Chemical and Biological Technologies in Agriculture

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The synergistic effect of biochar and poly(2-ethyl-2-oxazoline)/poly (2-hydroxyethylmethacarylate)/chitosan) hydrogels on saline soil properties and carrot productivity

Sayed A. Abdeen[1], Hassan H. H. Hefni[2*], Ahmed Awadallah-F[3] and Nasser R. Abd El-Rahman[2]

Abstract

Background Soil salinity is one of the most important factors limiting crop production. Furthermore, with the increasing population and saline soil worldwide there is no choice but to utilize saline soil to increase the agricultural regions. Therefore, to improve carrot productivity under saline conditions, it is necessary to provide good management such as applying hydrogels and biochar for improving soil properties.

Methodology Hydrogels (PEtOx-HEMA-CS) were synthesized from poly (2-ethyl-2-oxazoline), 2-hydroxyethyl methacrylate (HEMA as crosslinker) and chitosan (CS) via exposure those to gamma irradiation dose; 30 kGy of dose rate 0.9 kGy/h and obtained three types of hydrogels according to concentration of chitosan used. The PEtOx-HEMA-CS hydrogels were enhanced water holding capacity for agriculture purposes. The chemical structures of obtained hydrogels were characterized by FTIR, XRD and SEM. The swelling (%) and gelation (%) were determined. Biochar (BC) as an active substance was physically mixed with those hydrogels at various ratios (0/100, 0.5/99.5, 1/99 and 100/0 (g/g) biochar/hydrogels). BC, PEtOx-HEMA-CS and the mixture of PEtOx-HEMA-CS-BC were mixed with saline soil at ratio 0.05% and 0.1% w/w of obtained materials/soil. A pot experiment was conducted to mitigate the salinity hazards on carrot productivity using biochar with and without hydrogels. Mean maximum temperature, minimum temperature, precipitation, relative humidity and wind speed from September to December in the studied region are 28.66 ℃, 15.76 ℃, 0.01 mm, 58.81%, 5.94 km/h, respectively.

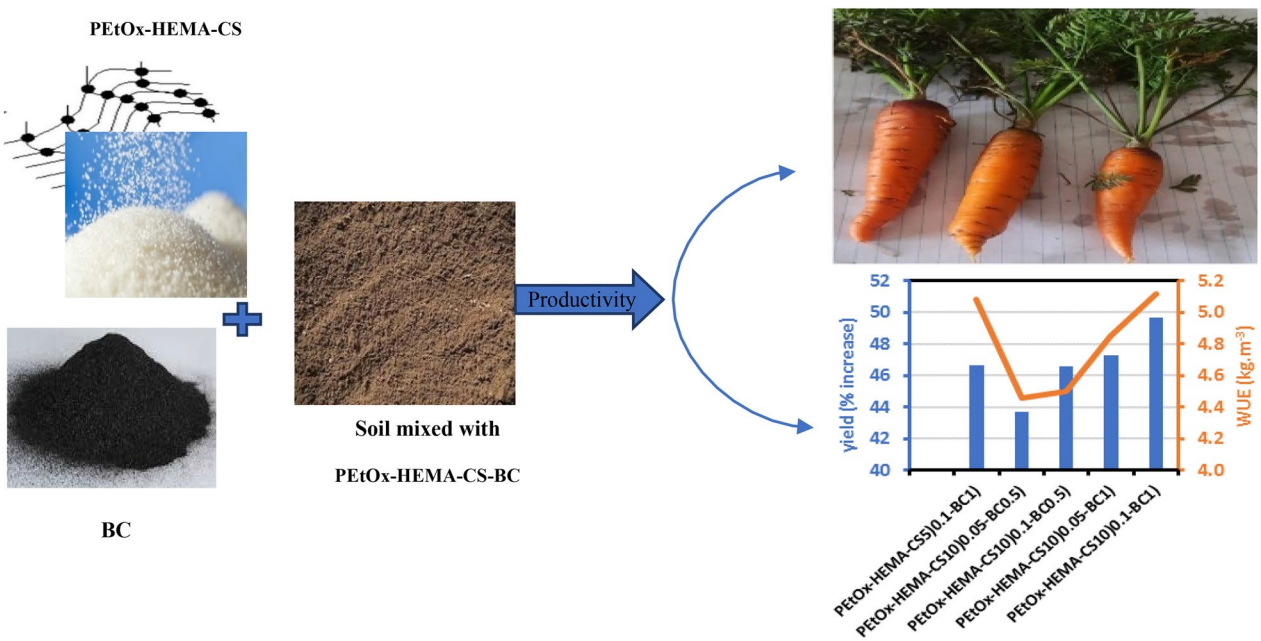
Findings The obtained data referred that there is a significant decrease in soil salinity and exchangeable sodium percentage and increase in organic matter, cation exchange capacity, field capacity, permanent wilting point and available water especially at (PEtOx-HEMA-CS5)0.1-BC1. The highest increment percentage of nitrogen, phosphorous and potassium were 36.36%, 70% and 72%, respectively. In addition, the relative increase of carrot productivity was 49.63% at the highest rates of biochar and hydrogels. However, the highest value of water use efficiency was observed at the mixture of biochar and hydrogels at (PEtOx-HEMA-CS5)0.1-BC1.

Conclusions Finally, applying biochar combined with (PEtOx-HEMA-CS5) could be recommended as a good approach to improve carrot productivity and water use efficiency under saline soil conditions.

Keywords Hydrogels, Biochar, Saline soil, Carrot productivity, Chitosan

*Correspondence:
Hassan H. H. Hefni
hassanhefni@yahoo.com; hassanhefni@epri.sci.eg
Full list of author information is available at the end of the article

Graphical Abstract



Introduction

Hydrogels play a vital role in the agricultural sector and are used as structural materials to create a climate conducive to plant growth and to raise irrigation water efficiency [1, 2]. Hydrogel has been utilized as a water-retaining material, enhance water penetration rate, improve the field capacity and increase the amount of water available to plants as well as the length of time it was available [3]. Hydrogels have an incredible ability to absorb and hold extremely large amounts of water. When it comes into touch with water, it swells and turns into gel materials [4]. The application of hydrogels to the soil aided in the retention of more moisture in the soil content, improved water holding capacity, decreased soil infiltration rate and form protective coating in plants under abiotic stress conditions [5, 6]. Polyacrylamide hydrogel is a macromolecular cross-linked and environmentally responsive hydrogel with high water absorption which is useful to plant growth. It could have deteriorated as a result of physical or chemical changes [7]. Hydrogels and biochar are considered soil conditioners and yield enhancers, which can retain both water and nutrients, and then release them over an extended period. Although most superabsorbent are comprised of synthetic polymers because of their excellent price/performance ratio, the idea of partially or completely replacing such synthetic materials with "greener" alternatives must be considered for environmental reasons. Biopolymers, such as polysaccharides, are an environmentally friendly alternative to synthetic polymers, because they are cheap, readily available, and renewable organic materials [8]. In addition, their natural origin makes them inherently biocompatible, biodegradable, and non-toxic, so they are often used in the synthesis of hydrogel materials with potential applications in agriculture field [9]. In addition, chitosan a highly deacetylated derivative of chitin, one of the most abundant natural and biodegradable polymers widely used in agriculture [10], a one-of-a-kind natural basic polysaccharide, excellent biocompatibility, multifunctional reactivities, polycationic characteristics, and antibacterial capabilities [11].

Biochar, a porous solid carbonaceous material created under a wide scale of temperature ranged from 300 to 1000 ℃ in an oxygen-deficient environment. In addition to the primary component of carbon, biochar also contains the macronutrients nitrogen, phosphorous, and potassium, which can increase the crop yield [12]. Physical adsorption and ionic exchange are the most reported methods for biochar amending saline soil. This is due to biochar's unique properties, which include high porosity,

surface area, functional groups, and carbon content [13]. Omondi et al. [14] concluded that biochar addition decreased soil bulk density between 3% and 31% in 19 out of 22 soils. Likewise, the addition of 30000 kg ha^{-1} of biochar decreased soil bulk density up to 75% compared with the no biochar addition [15]. Under saline conditions, applying biochar resulted in an increase in total yield of tomato from 14.0% to 43.3%. The positive impacts of biochar on crop productivity have been linked to both direct and indirect effects, including higher water and nutrient retention, as well as better soil physical qualities, such as infiltration rate in sandy soils. The biochar increased the maximum moisture content by 22–25% [16]. Biochar also prevents sodium uptake by plants by releasing nutrients into the soil solution and transient Na^+ binding due to its high adsorption capability [17]. The application of biochar can decrease the detrimental impacts that salt-affected soils have on plant growth and yield as well as on elements of soil quality containing soil aggregation and stability Furthermore, most of advantages of applying biochar have been noticed when it is combined with other organic and inorganic fertilizers and amendments [18].

Soil management affects soil quality and plays a significant part in agriculture sustainability. The utilization of soil amendments is an essential strategy to enhance the use of scarce water supplies for agricultural production and preserve optimal soil qualities [19]. Soil salinization is a major phenomenon of soil deterioration that has a significant effect on crop productivity, threatens food security and sustainability [20]. Due to geographical sites, limited water for irrigation, low rainfall rates, and high temperatures in some areas, agriculture in arid and semi-arid regions has various challenges [21]. Low precipitation, native rock weathering, saline water irrigation, limited rainfall, high surface evaporation, and poor cultural practices have all led to expansion of saline soil, which causes a negative impact on osmotic stress, nutritional shortage, and oxidative stress [22]. For saline soil restoration, a diversity of organic and inorganic amendments is utilized. Some natural soil amendments, such as biochar, can boost macro aggregation, organic carbon, and macronutrients while also sustaining microbial activity, improving soil characteristics and plant nutrient uptake [23]. As salt-affected areas occupy nearly 1 billion hectares worldwide, it is predicted that this area will grow due to climate change and inadequate management of land and water resources [22]. Therefore, the addition of amendment in salt-affected soils has gained clear attention for the scientists of agriculture [25].

