex diandra*
Islamabad	*Apluda mutica, Olea europaea L. subsp. cuspidata, Myrsine africana* and *Carissa spinarum*
Pahari Nala	*Saccharum spontaneum, Phragmites karka, Nerium oleander* and *Cynodon dactylon*
Manawala	*Cynodon dactylon, Oxalis corniculata, Melilotus indicus* and *Achyranthes aspera*
Nerian Sharif	*Themeda anathera, Cynodon dactylon, Dichanthium annulatum* and *Pinus roxburghii*
Daska	*Cynodon dactylon Tripidium bengalense* and *Malvastrum coromandelianum*
Phularwan Road	*Cynodon dactylon, Tripidium bengalense, Cannabis sativa* and *Oxalis corniculata*
Namal	*Eulaliopsis binata, Pennisetum orientale, Oxalis corniculata* and *Periploca aphylla*
Rasool Barrage	*Cannabis sativa Malvastrum coromandelianum* and *Achyranthes aspera*
Puran	*Cynodon dactylon, Malvastrum coromandelianum* and *Setaria verticillata*
Moderately saline	
Mong Depot	*Cannabis sativa, Prosopis glandulosa* and *Eucalyptus camaldulensis*
Pasror pond	*Cannabis sativa, Morus alba, Convolvulus arvensis* and *Cirsium arvense*
Layyah	*Cynodon dactylon, Xanthium strumarium* and *Malvastrum coromandelianum*
Pirkot	*Dodonaea viscosa, Dichanthium annulatum* and *Cymbopogon jwarancusa*
Dirkot	*Themeda anathera, Cynodon dactylon, Dichanthium annulatum* and *Pinus roxburghii*
Kharianwala	*Cynodon dactylon, Dalbergia sissoo* and *Xanthium strumarium*
Phularwan canal	*Cannabis sativa, Achyranthes aspera* and *Malvastrum coromandelianum*
Rasool Choki	*Cynodon dactylon, Tripidium bengalense* and *Euploca strigosa*
Majuhan	*Cymbopogon jwarancusa, Plantago lanceolata* and *Lespedeza floribunda*
Shahkot	*Cynodon dactylon, Eucalyptus camaldulensis* and *Prosopis juliflora*
Highly saline	
Gunjal	*Senegalia modesta, Cymbopogon jwarancusa* and *Saccharum griffithii*
Gutwala	*Eucalyptus camaldulensis, Malvastrum coromandelianum* and *Oxalis corniculata*
Skindarpura	*Cynodon dactylon, Eucalyptus kitsoniana* and *Eucalyptus melanophloia*
Choa Saidan Shah	*Cynodon dactylon, Senegalia modesta* and *Cymbopogon jwarancusa*
Phid	*Dichanthium foveolatum, Chrysopogon serrulatus* and *Salsola imbricata*
Buchal	*Saccharum griffithii, Heteropogon contortus* and *Senegalia modesta*
Kalar Kahar	*Cynodon dactylon, Senegalia modesta* and *Justicia adhatoda*
Cholistan Desert	*Lasiurus scindicus, Dipterygium glaucum* and *Calligonum polygonoides*
Sangala Hills	*Cynodon dactylon, Dalbergia sissoo* and *Xanthium strumarium*
Sahianwala	*Phragmites karka, Cyperus laevigatus* and *Cenchrus setigerus*



a. Non-saline habitats



b. Moderately-saline habitats



c. Highly saline habitats

Figure legends: ecological parameters: RD-Relative density; RF-Relative frequency; RC-Relative cover; IV-Importance value; MAP-Annual precipitation; ELE-Elevation; MxT-Maximum temperature; MnT-Minimum temperature. **Soil analysis:** EC (ECe); pH (pH); SOM-Organic matter; SCa-Ca^{2+}; SK-K^{+}; SNa-Na^{+}; SCl-Cl^{-}; SNO-NO_3^{-}; SPO-PO_4^{3-}; SSP-Saturation percentage; SMC-Moisture contents. Populations: KHA-Kohala; ISB-Islamabad; PNA-Pahari Nala; MWA-Manawala; NSF-Nerian Sharif; DKA-Daska; PRD-Phularwan road; NML-Namal; LJM-Lower Jhelum, PRN-Puran; MPO-Mong Depot; PPD-Pasrur Pond; LYH-Layyah; PKT-Pir Kot; DKT-Dhir Kot; KWA-Kharianwala; PWL-Phularwan Canal; RCI-Rasool Choki; MHN-Majuhan; SKT-Shah Kot; GJL-Gunjal; GWA-Gatwala; SPA-Skindar Pura; CSS-Choa Sadien Shah; PID-Phid; BCL-Buchal; KKR-Kallar Kahar; CDT-Cholistan Desert; SHL-Sangla Hills; SWA-Sahianwala

