Chapter 8
Interaction of Nanoparticles with Plant Macromolecules: Carbohydrates and Lipids

Lei Qiao and Chunlan Xu

Abstract Nanotechnology is proposed to improve plant growth and meet the global demand for food as a result of a rapidly increasing world population. Nanoparticles (NPs) are regarded as a feasible strategy for the implementation of sustainable agriculture due to their unique chemical and physical properties, including high reactivity, multi-biological activities, high surface area, and tunable particle size. Many NPs have received considerable attention due to their ability to enhance the growth and yield of various plants. NPs are able to stimulate plant development via positive effects on promoting plant seed germination, plant root or above-ground growth improving stress tolerance, which is closely associated with plant carbohydrates and lipids. Many studies have confirmed that NPs can promote the synthesis of carbohydrates and inhibit lipid peroxidation, thereby improving plant yield and stress resistance. Furthermore, biosynthetic NPs are an effective strategy to replace traditional NPs and agrochemicals. Compared to physical and chemical methods, plant macromolecules, especially carbohydrates, provide an environment-friendly, safe and efficient method for the synthesis of NPs. Biogenic NPs synthesized by plant carbohydrates also have been widely applied in agriculture to stimulate plant growth. This review summarizes the effects of the different NPs on plant carbohydrates and lipids and the green synthesis of NPs using plant carbohydrates.

Keywords Biosynthesis · Carbohydrates · Lipids · Nanoparticles · Plant

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J. M. Al-Khayri et al. (eds.), *Nanomaterial Interactions with Plant Cellular Mechanisms and Macromolecules and Agricultural Implications*,
https://doi.org/10.1007/978-3-031-20878-2_8

8.1 Introduction

Nanotechnology is a dynamic research and innovation field, which affects our daily life in many ways. Nanoparticles (NPs) are materials with the size of 1–100 nm and have unique biological, chemical and physical properties. NPs have many characteristics that traditional large-size materials do not have, such as surface and interface effect, small-size effect, and quantum tunnel effect making them widely used in biomedicine, agriculture, and the environment (Xu et al. 2019; Khan et al. 2021). To achieve as much as possible to obtain the largest agricultural output from the existing resources, and to alleviate the pressure caused by the increasing shortage of global resources and the growing population, many NPs are continuously being used in agriculture (Shang et al. 2019). NPs are able to stimulate plant development via positive effects on promoting plant seed germination, plant root or above-ground growth improving stress tolerance, which is closely associated with plant carbohydrates and lipids (Zhao et al. 2020; Josef et al. 2021; Wang et al. 2020). Carbohydrates and lipids are the main components of plants. Studies have shown that NPs can promote the synthesis of carbohydrates and inhibit lipid peroxidation to increase plant yield (Siddiqui et al. 2015; Zhao et al. 2020). In addition, the green synthesis of NPs via environment-friendly plant macromolecules, such as carbohydrates, has a significant potential to boost NPs production (Xu et al. 2021). In recent years, biogenic NPs synthesized by plant carbohydrates also have been widely applied in agriculture to stimulate plant growth (Landry et al. 2019; Kah et al. 2019). The present chapter summarizes recent advances in the application of different NPs to promote the synthesis and accumulation of plant carbohydrates and inhibit lipid peroxidation (Fig. 8.1), and the use of plant carbohydrates for the green synthesis of NPs.

8.2 Effects of Nanoparticles on Plant Carbohydrates and Lipids

The positive role of NPs in the environment, especially in plant ecosystems, has been extensively studied. Many NPs have received considerable attention due to their ability to enhance the growth and yield of various plants (Mittal et al. 2020). The main purpose of this section is to collect information on the positive effects of different NPs in plant growth and increase production, especially to promote the synthesis of carbohydrates and inhibit lipid peroxidation (Table 8.1).

8.2.1 Silver Nanoparticles

Silver nanoparticles (AgNPs) are widely used in coatings, medical fields, environmental remediation, textiles, and other fields because of their strong antibacterial