The combined application of biochar with manure, compost, or other organic materials can enhance nitrogen use efficiency as a result of slower leaching rates in saline soils [26]. Application of biochar and synthetic polymer improved the hydro-physical features of sandy soil in arid environments [27]. Biochar, combined with a superabsorbent polymeric hydrogel could be a novel technique for enhancing soil properties and increasing crop growth and yield [28].

Carrot root rot is highly impacted by growth media and other parameters that contribute to plant stress [29]. There is limited quantitative data on improving carrot yield responses to abiotic stress [30]. The modified biochar could be more appropriate for poor-nutrient soils and has a high absorption capacity and potential for water absorption [31]. Making a cost-effective composite material by mixing the biochar with polymers leads to better performance for increasing water absorption capacity. There is an increasing need for a potential technique to apply cost-effectively promising approaches globally to mitigate salinity hazards in agriculture, especially for environmentally acceptable technologies. Therefore, more efficient soil environmentally conditioners with better ability to grow crops in saline soils, which can occur in huge regions, are still needed. This study hypothesis that, both biochar and hydrogels have advantages of their own that can be obtained by combining the two to improve carrot productivity under saline soil conditions. Therefore, the aim of the current study is to prepare hydrogels from poly (2-ethyl-2-oxazoline), different concentrations of chitosan, and 2-hydroxyethyl methacrylate as crosslinker via gamma irradiation (green initiator for crosslinking process) to form (PEtOx-HEMA-CS1, PEtOx-HEMA-CS5, and PEtOx-HEMA-CS10) hydrogels. The outcome hydrogels and biochar will be used to enhance carrot productivity and their related parameters such as water use efficiency under saline soil conditions.

Materials and methods

Materials

Poly(2-ethyl-2-oxazoline) with average $M_w \sim 50{,}000$, 2-hydroxyethyl methacrylate (purity ≥ 99%,) were supplied from Sigma-Aldrich (Germany). Chitosan flakes with average $M_w \sim 110$ kDa and degree of deacetylation is > 85% was prepared elsewhere [32]. All chemicals were used without further purification.

Hydrogel preparation

60 g of poly(2-ethyl-2-oxazoline) is dissolved in 300 ml of distilled water using magnetic stirrer (150 rpm) at 45 ℃ for 24 h. 1, 5 and 10 g of chitosan were dissolved separately in 100 ml of 1%, 5%, and 10% (*v*/*v*) aqueous solutions of glacial acetic acid in glass conical flask, then magnetically stirred at 150 rpm for 24 h at 65 ℃. Then, chitosan solutions (named

CS1, CS5, and CS10) were filtered through polyester cloth to remove the remaining residues of insoluble impurities. 100 ml of poly(2-ethyl-2-oxazoline) solution is added to each chitosan solutions (CS1, CS5, and CS10) separately in three conical flasks and stirred magnetically at150 rpm at room temperature for 24 h till homogenized solutions. The homogenized mixtures of poly (2-ethyl-2-oxazoline) and chitosan are poured into glass tubes, then sealed tightly and exposure to gamma irradiation (gamma rays as green initiator for crosslinking process using Indian cell with irradiation dose rate 0.9 kGy/h from ^{60}Co as the main source). The fixed dose used is 30 kGy along the recent work. This value was chosen to avoid the CS degradation and guarantee the hydrogel formation [33].

It was noted from emerged out that glass tubes after exposure to gamma irradiation, all the mixtures are still liquid and do not form hydrogel. Therefore, 5 ml of 2-hydroxyethyl methacrylate is added to three mixtures as crosslinker between poly (2-ethyl-2-oxazoline) and chitosan, then again exposure to gamma irradiation of 30 kGy (gamma rays as green initiator for crosslinking process). It is noteworthy to mention that 1 to 4 ml of 2-hydroxyethyl methacrylate was not enough to make convenient gelation, while 5 ml of 2-hydroxyethyl methacrylate is helpful to make a good hydrogel.

The obtained hydrogels (PEtOx-HEMA-CS1, PEtOx-HEMA-CS5, and PEtOx-HEMA-CS10) are left for several days (4 days) to full drying at 50 °C followed g by grinding to obtain powder. The obtained hydrogels and their coded abbreviation suggested are listed in Table 3. Furthermore, a proposed reaction mechanism among poly (2-ethyl-2-oxazoline), 2-hydroxyethyl methacrylate and chitosan reactants are described in Fig. 1.

Determination of swelling and gelation percentage

The swelling (%) of hydrogel was evaluated by dipping the dried hydrogel in distilled water for a certain time at room temperature, and then weighed. The swelling (%) was determined according to the following formula:

$$Swelling(\%) = \frac{W_t - W_0}{W_0} \times 100$$

where Wt is the weight swollen hydrogel (g) and Wo is the weight of dry hydrogel (g).

Extraction of the sol fraction was carried out by Soxhlet apparatus for 3 h using distilled water as solvent. Then, hydrogel was dried at 50 °C to a constant weight in oven. The gelation (%) was determined gravimetrically using the following formula:

$$Gelation(\%) = \frac{W_d}{W_0} \times 100$$

where W_d is the weight of dry hydrogel after extraction process (g) and W_o is the weight of dry hydrogel before extraction process (g).

Preparation of biochar

Fresh wood of mango trees was collected and pyrolyzed at temperature range (400–600 ℃) for prepared biochar. Fresh wood of mango trees was spread out and air-dried, bagged and sealed for future use. The experimental device included a pyrolysis furnace, a thermostat, high purity N_2, and high purity CO_2. Then, taking an appropriate amount of fresh wood of mango trees was weighed then samples were pyrolyzed at 500 ℃ under the pyrolysis atmosphere of N_2 gas with flow rate 100 cm^3/min. The biochar material was manufactured at a heating rate of 20 °C/min. The furnace was evacuated for a sufficient time in advance to evacuate the air in the furnace, and the temperature was raised to the target temperature at a certain temperature increase rate and the inlet flow rate and maintained for 120 min. Then, the prepared biochar was cooled to room temperature in a dry dish and kept sealed. Furthermore, the setup diagram of biochar formation is depicted in Additional file 1: Fig. S1. The mixing between prepared hydrogels and biochar are conducted mechanically with deferent ratios as investigated in Table 1.

Experimental design

A pot experiment was conducted in a completely randomized design with three replicates at the Faculty of Agriculture, Al-Azhar University, Nasr city, Cairo, Egypt, in the second week of September 2021 to investigate the effect of biochar and hydrogel polymers on saline soil properties, water use efficiency and carrot productivity. Mean maximum temperature, minimum temperature, precipitation, relative humidity and wind speed from September to December are 28.66 ℃, 15.76 ℃, 0.01 mm, 58.81%, 5.94 km/h, respectively. The investigated soil was treated by biochar, PEtOx-HEMA-CS1, PEtOx-HEMA-CS5, and PEtOx-HEMA-CS10 at two ratios (0.05% and 0.1% (w/w) of hydrogel or biochar/soil) as alone or mixed with each other, as described in Table 1. The pots (30 cm diameter) were filled with 7 kg loamy sand soil and mixed by different rates of the studied materials.

The studied materials were added during the soil preparation with phosphate fertilization. Six seeds of carrot *(Daucus carota L.)* were sown per pot then thinned to three plants after germination and irrigated at field capacity during the experimental period. Carrot fertilized as follows: 200 kg.fed^{-1} Super phosphate (15% P_2O_5), 200 kg. fed^{-1} of Ammonium sulphate (21% N), and 100 kg.fed^{-1} Potassium sulfate (48% K_2O) were added in to three doses after 20 days of germination. At harvest

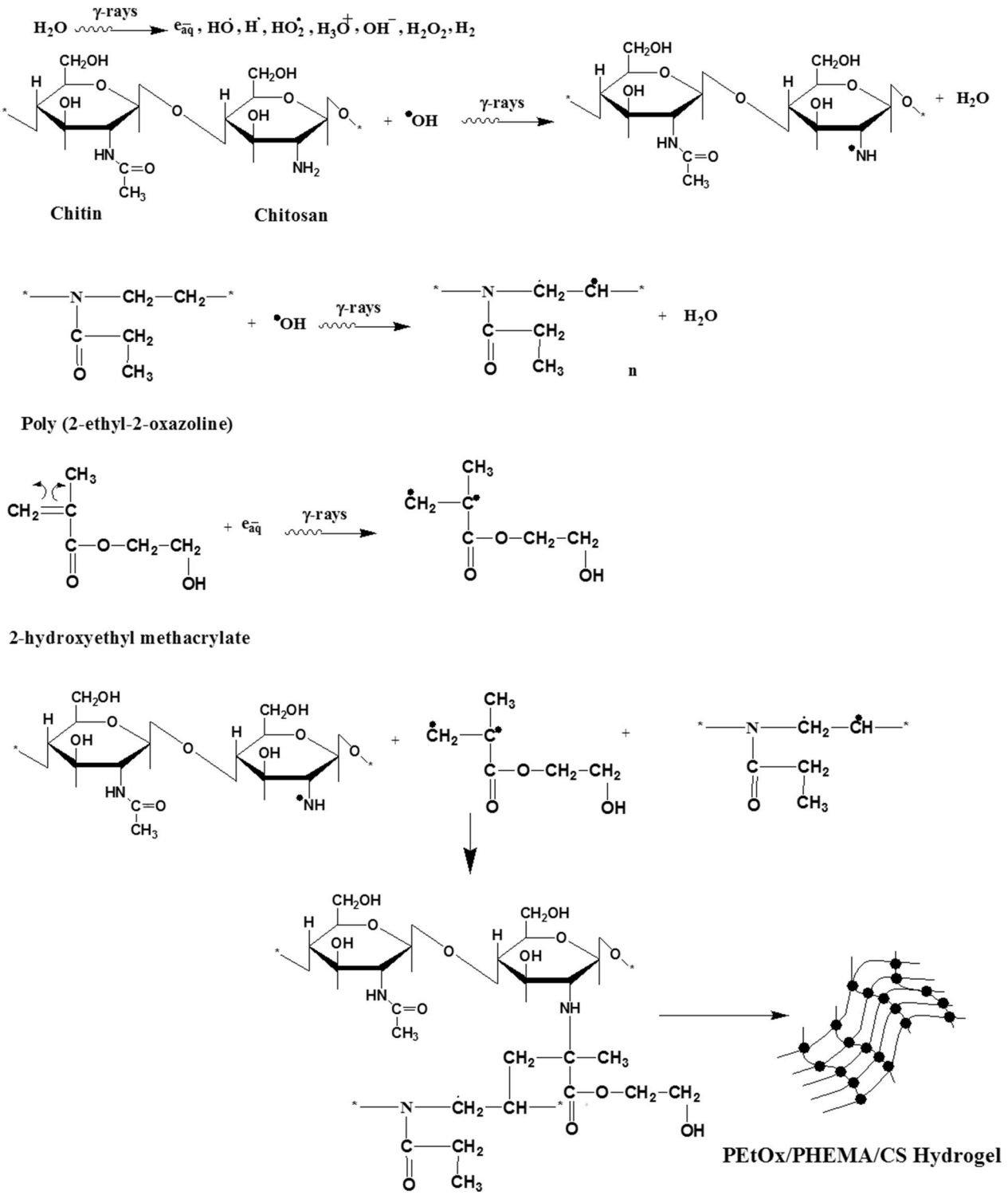


Fig. 1 Proposed reaction mechanism of poly(2-ethyl-2-oxazoline), chitosan and 2-hydroxyethyl methacrylate to form hydrogel