Fig. 5. Redundancy analysis (RDA) triplots of *Ipomoea carnea* Jacq. collected from different habitats of Punjab and Azad Jammu and Kashmir, Pakistan

Phularwan road site facing heavy traffic load was dominated by *I. carnea* and other associated species like *Cynodon dactylon, Tripidium bengalense, Cannabis sativa, Oxalis corniculata* and few other grasses (Iqbal *et al.*, 2019). *Eulaliopsis binata, Pennisetum orientale, O. corniculata* and *Periploca aphylla* and many other associated species with *I. carnea* inhabited Namal site, a steep mountainous range but the most dominated species was *E. binata* (Shah *et al.*, 2019). Lower Jhelum canal (Mandi Bahauddin) a fresh water wetland site near Rasul Barrage was dominated by *Cannabis sativa, M coromandelianum, Achyranthes aspera* and *Xanthium strumarium*, the associated species of *I. carnea.* (Khan *et al.*, 2015). Puran site, a village in Gujarat near the main canal of Rasool Barrage, was predominately invaded by *I. carnea*. Other associated species were *C. dactylon, D. sissoo, M. coromandelianum* and *Setaria verticillata* (Kamran *et al.*, 2014).

Mong Depo site, a barren land along roadside, was dominated by *Cannabis sativa* along with *I. carnea.* The other associated species were *Prosopis glandulosa* and *Eucalyptus camaldulensis* (Khan *et al.*, 2015). *Cannabis sativa, Morus alba, Convolvulus arvensis* and *Cirsium arvense* were the associated species with *I. carnea* inhabiting the Pasrur pond of sewerage water, but the most dominated species was *Cannabis sativa* (Zereen *et al.*, 2018). In Layyah, the *Cynodon dactylon* was the most dominated species. The other associated species included *Xanthium strumarium, Malvastrum coromandelianum, Tripidium bengalense, Oxalis corniculata* and *Achyranthes aspera*, most were the agricultural weeds (Shaheen *et al.*, 2014). Pirkot site was located in the mountainous range of Poonch Valley, AJK, which was dominated by associated species like *Dodonaea viscosa, Dichanthium annulatum* and *Cymbopogon jwarancusa.* Dirkot site, a mountainous range in district Bagh of AJK was dominated by three forest grasses *Themeda anathera, Cynodon dactylon, Dichanthium annulatum* along with *Pinus roxburghii*, the species of Himalayan mountains (Khan *et al.*, 2019).