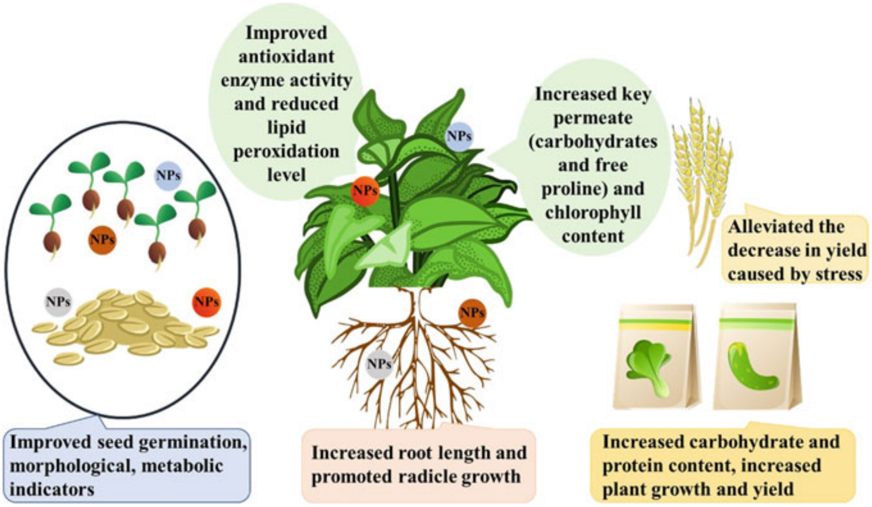

Fig. 8.1 The positive effects of nanoparticles (NPs) on seed germination, plant growth and yield. Graph by Lei Qiao

activity against different pathogenic microorganisms (Burdusel et al. 2018). In agricultural production, AgNPs have received great attention due to their ability to enhance the growth and yield of various crops (Mehmood 2018). Mehmood et al. (2017) described the effect of AgNPs prepared from *Berberis lycium* Royle root bark extract on field pea (*Pisum sativum* L.) seed metabolism. The results demonstrated that AgNPs-treated plants had higher carbohydrate contents, which led to better growth and yield of pea. In this study, the highest carbohydrate seed content of *Pisum sativum* L. after seed treatment and foliar spraying was recorded in response to the application of 60 ppm AgNPs. Sadak's (2019) work proved the effect of AgNPs on the fenugreek plant (*Trigonella foenum-graecum*), and the results indicated that treatment with AgNPs on the foliage of the fenugreek plant led to a significant increase in total carbohydrates compared to control plants and 40 mg/L AgNPs treatment made the carbohydrate content reach the maximum level. A study carried out by Latif et al. (2017) demonstrated that AgNPs (20 and 40 ppm) biosynthesized using *Mangifira indica* and *Ocimum basilicum* had significant effects on the growth of wheat (*Triticum aestivum*) seedlings, as revealed by the increases in dry and fresh weights, carbohydrate content, and chlorophyll content. Salama's (2012) research showed that after applying 60 ppm AgNPs, the carbohydrate content of *Zea mays* L. and *Phaseolus vulgaris* L. plants increased by 57% and 62%, respectively, compared with the control. A study by Krishnaraj and co-workers (2012) reported the beneficial effects of the synthesized AgNPs on *Bacopa monnieri* (Linn.) Wettst seed germination, which induced the synthesis of protein and carbohydrate, and decreased the levels of total phenol content, catalase (CAT), and peroxidase compared to the $AgNO_3$ treated plants. In addition, Gupta et al. (2018) found that the addition of of biosynthesized AgNPs into the medium enhanced rice (*Oryza sativa* L.) seedling growth (Fig. 8.2),

Table 8.1 Positive effects of different NPs plant carbohydrates and lipids

Nanoparticles	Plant	Responses	References
AgNPs	*Pisum sativum* L	Increased carbohydrate contents and enhanced growth and yield of pea	Mehmood et al. (2017)
AgNPs	*Trigonella foenum-graecum*	Improved the total carbohydrates	Sadak (2019)
AgNPs	*Triticum aestivum*	Increased the fresh and dry weight, chlorophyll and carbohydrate contents of seedlings	Latif et al. (2017)
AgNPs	*Phaseolus vulgaris* L *Zea mays* L	Improved the level of carbohydrates	Salama's (2012)
AgNPs	*Bacopa monnieri*	Enhanced germination and growth of seedlings, induced the synthesis of carbohydrate and protein, and reduced the levels of total phenol content, catalase (CAT), and peroxidase activities	Krishnaraj et al. (2012)
AgNPs	*Oryza sativa* L	Improved the growth of rice seedlings, decreased hydrogen peroxide (H_2O_2), reactive oxygen species (ROS) and lipid peroxidation levels	Gupta et al. (2018)
AgNPs	*Daucus carota L*	Increased activities of antioxidant enzymes and reduced the level of ROS and malondialdehyde (MDA)	Faiz et al. (2022)
AgNPs	*B. campestris L*	Accelerated seed germination speed and seedling development and increased cabbage yield	Zhou X et al. (2022)
SeNPs	*Fragaria* × *ananassa* Duch	Alleviated the adverse effects of soil salinity on the growth and yield of strawberry plants, increased the levels of total soluble carbohydrates and free proline reducing soil-salinity stress-induced lipid peroxidation and H_2O_2 content	Zahedi et al. (2019)

(continued)

Table 8.1 (continued)