(100 days after planting), plant heights (shoot and root) were measured by a measuring scale, weight of shoot and root (g/plant) were recorded, and root diameter of carrot plants was measured at the middle portion by vernier calipers. Furthermore, root yield of each pot was cleaned, recorded and converted to the fed^{-1}.

Table 1 Treatments of the current experiment

Sample	Ratio Hydrogel (%) + Biochar (%)	After irradiation
Biochar	(0.5)	BC0.5
	(1)	BC1
Poly(2-ethyl-2-oxazoline)-2 hydroxyethyl methacrylate- Chitosan1%	(0.05 + 0)	(PEtOx-HEMA-CS1)0.05
	(0.1% + 0)	(PEtOx-HEMA-CS1)0.1
Poly(2-ethyl-2-oxazoline)-2 hydroxyethyl methacrylate-Chitosan5%	(0.05 + 0)	(PEtOx-HEMA-CS5)0.05
	(0.1 + 0)	(PEtOx-HEMA-CS5)0.1
Poly(2-ethyl-2-oxazoline)-2 hydroxyethyl methacrylate-Chitosan10%	(0.05 + 0)	(PEtOx-HEMA-CS10)0.05
	(0.1 + 0)	(PEtOx-HEMA-CS10)0.1
Poly(2-ethyl-2-oxazoline)-2 hydroxyethyl methacrylate-Chitosan1% + Biochar	(0.05 + 0.5)	(PEtOx-HEMA-CS1)0.5-BC0.5
	(0.1 + 0.5)	(PEtOx-HEMA-CS1)0.1-BC0.5
	(0.05 + 1)	(PEtOx-HEMA-CS1)0.05-BC1
	(0.1 + 1)	(PEtOx-HEMA-CS1)0.1-BC1
Poly(2-ethyl-2-oxazoline)-2 hydroxyethyl methacrylate-Chitosan5% + Biochar	(0.05 + 0.5)	(PEtOx-HEMA-CS5)0.5-BC0.5
	(0.1 + 0.5)	(PEtOx-HEMA-CS5)0.1-BC0.5
	(0.05 + 1)	(PEtOx-HEMA-CS5)0.05-BC1
	(0.1 + 1)	(PEtOx-HEMA-CS5)0.1-BC1
Poly(2-ethyl-2-oxazoline)-2 hydroxyethyl methacrylate-Chitosan10% + Biochar	(0.05 + 0.5)	(PEtOx-HEMA-CS10)0.05-BC0.5
	(0.1 + 0.5)	(PEtOx-HEMA-CS10)0.1-BC0.5
	(0.05 + 1)	(PEtOx-HEMA-CS10)0.05-BC1
	(0.1 + 1)	(PEtOx-HEMA-CS10)0.1-BC1

Soil and plant analysis

Surface samples of the studied soil were collected from El-Khatatba, Cairo-Alexandria, desert road, Menoufiya Governorate. Particle size distribution was determined with hydrometer method [34]. The Bulk density of soil was determined according to Blake and Hertage [35]. Field capacity and permanent wilting point were determined elsewhere according to Arnold and Page [36]. Soil reaction (pH) and electrical conductivity (EC) were measured soil extract as published in [37]. Organic carbon (OC) was estimated by wet oxidation with chromic acid and titrated with ferrous ammonium sulfate as has been reported in [38]. Cation exchange capacity (CEC) was determined as method reported in [39]. The exchangeable sodium percentage (ESP) of the studied soil was calculated using the following formula [40].

$$ESP = \frac{Exchangeable\ sodium}{CEC} \times 100$$

Available nitrogen was extracted by potassium chloride solution and estimated according to Dhank and Johnson [41]. Available potassium and phosphorous were measured according to the method as reported by Solyanpour [42]. Water holding capacity is determined by the following formula:

$$(WHC\%) = \frac{M_w - M_d}{M_d} \times 100$$

where M_w is mass of wet soil at saturated and M_d is mass of oven-dried soil at 105 °C. The amount of irrigation water was calculated using gravimetric methods based on the weight of sowed pots on field capacity and then reweighed at regular intervals [43]. Water use efficiency (WUE) in kg m^{-3} was calculated from the relation between yield and water consumptive use (WCU) according to the following formula [44].

$$\text{WUE (kg m}^{-3}) = \frac{\text{Yield (kgfed}^{-1})}{\text{WCU (m}^3\ \text{fed}^{-1})}$$

Some physical and chemical properties of the investigation soil are listed in Table 2. Carrot samples were washed carefully by tap water then distilled water and oven dried at 75 °C for 48 h. Dried material was wet digested using concentrate of H_2SO_4 and H_2O_2 [45]. NPK content in root (%) was estimated by the Kjeldahl procedure, colorimeter method using a spectrophotometer, and photometrically utilizing a Flame Photometer, respectively, as described elsewhere [46].

Table 2 Physical and chemical properties of the soil

Chemical properties of soil						Available macronutrients (mg. kg^{-1})		
pH (1:2.5 soil suspension)	EC dSm^{-1} (1:2.5 soil extract)	OM (%)	CEC ($cmol_c$ kg^{-1})	EX. Na $cmol_c$ kg^{-1}))	ESP (%)	N	P	K
7.70 ± 0.01	5.40 ± 0.04	0.30 ± 0.01	3.15 ± 0.02	0.30 ± 0.02	9.52 ± 0.30	55.0 ± 1.3	11.20 ± 0.6	78.0 ± 1.7

Physical properties of soil									Texture class
BD ($Mg.m^{-3}$)	Porosity (%)	FC (%)	WP (%)	AW (%)	WHC (%)	Particle size distribution%			
						Sand	Silt	Clay	
1.60 ± 0.01	39.62 ± 1.6	10.20 ± 0.9	3.45 ± 0.1	6.75 ± 0.5	23.0 ± 1.9	73.0 ± 0.5	17.50 ± 0.2	9.50 ± 0.03	Loamy sand

Characterization

The infrared spectra were studied by Fourier transform infra-red (FTIR) spectrophotometer, Perkin Elmer, USA, with range of 4000–400 cm^{-1}. Surface morphologies of samples were carried out by scanning electron microscope (SEM), Model ZEISS-EVO15-UK. X-Ray Diffraction (XRD) patterns of samples were investigated by X-ray diffractometer (a Shimadzu XRD 600). XRD patterns were obtained at a scan rate of 5° min^{-1} on the diffractometer with CuK_{α} radiation source, a generator voltage of 40 kV, a generator current of 40 mA and a wavelength of 0.1546 nm at room temperature. All the diffraction patterns were measured at room temperature and under fixed operation conditions.

Statistical analysis

The experimental data were analyzed by between treatments using SPSS package version 20 by one-way analysis of variance (ANOVA) and least significant difference (LSD) Statistical significance was considered when $P \leq 0.05$. Results are expressed as mean ± standard deviations.

Results and discussion

FTIR analysis

Figure 2 shows the FTIR spectra of (a) chitosan, (b) PEtOx, (c) PEtOx-HEMA-CS1, (d) PEtOx-HEMA-CS5 and (e) PEtOx-HEMA-CS10 hydrogels. The FTIR spectral details of pure CS exposed that the overlapping broad band at 3464 cm^{-1} could be assigned to hydroxyl (OH) and amino (NH_2) groups, and alkyl C–H stretching vibration was identified as doublets at 2928 and 2874 cm^{-1}, respectively [47]. Strong peaks observed at 1640 cm^{-1}, 1587 cm^{-1} and 1427 cm^{-1} declaring the presence of C=O stretching (amide-I band), N–H bending and C–H deformation, respectively [48]. The bands at 997 cm^{-1} and 872 cm^{-1} may have come from the amino group of chitosan [49]. The presence of residual N-acetyl groups was confirmed by the bands at around 1640 cm^{-1} (C=O stretching of amide I) and 1312 cm^{-1} (C–N stretching of amide III), respectively. The band at 1152 cm^{-1} can be attributed to asymmetric stretching of the C–O–C bridge. The bands at 1084 and 1027 cm^{-1} correspond to C3–OH and C6–OH stretching, respectively. The peak of CH_3 appears at 1381 cm^{-1} [50]. The full spectrum of PEtOx exposes the appearance of an overlapping peak at 1640 cm^{-1} due to the presence of amide carbonyl bonds. The respective strong double peaks at 2874, 2933 and 2974 are assignable to alkane -CH_2- stretching and bending groups [51]. The OH bonding at 3484 cm^{-1} on the PEtOx hydrogel was attributed to the hydroxyl terminated feature of the hydrogel [52]. The band at 1428 cm^{-1} was attributed to CH_3 bending groups [53]. The bands at 1061, 1191, and 1236 cm^{-1} indicated the presence of C–C stretching groups, while the bands at 1320 cm^{-1}, 1373 cm^{-1}, and 1473 cm^{-1} referred to the presence of C–H bending groups.