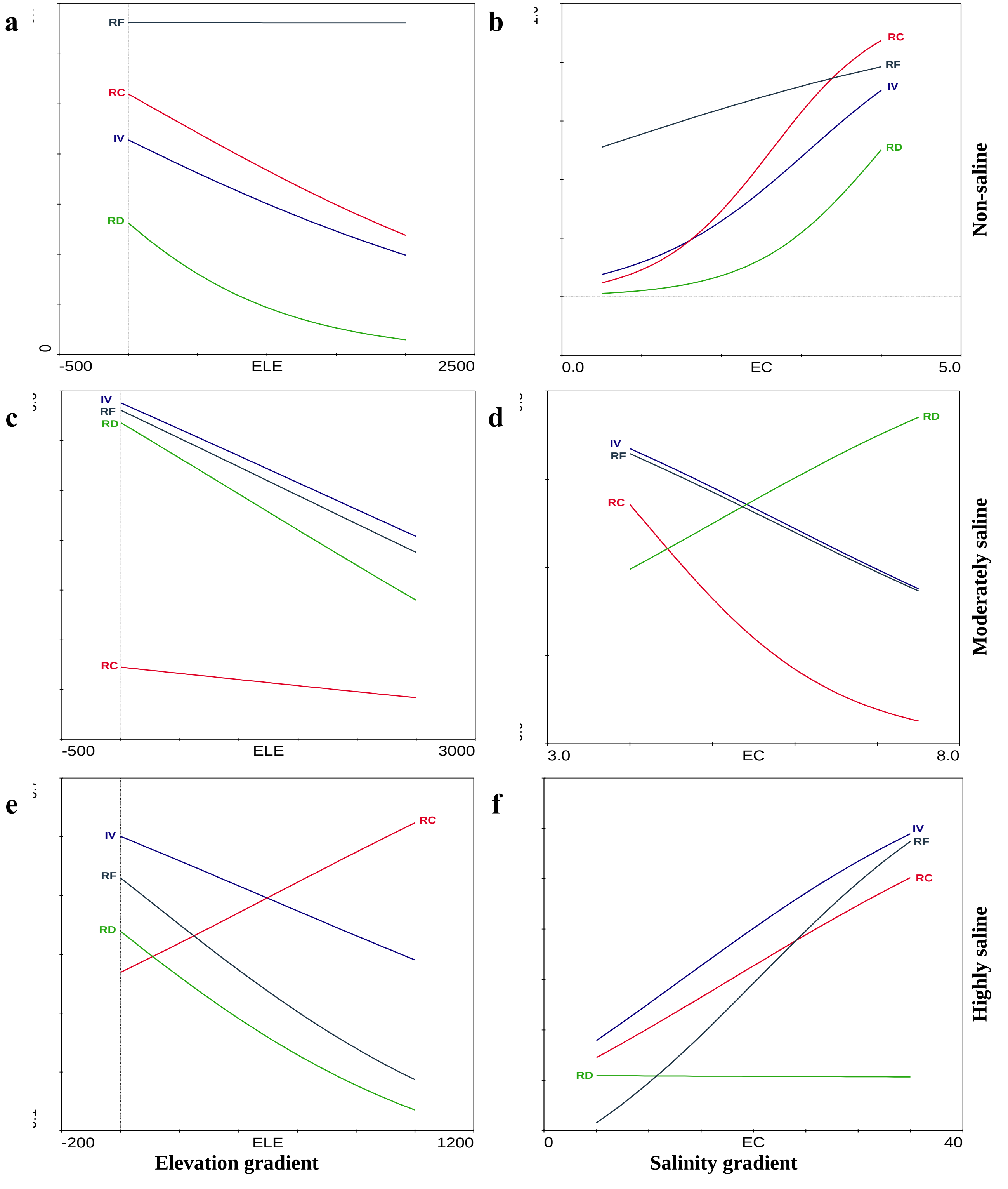


Fig. 6. Response curve along elevation (0 to 1200 m left to right) and salinity gradients (0 to 40 dS m^{-1} left to right) of *Ipomoea carnea* Jacq. collected from different habitats of Punjab and Azad Jammu and Kashmir, Pakistan.
Figure legends: RD-Relative density; RF-Relative frequency; RC-Relative cover; IV-Importance value; ELE-Elevation; EC, ECe

Kharianwala population was collected from the bank of main canal in district Gujrat having moderately saline soil. The associated species with *I. carnea* were *Cynodon dactylon*, *Dalbergia sissoo* and *Xanthium strumarium* (Parvaiz, 2014). Phularwan canal, the population collected from wetland near main canal, was dominated by *I. carnea*. The other associated species were *Cannabis sativa*, *Achyranthes aspera* and *Malvastrum coromandelianum* (Iqbal *et al.*, 2019). Rasool Choki site, located near to Rasool Barrage, was dominated by *Cynodon dactylon, Populus nigra* and *Euploca strigosa* with *I. carnea* (Khan *et al.*, 2015). Majuhan (Himalayan mountains in Azad Jammu and Kashmir) was dominated by *Cymbopogon jwarancusa*, *Plantago lanceolata* and *Lespedeza floribunda* with invasive species *I. carnea* (Khan *et al.*, 2019). *Cynodon dactylon, Eucalyptus* *camaldulensis* and *Prosopis juliflora* were the associated species with *I. carnea* inhabiting Shahkot population near industrial waste water (Raza, 2018).