Nanoparticles	Plant	Responses	References
SeNPs	*Capsicum annuum* L	Increased the levels of chlorophyll and soluble sugars	Li et al. (2020)
SeNPs	*Punica granatum* L	Reduced the lipid peroxidation and H_2O_2 content induced by drought stress by enhancing the activity and content of antioxidant enzymes	Zahedi et al. (2021)
SeNPs	*Brassica napus* L	Reduced the oxidative stress and membrane lipid damage caused by Cadmium (Cd)	Qi et al. (2021)
SeNPs	*Vicia faba*	Enhanced seed germination, morphological and metabolic indicators, and suppressed pathogen *Rhizoctonia solani*	Hashem et al. (2021)
SeNPs	*Coriandrum sativum* L	Alleviated Cd toxicity through enriching chlorophyll content, total soluble sugars, leaf relative water content, improving gas exchange parameters and modulating the antioxidant system	Sardar et al. (2022)
SeNPs	*Gerbera jamesonii*	Promoted antioxidant defense system activity and endogenous hormone alterations	Khai et al. (2022)
ZnONPs	*Linum uitatissimum* L	Increased the growth and yield of flax, improved the levels of photosynthetic pigments, free amino acids and carbohydrates of flax plants	Sadak et al. (2020)
ZnONPs	*Cucumis sativus*	Increased the content of starch on cucumber fruit	Zhao et al. (2014)
ZnONPs	*Zea mays* L	Improved the activities of antioxidant enzymes, and reduced lipid peroxidation in the maize cell membrane system due to drought	Sun et al. (2020a)

(continued)

Table 8.1 (continued)

Nanoparticles	Plant	Responses	References
ZnONPs	*Zea mays* L	Improved the plant growth, biomass, and photosynthetic machinery in maize under cobalt (Co) stress by reducing ROS and MDA	Salam et al. (2022)
CuONPs	*Lactuca sativa* L	Enhanced growth and promoted the dry weight, total phenol content and flavonoid content of lettuce	Pelegrino et al. (2021)
CuONPs	*Coriandrum sativum*	yielded more biomass in cilantro	Zuverza-Mena et al. (2015)
CuONPs	*Cucumis sativus*	Increased the accumulation of metabolites such as sugars, organic acids, amino acids and fatty acids	Zhao et al. (2017)
CuONPs	*Hordeum vulgare L*	Enhanced seed germination parameters, and seedling growth parameters (roots and shoots' lengths, fresh biomasses and dry biomasses)	Kadri et al. (2022)
MgONPs	*Macrotyloma uniforum*	Increased the above-ground length, fresh biomass and the content of carbohydrate and protein	Sharma et al. (2021a)
SiO_2NPs	*Zea mays* L *Phaseolus vulgaris* L *Hyssopus officinalis* L. *Nigella sativa* L	Increased seed germination, root and shoot lengths, fresh weights (except for *Hyssopus officinalis* L.) and dry weights, photosynthetic pigments, total protein, and total amino acid (except for *Hyssopus officinalis* L.)	Sharifi-Rad et al. (2016)
SiO_2NPs	*Fragaria × ananassa* Duch	Treated with SiO_2NPs retained more photosynthetic pigments and exhibited higher levels of key permeates, such as carbohydrates and proline, and improved the drought tolerance by increasing the activity of antioxidant enzymes and reducing the degree of lipid peroxidation	Zahedi et al. (2020)

(continued)

Table 8.1 (continued)

Nanoparticles	Plant	Responses	References
SiO_2NPs	*Cucurbita pepo* L	Reduced cellular oxidative damage by enhancing antioxidant enzyme activity	Siddiqui et al. (2014)
SiO_2NPs	*Lavandula officinalis*	Enhanced the multiplication and growth of in vitro plantlets and modified its phytochemical compositions and essential oil bioactivities	Khattab et al. (2022)
MSNs	*Triticum aestivum* *Lupinus angustifolius*	Enhanced the germination of seeds and increased the content of plant biomass, total protein and chlorophyll	Sun et al. (2016)

which may be related to the reduction of hydrogen peroxide (H_2O_2), reactive oxygen species (ROS) and lipid peroxidation levels and the increase in the activities of glutathione reductase (GR), ascorbate peroxidase (APX) and CAT. Additionally, the increased activities of antioxidant enzymes and reduced the levels of ROS and malondialdehyde (MDA) by the application of AgNPs advocate stress ameliorative role against Cadmium (Cd) stress in carrot (*Daucus carota* L.) plant (Faiz et al. 2022). However, research on wheat (*Triticum aestivum* L.) found that AgNPs treatment increased the lipid peroxidation of wheat seedling tissues, indicating that exposure to AgNPs may have negative effects and toxicity problems on plants (Dimkpa et al. 2013; Siddiqi and Husen 2021).