The FTIR spectra of PEtOx-HEMA-CS, PEtOx-HEMA-CS5 and PEtOx-HEMA-CS10 hydrogels expose all the characteristic peaks of crosslinked hydrogels of chitosan and PEtOx by HEMA crosslinker. As can be seen from Fig. 2a–d, the decreasing peak intensity at 3464 cm^{-1} for OH and N–H of CS, further the disappearing peaks at 1587 cm^{-1} and 1027 cm^{-1} for NH_2 and C6-OH of CS, as well as, the decreasing peak intensity for CH_2 of PEtOx at 2974 cm^{-1}, referring to the crosslinking process by HEMA may be occurred on OH and N–H on backbone of chitosan and on CH_2 on backbone of PEtOx. Furthermore, the ester and OH groups of HEMA appeared in 1724 and 1061 cm^{-1}, respectively, as well as the peak intensities of carbonyl groups of HEMA and CS at 1640 cm^{-1} increased due to crosslinking process.

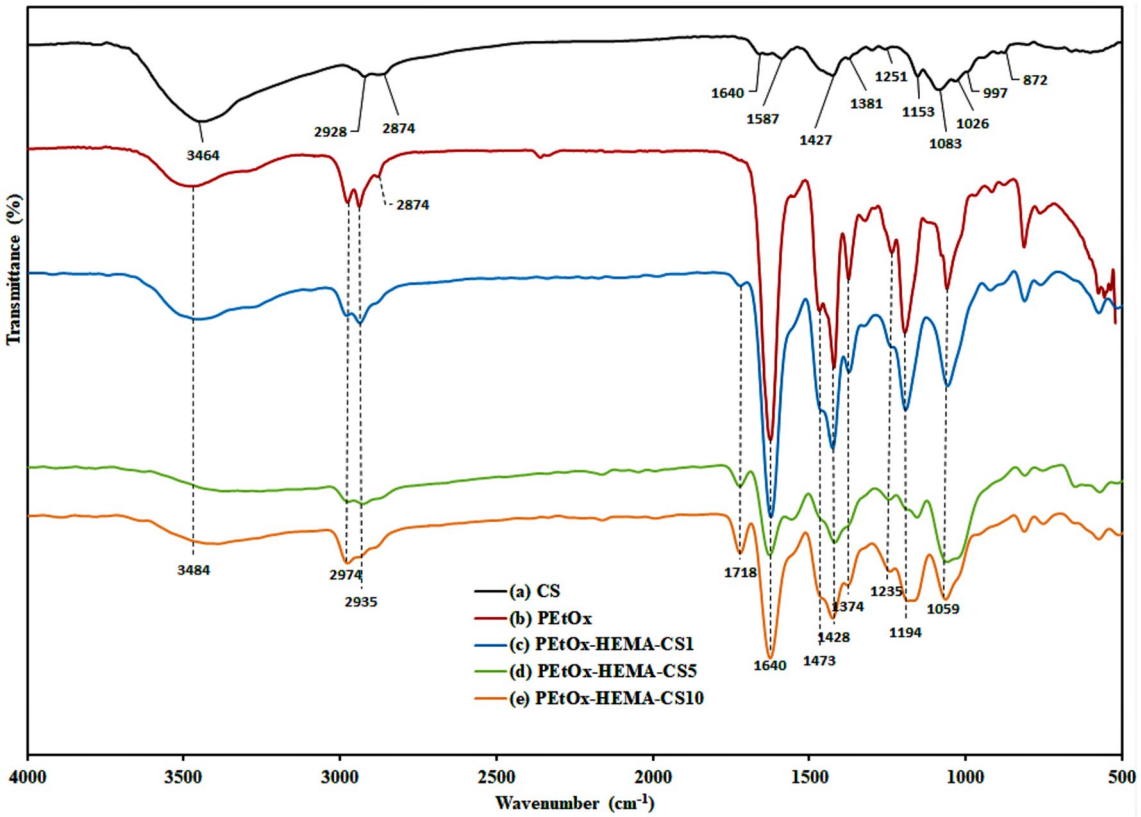


Fig. 2 FTIR spectra of (**a**) chitosan, (**b**) PEtOx, (**c**) PEtOx-HEMA-CS1, (**d**) PEtOx-HEMA-CS5 and (**e**) PEtOx-HEMA-CS10 hydrogels

Effect of CS concentration on swelling and gelation

Figure 3a, b illustrates the influence of CS concentration (%) on swelling (%) and gelation (%), respectively. It is seen from Fig. 3a that the swelling (%) decreases by augmenting CS concentration (%). This is assignable to increasing the hydrophobic feature of CS [2]. However, CS has abundant water-loving groups, it was reported that CS is hydrophilic in nature [54, 55]. The swelling (%) decreases is due to the additional physical crosslinking occurring by the formation of hydrogen bonds with chitosan OH and NH_2 groups [56]. Furthermore, by increasing the CS concentration increased the density of crosslinking of hydrogels and resulted in reducing the water diffusions in hydrogel matrix. This may be assigned to the increase of CS concentration; the swelling (%) of hydrogels decreased [57]. Moreover, it is seen from Table 3 that the relationship between swelling and CS concentration (%) is strong according to $R^2 = 0.99$. Figure 3b shows the relationship between the gelation (%) versus CS concentration (%). It can be noticed that the gelation (%) decreases by increasing CS concentration. This is attributed to augmenting the crosslinking density that increases the content of gelation (%). Furthermore, the results refer to that the relationship between the gelation (%) and CS (%) is strong according $R^2 = 0.99$ and the formula parameters are listed in Table 3

XRD analysis

XRD diffractogram of PEtOx-HEMA-CS1, PEtOx-HEMA-CS5 and PEtOx-HEMA-CS10 hydrogels are shown in Fig. 4. From diffractogram of chitosan into PEtOx-HEMA-CS1, PEtOx-HEMA-CS5 and PEtOx-HEMA-CS10 hydrogels shows the presence of peaks, at around $2\theta = 9.5°$, 14.5, 20.0° and 28.4°, showed that CS displayed a high degree of crystallinity phase [50, 58]. Furthermore, the intensity of these peaks increases by increasing the amount of CS into hydrogels that the wide X-ray peak is at $2\theta = 41°$. It is obvious in the previous studies that the wide peaks within the XRD patterns of pure CS polymers are generated because of the interchain segment scattering found in the amorphous state [60]. The broad peak at around 20.0° refers to the presence of both; PEtOx and HEMA as reported in literature [61, 62].

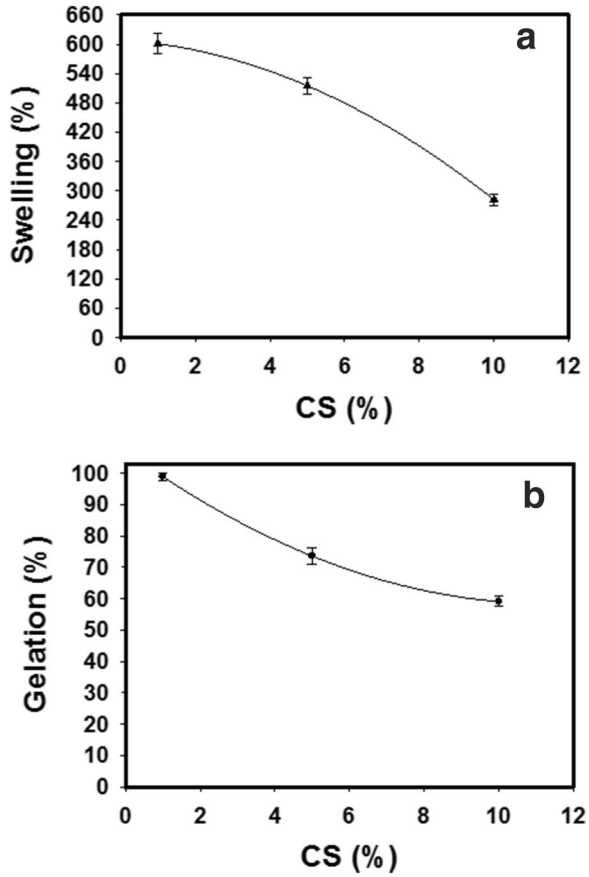


Fig. 3 Effect of CS concentration (%) on (**a**) swelling (%) and (**b**) gelation (%) at 30 kGy of dose rate 0.9 kGy/h

Morphology analysis

Figure 5a–d shows the SEM photomicrographs of (a) PEtOx-HEMA-CS1, (b) PEtOx-HEMA-CS5, (c) PEtOx-HEMA-CS10 and (d) biochar. It is noticed that the pore size of PEtOx-HEMA-CS1 hydrogel is smaller than PEtOx-HEMA-CS5 and PEtOx-HEMA-CS10 hydrogels. Overall, through the observations into the SEM photomicrographs approximately, it could be seen that the pore size number of PEtOx-HEMA-CS5 is similar morphology. However, the number in case of PEtOx-HEMA-CS10 is higher than in case of PEtOx-HEMA-CS5. Consequently, it can be deduced that the augmentation of CS concentration into the in-situ reaction media has a significant impact on the morphology of hydrogels produced. Otherwise, these may be attributed to reducing the degree of crosslinking density by HEMA by augmenting CS percentage