Gunjal (Potohar region) was dominated by grasses *Cymbopogon jwarancusa* had a useful diagnostic feature is the aromatic flavor when a leaf of it is chewed and *Saccharum griffithii* which are economically very important (Qureshi *et al.*, 2011). Gutwala plantation was dominated by *Eucalyptus camaldulensis, Malvastrum coromandelianum* and *Oxalis corniculata.* Gutwala Artificial Forest Plantation is very vital due to conservation of many endangered species therein (Hameed *et al.*, 2011). Skindarpura is a saline wetland near canal expressway in Faisalabad, which was dominated by *I. carnea* and many other species like *Cynodon dactylon, Eucalyptus kitsoniana* and *Eucalyptus melanophloia*. Faisalabad is an arid region and the temperature of the urban area and its surrounding ranges from 38 to 48°C in summer and of 17-6°C in winter. The average annual precipitation is about 200 mm. *Cynodon dactylon, Cenchrus pennisetiformis, Dichanthium annulatum, Panicum antidotale, Oxalis corniculata* and *Malvastrum coromandelianum* are the dominated species of Faisalabad (Malik *et al.*, 2013).

The Salt Range comprises the most vital geologic and paleontologic zones in Pakistan, and is one of the important field ranges in the whole world. In spite of its easy accessibility, it has a treasure of geological and paleontological geographies. Our populations Choa Sadien Shah, Phid, Buchal and Kalar Kahar were from Salt Range and mostly dominated by *Senegalia modesta, Justicia adhatoda, Cymbopogon jwarancusa* and *Cynodon dactylon* (Hussain & Ali, 2006).

The Cholistan Desert can be divided into two parts, the northern Lesser Cholistan and southern Greater Cholistan. The desert is characterized by highly saline alluvial clay, dunes and sandy ridges, and semi-stabilized to frequently shifting dunes. The climate is subtropical, harsh, hot and arid, and influenced by seasonal monsoons dominated by *Lasiurus scindicus, Dipterygium glaucum* and *Calligonum polygonoides.* Sangala Hills and Sahianwala sites were two highly saline habitats in Faisalabad and dominated by *Cynodon dactylon, Dalbergia sissoo, Xanthium strumarium, Phragmites karka, Cyperus laevigatus* and *Cenchrus setigerus* (Kamal *et al.*, 2021).

Pinus roxburghii, Myrsine africana, Cymbopogon jwarancusa, Dichanthium annulatum, Apluda mutica Oplismenus compositus, Themeda anathera and *Carex diandra* were the most dominated species in Himalayan Region populations (Kohla, Islamabad, Nerian Sharif, Namal, Pirkot, Dirkot and Majhuan). The Himalayan region had the highest peaks and geologically youngest mountainous region at globe scale (Burchfiel & Royeden, 1985) with diverse flora and fauna, therefore vital for conservationists and ecologists (Mahagaonkar *et al.*, 2017). Ecologists and environmentalists are attracted to investigate the biological alteration among species diversity by different environmental factors in an ecosystem (Grytnes, 2003).

Saccharum spontaneum, Phragmites karka, Cynodon dactylon, Malvastrum coromandelianum, Achyranthes aspera, Malvastrum coromandelianum, Convolvulus arvensis Cynodon dactylon, Tripidium bengalense and *Euploca strigosa* were the dominated species of canal and river bank populations. The vegetation along the river or stream banks is characterized as riparian vegetation, riverbed vegetation or floodplain vegetation (Masahito *et al.*, 2001) and forms a vital component of the wetlands (Naiman & Décamps, 1997). The riparian biomes are highly diverse in species composition due to variability in topography, soil composition and hydrological processes (Tabacchi *et al.*, 2000). *Cynodon dactylon, Tripidium bengalense, Cannabis sativa, Oxalis corniculata, Dichanthium foveolatum, Chrysopogon serrulatus, Salsola imbricate, Dalbergia sissoo* and *Xanthium strumarium* were the dominated species along roadside. Urbanization is a main threat to biodiversity (McKinney, 2006) and a source of biotic homogenization (Wittig and Becker, 2010). The road system is one of the chief landscape units that characterize urbanization (Forman *et al.*, 2002).

Conclusion

It was concluded that invasiveness and spreading of *I. carnea* did not depend upon a single environmental factor but altitude, salinity and soil structure collectively determined its invasive success in the studied habitats. Apparently the soil ECe was the prominent factor for distribution pattern whereas altitude may have restrained the invasion to some extent. Invasion success based on frequency, density and percent cover decreased with increase in elevation at non-saline, moderately saline and highly saline habitats. Invasive success decreased along salinity gradient at moderately saline habitats, while increased at non-saline and highly saline habitats.

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