Effect of biochar and hydrogels on soil chemical properties after carrot harvest

The characterization of obtained biochar has pH 8.11, EC 2.11 dSm^{-1}, N 1.47, P 0.40%, K, 1.75%, CEC 35.5 cmolc kg^{-1}, total organic carbon 49.50%, total porosity 45% and ash content 11.20%. Soil chemical properties (pH, EC, OM and CEC) were affected by addition of biochar, PEtOx-HEMA-CS1, PEtOx-HEMA-CS5 and PEtOx-HEMA-CS10 under saline soil conditions (Table 4). The variations in soil pH level across all treatments were not significant. Lin et al. [63] reported that pH value did not differ significantly between control and biochar-treated saline soil. Abrisham et al. [64] also reported that there is no noticeable influence on soil pH as application of polymers. A significant decrease in EC of soil treated with biochar and polymers was found. These are in trend with those obtained elsewhere [65]. The EC values of the investigated soil fluctuated between 4.0 and 5.43 dSm^{-1} at (PEtOx-HEMA-CS5)0.1-BC1 and control, respectively. The EC reduction is attributed to the adsorption or retention of Na on the surfaces of biochar, or the physical entrapment of salts in its fine pores, and the biochar-induced reduction in upwards movement of saline water, resulting in less salt on the soil surface [66]. In addition, hydrophilic materials can mitigate salinity and drought stresses, due to held water, retained Cl^- and Na^+ in soil solution, enhance K^+/Na^+ ratio, and resist interactive effects of salinity and drought stresses [1]. Overall, pH and EC values decreased due to

Table 3 Relationship between swelling and CS concentration and their parameters

Composition	Conditions						Hydrogel code
	PEtOx (g)	HEMA (g)	CS (g)	Status	Dose (kGy)	(C°)	
PEtOx-HEMA-CS1	20	5	1	Formed	30	25	PEtOx-HEMA-CS1
PEtOx-HEMA-CS5	20	5	5	Formed	30	25	PEtOx-HEMA-CS5
PEtOx-HEMA-CS10	20	5	10	Formed	30	25	PEtOx-HEMA-CS10
Parameters of swelling and gelation versus CS concentration							
Swelling				$y = -2.7x^2 - 4.7x + 608$			$R^2 = 0.99$
Gelation				$y = 0.4.6x^2 - 8.6x + 107$			$R^2 = 0.99$

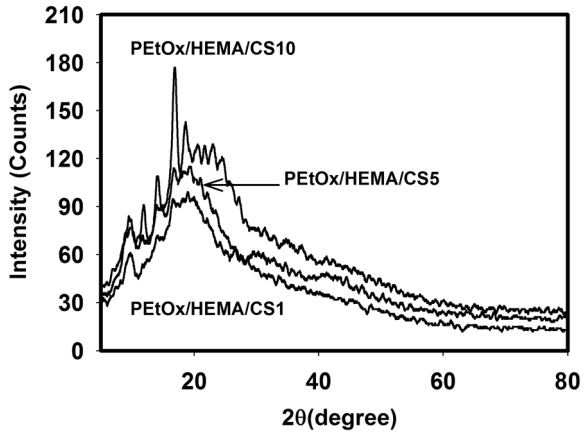


Fig. 4 XRD patterns of PEtOx-HEMA-CS1, PEtOx-HEMA-CS5 and PEtOx-HEMA-CS10 at 30 kGy of dose rate 0.9 kGy/h

super-absorbent polymers [67]. The different changes in soil pH and EC with the application of different types of polymers depending upon type, the synthetic materials, the chemical structure and soil physical and chemical characteristics [68]. Organic matter (OM) and cation exchange capacity (CEC) in saline soil were increased as increasing of the application rates of biochar and polymers. Soil cation exchange capacity increased significantly with increasing hydrogel content [64, 69]. The highest values of OM and CEC were 0.57% and 4.90 mmolc.kg^{-1}, respectively, at (PEtOx-HEMA-CS10) 0.1-BC1 as compared control. Chitosan can be used to improve soil organic matter and soil nutrients [70]. The exchangeable sodium percentage (ESP) in relation to cation exchange capacity (CEC) is used to determine the relative amount of Na^+ present on the soil surface (Table 4). The combination of biochar and polymers are useful in reducing the ESP in saline soil. The mechanisms are determined by the qualities of the soil, plants, and biochar. Chaganti et al. [71] biochar could lower ESP by replacing Na^+ in saline soil with Ca^{++} ions. Soil amendment by biochar may increase soil structure and porosity, facilitating Na^+ leaching and lowering the ESP or SAR of saline soils [72]. Biochar reduces soil EC, SAR and ESP by Na adsorption, and shows a positive effect on the physicochemical properties of saline soils [1].

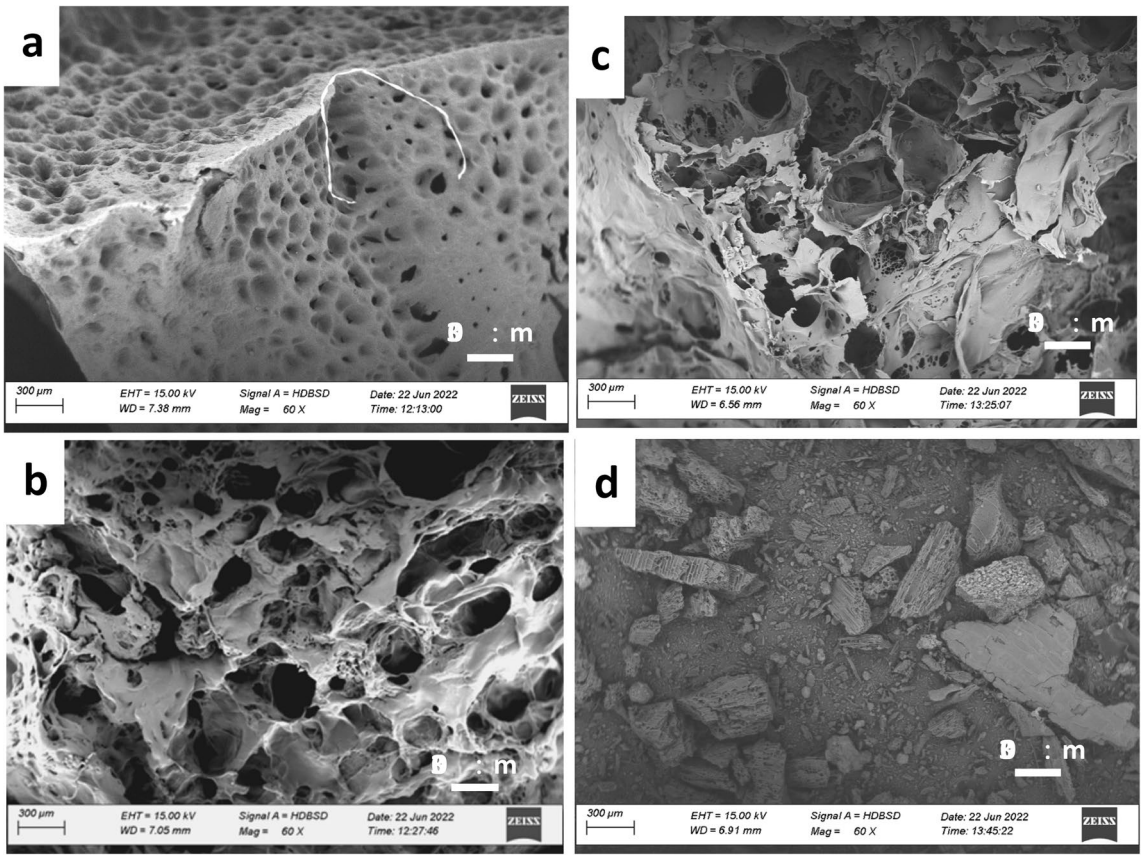


Fig. 5 SEM photomicrographs of (**a**) PEtOx-HEMA-CS1, (**b**) PEtOx-HEMA-CS5, (**c**) PEtOx-HEMA-CS10 at 30 kGy of dose rate 0.9 kGy/h and (**d**) Biochar

Table 4 Effect of biochar and hydrogels on soil chemical properties after carrot harvest

Treatments (%)	pH (1:2.5 soil suspension)	EC dSm^{-1} (1:2.5 soil extract)	OM %	CEC cmolc kg^{-1}	ESP %	FC (%)	PWP (%)	AW (%)	BD Mg. (m^{-3})
Control	7.67 ± 0.01^{a}	5.43 ± 0.04^{a}	0.30 ± 0.01^{b}	3.20 ± 0.06^{b}	9.40 ± 0.15^{a}	10.40 ± 0.45^{b}	3.10 ± 0.01^{b}	7.30 ± 0.04^{b}	1.62 ± 0.01^{a}
BC0.5	7.65 ± 0.02^{a}	4.65 ± 0.06^{a}	0.38 ± 0.01^{a}	3.65 ± 0.05^{b}	8.10 ± 0.19^{a}	11.5 ± 0.70^{b}	3.30 ± 0.03^{b}	8.20 ± 0.36^{a}	1.59 ± 0.03^{a}
BC1	7.75 ± 0.02^{a}	4.30 ± 0.05^{b}	0.45 ± 0.02^{a}	4.15 ± 0.04^{b}	8.45 ± 0.30^{a}	12.85 ± 0.80^{a}	3.50 ± 0.02^{a}	9.35 ± 0.66^{a}	1.54 ± 0.01^{a}
(PEtOx-HEMA-CS1)0.05	7.65 ± 0.03^{a}	5.00 ± 0.02^{a}	0.30 ± 0.01^{a}	3.20 ± 0.03^{b}	9.40 ± 0.30^{a}	10.80 ± 0.67^{b}	3.20 ± 0.03a	7.60 ± 0.80^{b}	1.59 ± 0.01^{a}
(PEtOx-HEMA-CS1)0.1	7.65 ± 0.01^{a}	4.95 ± 0.05^{a}	0.30 ± 0.02^{a}	3.21 ± 0.03^{b}	9.40 ± 0.19^{a}	11.00 ± 0.65^{b}	3.50 ± 0.01^{a}	7.50 ± 0.60^{b}	1.55 ± 0.01^{a}
(PEtOx-HEMA-CS5)0.05	7.60 ± 0.04^{a}	4.90 ± 0.06^{a}	0.30 ± 0.02^{b}	3.18 ± 0.03^{b}	9.40 ± 0.20^{a}	11.10 ± 0.70^{b}	3.23 ± 0.02^{b}	7.87 ± 0.50^{b}	1.57 ± 0.01^{a}
(PEtOx-HEMA-CS5)0.1	7.60 ± 0.01^{ab}	4.70 ± 0.03^{a}	0.33 ± 0.01^{b}	3.25 ± 0.03^{b}	8.60 ± 0.18^{a}	11.35 ± 0.55^{a}	3.75 ± 0.01^{a}	7.60 ± 0.30^{b}	1.53 ± 0.02^{a}
(PEtOx-HEMA-CS10)0.05	7.63 ± 0.02^{a}	4.90 ± 0.04^{a}	0.35 ± 0.01^{b}	3.80 ± 0.04^{b}	8.00 ± 0.19^{a}	11.23 ± 0.63^{b}	3.35 ± 0.03^{a}	7.88 ± 0.40^{b}	1.56 ± 0.02^{a}
(PEtOx-HEMA-CS10)0.1	7.67 ± 0.03^{a}	4.74 ± 0.05^{a}	0.38 ± 0.01^{a}	4.00 ± 0.03^{b}	7.40 ± 0.15^{b}	12.10 ± 0.66^{a}	3.95 ± 0.01^{a}	8.15 ± 0.60^{b}	1.53 ± 0.01^{a}
PEtOx-HEMA-CS1)0.05-BC0.5)	7.66 ± 0.04^{a}	4.83 ± 0.03^{b}	0.40 ± 0.01^{a}	3.60 ± 0.01^{b}	8.90 ± 0.10^{a}	12.15 ± 0.46^{a}	3.60 ± 0.03^{a}	8.55 ± 0.70^{a}	1.55 ± 0.01^{a}
PEtOx-HEMA-CS1)0.1-BC0.5)	7.66 ± 0.01^{a}	4.80 ± 0.05^{b}	0.42 ± 0.02^{a}	3.81 ± 0.03^{b}	9.10 ± 0.50^{a}	12.85 ± 0.66^{a}	4.00 ± 0.05^{a}	8.85 ± 0.71^{a}	1.55 ± 0.01^{a}
PEtOx-HEMA-CS1)0.05-BC1)	7.65 ± 0.01^{a}	4.63 ± 0.03^{b}	0.42 ± 0.01^{a}	4.10 ± 0.05^{b}	7.90 ± 0.50^{a}	13.00 ± 1.01^{a}	3.55 ± 0.04^{a}	9.45 ± 0.95^{a}	1.53 ± 0.02^{a}
PEtOx-HEMA-CS1)0.1-BC1)	7.67 ± 0.02^{a}	4.50 ± 0.02^{b}	0.43 ± 0.03^{a}	4.30 ± 0.06^{a}	7.65 ± 0.35^{b}	13.20 ± 0.97^{a}	4.00 ± 0.03^{a}	9.20 ± 0.90^{a}	1.53 ± 0.02^{a}
PEtOx-HEMA-CS5)0.05-BC0.5)	7.65 ± 0.03^{a}	4.32 ± 0.01^{b}	0.42 ± 0.03^{a}	3.65 ± 0.03^{b}	8.65 ± 0.40^{a}	13.11 ± 0.89^{a}	3.80 ± 0.02^{a}	9.31 ± 0.88^{a}	1.55 ± 0.01^{a}
PEtOx-HEMA-CS5)0.1-BC0.5)	7.65 ± 0.04^{a}	4.15 ± 0.01^{b}	0.46 ± 0.03^{a}	3.85 ± 0.03^{b}	8.90 ± 0.51^{a}	13.45 ± 1.03^{a}	4.10 ± 0.04^{a}	9.35 ± 0.91^{a}	1.52 ± 0.02^{a}
PEtOx-HEMA-CS5)0.05-BC1)	7.65 ± 0.01^{a}	4.30 ± 0.02^{b}	0.45 ± 0.02^{a}	4.20 ± 0.02^{b}	7.20 ± 0.41^{b}	13.00 ± 0.96^{a}	3.65 ± 0.03^{a}	9.35 ± 0.63^{a}	1.53 ± 0.02^{a}
PEtOx-HEMA-CS5)0.1-BC1)	7.68 ± 0.04^{a}	4.00 ± 0.04^{b}	0.45 ± 0.01^{a}	4.50 ± 0.04^{a}	6.60 ± 0.51^{b}	13.60 ± 0.98^{a}	4.20 ± 0.04^{a}	9.40 ± 0.38^{a}	1.50 ± 0.01^{a}
PEtOx-HEMA-CS10)0.05-BC0.5)	7.67 ± 0.03^{a}	4.55 ± 0.05^{a}	0.40 ± 0.03^{a}	3.75 ± 0.05^{b}	8.50 ± 0.61^{a}	12.00 ± 0.87^{a}	3.50 ± 0.04^{a}	8.50 ± 0.70^{a}	1.56 ± 0.02^{a}
PEtOx-HEMA-CS10)0.1-BC0.5)	7.69 ± 0.01^{a}	4.40 ± 0.04^{a}	0.40 ± 0.02^{a}	4.00 ± 0.06^{b}	7.50 ± 0.50^{a}	12.12 ± 0.69^{a}	3.70 ± 0.04^{a}	8.42 ± 0.57^{a}	1.54 ± 0.02^{a}
PEtOx-HEMA-CS10)0.05-BC1)	7.70 ± 0.03^{a}	4.44 ± 0.03^{a}	0.50 ± 0.03^{a}	4.50 ± 0.04^{a}	7.25 ± 0.61^{b}	13.10 ± 0.89^{a}	3.90 ± 0.02^{a}	9.20 ± 0.40^{a}	1.52 ± 0.01^{a}
PEtOx-HEMA-CS10)0.1-BC1)	7.71 ± 0.02^{a}	4.15 ± 0.06^{b}	0.57 ± 0.03^{a}	4.90 ± 0.06^{a}	6.70 ± 0.40^{b}	13.40 ± 0.90^{a}	4.10 ± 0.01^{a}	9.30 ± 0.37^{a}	1.50 ± 0.02^{a}

Treatments are descending order alphabetically (a,b and c) according to the significance at $p \leq 0.05$

Effect of biochar and hydrogels on soil physical properties after carrot harvest

The values of field capacity (FC), permanent wilting point (PWP) available water (AW) are listed in Table 4. FC, PWP and AW were increased by increasing the application rates of biochar, PEtOx-HEMA-CS1, PEtOx-HEMA-CS5, and PEtOx-HEMA-CS10 under saline soil conditions especially at mixture of biochar and with PEtOx-HEMA-CS5. The application of biochar improved soil physical characteristics [1]. The highest value of AW (9.40%) was obtained at (PEtOx-HEMA-CS5)0.1-BC1. Soil moisture contents and available water in the soil treated with polymer were greater than in control soil [73]. Hydrogels can promote water saving in soil and gradually release it when the soil moisture content decreases [69, 70]. The maximum values of FC and PWP were 13.60% and 4.2%, respectively, at (PEtOx-HEMA-CS5)0.1-BC1, followed by (PEtOx-HEMA-CS10)0.1-BC0.5 treatment. Application of polymer improved water retention, leading to a larger

amount of water in the plant rooting environment and decreased soil infiltration rate [74]. While soil bulk density decreased by increasing the investigated materials alone or combination with each other. Abrisham et al. [64] observed that soil bulk density decreased from 1.56 to 1.45 Mg m^{-3} as a result application of hydrogel polymer. The lowest value (1.50 Mg m^{-3}) was observed at PEtOx-HEMA-CS5)0.1-BC1. Water-retaining polymers can cause stable aggregates, improve soil porosity, and decrease soil bulk density [75].

Effect of biochar and hydrogels on growth parameters of carrot

The growth parameters of carrot (shoot weight, root weight, shoot length, root length and root diameter) were increased significantly by increasing the application rates of biochar, PEtOx-HEMA-CS1, PEtOx-HEMA-CS5, and PEtOx-HEMA-CS10 under saline soil conditions (see Table 5). This is attributed to considerable absorption of nutrient solution by polymers and slow release of absorbed solution to plant roots [76]. It was observed that the highest values of shoot weight and shoot length were 15.32 g/plant and 34.52 cm, respectively, at (PEtOx-HEMA-CS5)0.1-BC1. The interaction between polymers and biochar comprises organic elements that may promote soil porosity, reducing soil bulk density and providing favorable circumstances for crop growth. In addition, polymers increase plant growth through enhancing soil water retention [77]. While the highest values of roots weight, root length and root diameter were 45.65 g/plant, 13.47 cm and 23.65 mm, respectively, at (PEtOx-HEMA-CS10)0.1-BC1.

It could be seen that the increase of chitosan percent increased root attributes**.** Chitosan enhances the root system development, hence enhancing water absorption capacity**.** Furthermore, it was reported from literature that optimal moisture availability led to higher production of carrot roots, which ultimately resulted in the formation of thicker carrot roots [78]. This increment is related to the increasing of water availability due to the polymers can promote plant growth by improving soil water retention and extending the time it takes for plants to wilt, hence enhancing plant survivability under abiotic stress [78, 79].

Macronutrients content

There is a clear variation of macronutrients contents in carrot root due to the application rates of biochar, PEtOx-HEMA-CS1, PEtOx-HEMA-CS5, and

Table 5 Effect of biochar and hydrogels on growth parameters of carrot

Treatments (%)	Shoot weight (g/plant)	Root weight (g/plant)	Shoot length (cm)	Root length (cm)	Root diameter (mm)
Control	9.54 ± 0.06^{c}	28.80 ± 1.03^{c}	19.11 ± 88^{c}	8.55 ± 0.07^{b}	14.57 ± 0.02^{c}
BC0.5	12.33 ± 0.10^{b}	38.95 ± 1.06^{b}	25.45 ± 0.50^{b}	11.90 ± 0.09^{a}	19.00 ± 0.07^{b}
BC1	12.65 ± 0.31^{b}	41.58 ± 1.08^{a}	27.00 ± 0.44^{b}	12.32 ± 0.06^{a}	19.66 ± 0.09^{b}
(PEtOx-HEMA-CS1)0.05	11.21 ± 1.25^{b}	35.33 ± 1.10^{b}	23.11 ± 0.36^{b}	11.20 ± 0.08^{b}	19.11 ± 0.08^{b}
(PEtOx-HEMA-CS1)0.1	11.00 ± 0.12^{b}	37.56 ± 1.09^{a}	25.30 ± 0.31^{a}	11.61 ± 0.09^{a}	19.21 ± 0.10^{a}
(PEtOx-HEMA-CS5)0.05	12.11 ± 0.15^{b}	38.63 ± 1.16^{b}	26.23 ± 0.32^{b}	11.88 ± 0.07^{b}	19.33 ± 0.13^{b}
(PEtOx-HEMA-CS5)0.1	11.17 ± 0.18^{b}	41.44 ± 1.9^{a}	30.80 ± 0.31^{a}	12.00 ± 0.03^{a}	19.52 ± 0.15^{a}
(PEtOx-HEMA-CS10)0.05	11.17 ± 0.20^{b}	41.44 ± 1.15^{a}	30.80 ± 0.30^{a}	12.00 ± 0.70^{a}	19.52 ± 0.14^{a}
(PEtOx-HEMA-CS10)0.1	12.25 ± 0.15^{b}	43.25 ± 1.09^{a}	31.14 ± 0.34^{a}	12.00 ± 0.08^{a}	20.55 ± 0.16^{a}
PEtOx-HEMA-CS1)0.05-BC0.5)	12.85 ± 0.12^{a}	41.20 ± 1.07^{a}	28.95 ± 0.33^{a}	11.53 ± 0.06^{a}	18.65 ± 0.16^{a}
PEtOx-HEMA-CS1)0.1-BC0.5)	13.74 ± 0.12^{a}	42.53 ± 1.06^{a}	30.51 ± 0.32^{a}	11.90 ± 0.08^{a}	19.35 ± 0.14^{a}
PEtOx-HEMA-CS1)0.05-BC1)	13.90 ± 0.11^{a}	42.00 ± 1.04^{a}	31.80 ± 0.31^{a}	12.50 ± 0.09^{a}	20.44 ± 0.11^{a}
PEtOx-HEMA-CS1)0.1-BC1)	14.00 ± 0.09^{a}	42.10 ± 1.06^{a}	32.63 ± 0.32^{a}	12.64 ± 0.06^{a}	21.11 ± 0.13^{a}
PEtOx-HEMA-CS5)0.05-BC0.5)	13.54 ± 0.04^{a}	42.00 ± 1.06^{a}	30.55 ± 0.25^{a}	12.15 ± 0.04^{a}	19.85 ± 0.13^{a}
PEtOx-HEMA-CS5)0.1-BC0.5)	14.66 ± 0.06^{a}	43.65 ± 1.04^{a}	31.65 ± 0.18^{a}	12.86 ± 0.08^{a}	20.33 ± 0.14^{a}
PEtOx-HEMA-CS5)0.05-BC1)	15.00 ± 0.37^{a}	42.50 ± 1.06^{a}	33.50 ± 0.19^{a}	13.00 ± 0.50^{a}	22.56 ± 0.14^{a}
PEtOx-HEMA-CS5)0.1-BC1)	15.32 ± 0.51^{a}	43.12 ± 1.07^{a}	34.52 ± 0.19^{a}	13.14 ± 0.40^{a}	23.00 ± 0.16^{a}
PEtOx-HEMA-CS10)0.05-BC0.5)	13.00 ± 0.06^{b}	40.00 ± 1.18^{a}	28.00 ± 0.16^{b}	12.65 ± 0.40^{a}	21.00 ± 0.16^{a}
PEtOx-HEMA-CS10)0.1-BC0.5)	13.25 ± 0.09^{a}	41.65 ± 1.10^{a}	30.15 ± 0.11^{a}	13.00 ± 0.50^{a}	23.35 ± 0.15^{a}
PEtOx-HEMA-CS10)0.05-BC1)	14.00 ± 0.44^{a}	43.00 ± 1.30^{a}	30.89 ± 0.19^{a}	12.95 ± 0.60^{a}	23.31 ± 0.02^{a}
PEtOx-HEMA-CS10)0.1-BC1)	14.90 ± 0.13^{a}	45.65 ± 1.03^{a}	32.95 ± 0.18^{a}	13.47 ± 0.50^{a}	23.65 ± 0.30^{a}

Treatments are descending order alphabetically (a,b and c) according to the significance at $p \leq 0.05$

Table 6 Effect of biochar and hydrogels on macronutrients content in carrot roots

Treatments (%)	*N* (%)		*P* (%)		*K* (%)	
	Value	Relative increase	Value	Relative increase	Value	Relative increase
Control	1.10 ± 0.06^{c}	0.00	0.30 ± 0.00^{b}	0.00	0.50 ± 0.01^{b}	0.00
BC0.5	1.35 ± 0.04^{a}	22.73	0.40 ± 0.01^{a}	33.33	0.62 ± 0.02^{a}	24.00
BC1	1.40 ± 0.03^{a}	27.27	0.48 ± 0.01^{a}	60.00	0.70 ± 0.05^{a}	40.00
(PEtOx-HEMA-CS1)0.05	1.20 ± 0.06^{b}	9.09	0.40 ± 0.02^{a}	33.33	0.55 ± 0.03^{a}	10.00
(PEtOx-HEMA-CS1)0.1	1.20 ± 0.04^{b}	9.09	0.40 ± 0.01^{a}	33.33	0.60 ± 0.04^{a}	20.00
(PEtOx-HEMA-CS5)0.05	1.30 ± 0.05^{b}	18.18	0.40 ± 0.01^{a}	33.33	0.60 ± 0.01^{a}	20.00
(PEtOx-HEMA-CS5)0.1	1.30 ± 0.07^{b}	18.18	0.42 ± 0.01^{a}	40.00	0.63 ± 0.02^{a}	26.00
(PEtOx-HEMA-CS10)0.05	1.30 ± 0.09^{b}	18.18	0.43 ± 0.01^{a}	43.33	0.70 ± 0.03^{a}	40.00
(PEtOx-HEMA-CS10)0.1	1.35 ± 0.06^{a}	22.72	0.46 ± 0.01^{a}	53.33	0.70 ± 0.02^{a}	40.00
PEtOx-HEMA-CS1)0.05-BC0.5)	1.35 ± 0.04^{a}	2273	0.40 ± 0.01^{a}	33.33	0.68 ± 0.02^{a}	36.00
PEtOx-HEMA-CS1)0.1-BC0.5)	1.37 ± 0.06^{a}	24.55	0.41 ± 0.01^{a}	36.67	0.70 ± 0.03^{a}	40.00
PEtOx-HEMA-CS1)0.05-BC1)	1.35 ± 0.04^{a}	22.73	0.42 ± 0.01^{a}	40.00	0.75 ± 0.04^{a}	50.00
PEtOx-HEMA-CS1)0.1-BC1)	1.40 ± 0.02^{a}	27.27	0.42 ± 0.01^{a}	40.00	0.75 ± 0.02^{a}	5.00
PEtOx-HEMA-CS5)0.05-BC0.5)	1.40 ± 0.01^{a}	27.27	0.44 ± 0.01^{a}	46.67	0.71 ± 0.02^{a}	42.00
PEtOx-HEMA-CS5)0.1-BC0.5)	1.42 ± 0.02^{a}	29.09	0.44 ± 0.01^{a}	46.67	0.75 ± 0.02^{a}	50.00
PEtOx-HEMA-CS5)0.05-BC1)	1.40 ± 0.03^{a}	27.27	0.46 ± 0.01^{a}	53.33	0.65 ± 0.02^{a}	30.00
PEtOx-HEMA-CS5)0.1-BC1)	1.44 ± 0.02^{a}	30.91	0.45 ± 0.01^{a}	50.00	0.65 ± 0.05^{a}	30.00
PEtOx-HEMA-CS10)0.05-BC0.5)	1.40 ± 0.02^{a}	27.27	0.43 ± 0.02^{a}	43.33	0.70 ± 0.01^{a}	40.00
PEtOx-HEMA-CS10)0.1-BC0.5)	1.45 ± 0.01^{a}	31.82	0.50 ± 0.02^{a}	66.67	0.80 ± 0.02^{a}	60.00
PEtOx-HEMA-CS10)0.05-BC1)	1.46 ± 0.03^{a}	32.73	0.48 ± 0.03^{a}	60.00	0.80 ± 0.05^{a}	60.00
PEtOx-HEMA-CS10)0.1-BC1)	1.50 ± 0.03^{a}	36.36	0.51 ± 0.03^{a}	70.00	0.86 ± 0.06^{a}	72.00

Treatments are descending order alphabetically (a,b and c) according to the significance at $p \leq 0.05$

PEtOx-HEMA-CS10 under saline soil conditions (Table 6). This is due to the increment of water accessibility which enhances the nutrients availability in the root zone [78]. The data revealed that N P and K values were increased significantly by increasing biochar rates as alone or combination with polymers.

This trend agrees with those obtained by Başak [76] who reported that macronutrients content (N P K) of tomato plant were greatly significantly by polymer application. The highest values of NP and K were 1.50%, 0.51% and 0.86% as increased by 36.36%, 70% and 72%, respectively, at (PEtOx-HEMA-CS10)0.1-BC1. This is assignable to the application of biochar mixed by polymers improving root development and plant growth, decreases nutrient losses by leaching out, and enhances soil penetration. It also decreases the negative effects of abiotic stress in soil [73]. Hence, it is possible that the improving moisture retention increased the nutritious supply. Chitosan can provide a carbon source for soil bacteria, speeding the transition of organic matter, where it has a symbiotic relationship with growth-promoting rhizobacteria, triggering germination and supporting plant nutrient uptake [80, 81]. In addition, Sharif et al. [82] observed that chitosan has been used in soil as a plant nutrient and has confirmed tremendous efficacy in combination with other industrial fertilizers without hurting the soil's beneficial bacteria.

Carrot root productivity as affected by biochar and tested hydrogels

Data of carrot yield as affected by the application rates of biochar, PEtOx-HEMA-CS1, PEtOx-HEMA-CS5, and PEtOx-HEMA-CS10 hydrogels under saline soil are listed in Table 7. Carrot productivity increased noticeably by increasing the application rates of biochar and the investigated hydrogels, especially at the highest rates. Biswas et al. [83] reported that carrot productivity increased significantly by application of biochar and vermicompost. Therefore, hydrogels have the good potential to enhance conserving water of carrot production. Therefore, the hydrogels can be employed as a water conserver in plant production [84]. The highest values of carrot yield were 20.22 t ha^{-1} at (PEtOx-HEMA-CS10)0.1-BC1. This is due to the hydrogels having a good ability to boost water retention, water uptake, and water use efficiency, which alleviate abiotic stress in plants and improve plant performance, resulting in increased growth and

Table 7 Carrot yield as affected by biochar and tested hydrogels

Treatments (%)	Applied water m^3 ha^{-1}	Root yield		Water use efficiency (WUE) $kg.m^{-3}$
		t ha^{-1}	Relative increase %	
Control	4800	13.51 ± 0.30^{c}	0.00	2.81 ± 0.02^{c}
BC0.5	4500	15.10 ± 0.41^{b}	11.77	3.36 ± 0.04^{b}
BC1	4540	15.40 ± 0.50^{b}	13.99	3.39 ± 0.03^{b}
(PEtOx-HEMA-CS1)0.05	4500	14.00 ± 0.20^{b}	3.63	3.11 ± 0.01^{b}
(PEtOx-HEMA-CS1)0.1	4450	14.20 ± 0.41^{b}	5.12	3.19 ± 0.04^{b}
(PEtOx-HEMA-CS5)0.05	4400	14.22 ± 0.52^{b}	5.22	3.23 ± 0.06^{b}
(PEtOx-HEMA-CS5)0.1	4250	14.81 ± 0.33^{b}	9.62	3.48 ± 0.03^{b}
(PEtOx-HEMA-CS10)0.05	4550	14.22 ± 0.41^{b}	5.26	3.13 ± 0.05^{b}
(PEtOx-HEMA-CS10)0.1	4400	14.42 ± 0.22^{b}	6.74	3.28 ± 0.02^{b}
PEtOx-HEMA-CS1)0.05-BC0.5)	4380	15.50 ± 0.60^{b}	14.73	3.54 ± 0.04^{b}
PEtOx-HEMA-CS1)0.1-BC0.5)	4300	15.60 ± 0.50^{b}	15.47	3.63 ± 0.03^{b}
PEtOx-HEMA-CS1)0.05-BC1)	4250	16.00 ± 0.30^{b}	18.43	3.76 ± 0.05^{b}
PEtOx-HEMA-CS1)0.1-BC1)	4150	19.81 ± 0.90^{a}	46.63	4.77 ± 0.06^{a}
PEtOx-HEMA-CS5)0.05-BC0.5)	4300	16.59 ± 0.36^{b}	22.77	3.86 ± 0.09^{b}
PEtOx-HEMA-CS5)0.1-BC0.5)	4200	16.81 ± 0.63^{b}	24.43	4.00 ± 0.04^{b}
PEtOx-HEMA-CS5)0.05-BC1)	4100	17.63 ± 0.40^{b}	30.50	4.06 ± 0.03^{b}
PEtOx-HEMA-CS5)0.1-BC1)	3900	19.81 ± 0.57^{a}	46.63	5.08 ± 0.04^{a}
PEtOx-HEMA-CS10)0.05-BC0.5)	4350	19.42 ± 0.40^{a}	43.71	4.46 ± 0.05^{a}
PEtOx-HEMA-CS10)0.1-BC0.5)	4400	19.80 ± 0.40^{a}	46.56	4.50 ± 0.03^{a}
PEtOx-HEMA-CS10)0.05-BC1)	4100	19.90 ± 0.30^{a}	47.26	4.85 ± 0.04^{a}
PEtOx-HEMA-CS10)0.1-BC1)	3950	20.22 ± 0.40^{a}	49.63	5.12 ± 0.08^{a}

Treatments are descending order alphabetically (a,b and c) according to the significance at $p \leq 0.05$

productivity [21]. Moreover, the relative increase of carrot productivity was improved with increasing of the examined materials. The highest relative increase was 49.63% for the sample of (PEtOx-HEMA-CS10)0.1-BC1. Figure 6a, b exposes the demonstration photos of impact of (PEtOx-HEMA-CS10)0.1-BC1 on carrot productivity. It can be seen from photos that the growth of carrots in presence of (PEtOx-HEMA-CS10)0.1-BC1 is more productive than absence of (PEtOx-HEMA-CS10)0.1-BC1 during agriculture process.

Water use efficiency

Carrot productivity per unit of conducted water under different levels of moisture content is listed in Table 7. Water use efficiency (WUE) is a term used to describe the ratio of productivity to water consumptive utilization, and it is affected by crop type, cultivation practices, and soil conditions [85]. The data revealed that the amount of applied water decreased with increasing of biochar and polymers rates especially at (PEtOx-HEMA-CS5)0.1-BC1. Polymers enhance water use efficiency, abiotic stress, soil physical properties, and crop yield, as well as to obtain higher soil moisture and seed germination rates, enhance maize dry matter accumulation, and water use efficiency [67].

The positive effects of biochar on crop productivity have been linked to both direct and indirect impacts, including higher water and nutrient retention, as well as better soil physical properties such as infiltration rate in sandy soils [14]**.** The highest values of WCU were seen at the mixture of biochar and polymers at (PEtOx-HEMA-CS5)0.1-BC1 as shown in Additional file 1: Fig. S2. These data are confirmed elsewhere [86], who found that polymers and biochar enhanced water retention capacity. The little maize plants consumed less water during this early growth period, and the BC treatments allowed the soil to retain more soil. Therefore, polymers have the potential to improve water use efficiency and conserve water of carrot production saline soil [84].

Conclusions

The hydrogels were prepared by gamma rays as initiator for from 60Co as the main sources of gamma irradiation. The combined addition of biochar and hydrogels of poly (2-ethyl-2-oxazoline)/poly(2-hydroxyethyl methacrylate)/chitosan have a good significant to improve soil

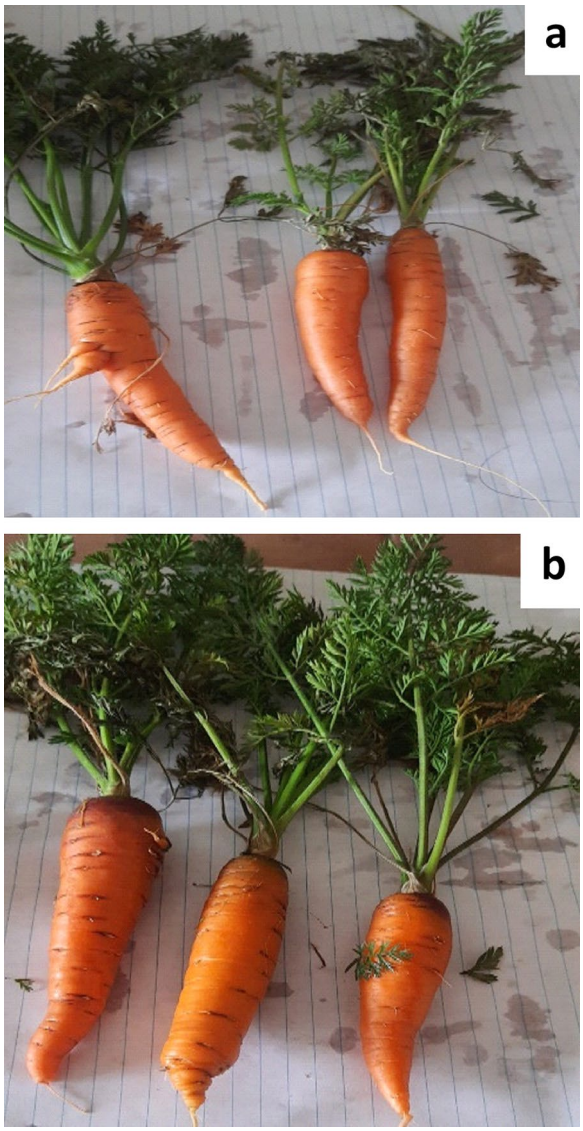


Fig. 6 Demonstration photos (**a**) control before treatment and (**b**) after treatment with (PEtOx-HEMA-CS10)0.1-BC1 sample

physical and chemical properties. Under saline soil conditions field capacity, wilting point, available water, bulk density, soil pH, soil electrical conductivity, exchangeable sodium percentage, organic matter and cation exchange capacity were improved significantly. In addition, carrot growth and productivity, water use efficiency and macro nutrients content were significantly increased. The application of 1% of biochar combined with 0.1% poly (2-ethyl-2-oxazoline)-2 hydroxyethyl methacrylate-5% chitosan reduced the harmful effect of salinity and provided favorable circumstances for carrot productivity.

Supplementary Information

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Additional file 1: Fig S1. Setup diagram for the preparation of biochar from fresh wood of mango trees. **Fig S2.** Water use efficiency (WUE) and relative increase of carrot yield as affected by the highest rate of the studied materials.

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Author contributions
SAA designed and implemented the study, performed data analysis, wrote the first draft of the manuscript. HHHH and AA-F prepared the studied materials, contributed to the design of study, wrote and reviewed the final manuscript. NRAE-R has identified the chemical reaction of hydrogel by different analyses. All authors read and approved the final manuscript.

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Declarations

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Author details
[1]Soils and Water Department, Faculty of Agriculture, Al-Azhar University, Cairo, Egypt. [2]Polymer Laboratory, Petrochemical Department, Egyptian Petroleum Research Institute, Nasr City, Cairo 11727, Egypt. [3]Radiation Research of Polymer Department, National Centre for Radiation Research and Technology (NCRRT), Egyptian Atomic Energy Authority (EAEA), Cairo, Egypt.

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