8.2.2 Selenium Nanoparticles

Selenium (Se) is an essential micronutrient that promotes human and animal health, and it is also a beneficial element for plant growth (Hu et al. 2018). Early studies have demonstrated that low-dose sodium selenite spraying on foliage increased the Se content of grapes and winter wheat, and increased their growth and yield (Ducsay et al. 2006; Zhu et al. 2017). Se nanoparticles (SeNPs) have gained extensive interest due to their unique biological properties and have been recommended as a more effective, safer platform for Se delivery (Xu et al. 2018). Zahedi and colleagues (2019) assessed the potential effects of SeNPs in alleviating the adverse impact of soil salinity on strawberry (*Fragaria* × *ananassa* Duch.) plant growth and yield. The results showed that strawberry plants treated with SeNPs had higher contents of major osmolytes, such as free proline and total soluble carbohydrates, compared to the control group under stress conditions. Foliar spraying of SeNPs enhanced salinity tolerance in strawberries by decreasing soil-salinity stress-triggered H_2O_2

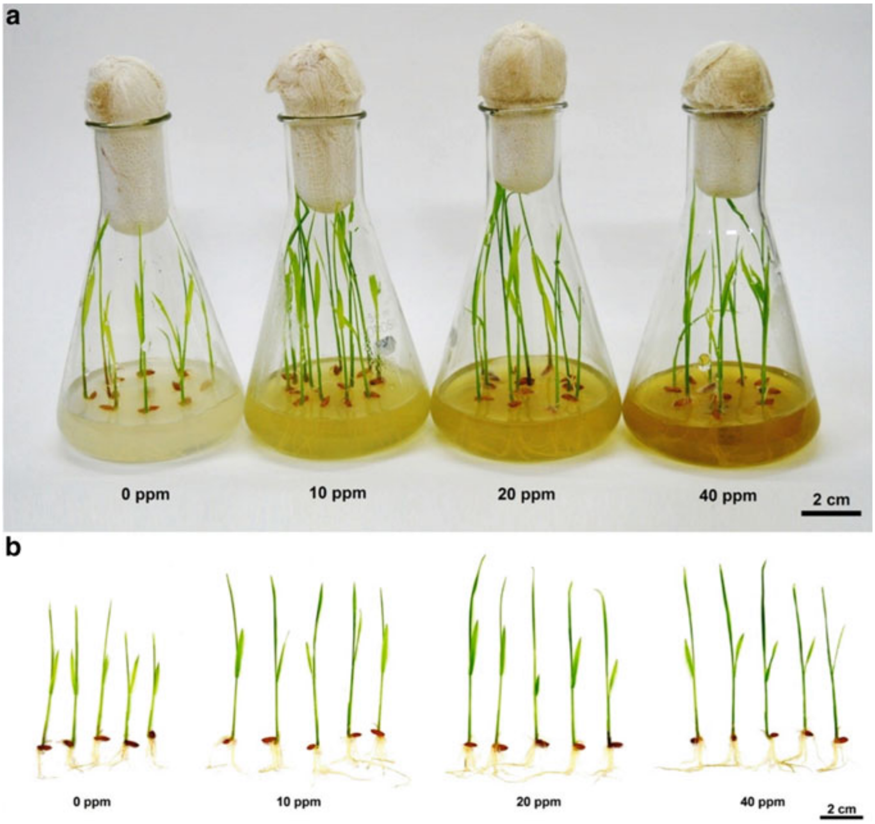

Fig. 8.2 Germination and seedling growth of rice on medium containing various concentrations of AgNPs at 14 d of incubation (**a**), and shoot and root elongation at 14 d under the exposure of AgNPs (**b**). *Source* Gupta et al. (2018)

level and lipid peroxidation via increasing superoxide dismutase (SOD) and CAT activities. In addition, spraying SeNPs (20 mg/L) on pepper (*Capsicum annuum* L.) leaves can increase the levels of chlorophyll and soluble sugars, thereby activating the branched-chain fatty acid and phenylpropane pathways, as well as the expression of AT3-related genes and enzymes. SeNPs treatment remarkably increased the levels of proline pathway-associated compounds, which can reduce the levels of malondialdehyde and hydroxyl free radicals in crops (Li et al. 2020). Studies have also shown that foliar application of SeNPs can reduce the lipid peroxidation and H_2O_2 content induced by drought stress by improving the activity and content of antioxidant enzymes, thereby reducing the harmful effects of oxidative stress on pomegranate (*Punica granatum* L.) fruits and leaves (Zahedi et al. 2021). It is also reported that SeNPs can reduce the oxidative stress and membrane lipid damage caused by Cd by inhibiting the expression of NADPH oxidase and glycolate oxidase in *Brassica napus* L. (Qi et al. 2021). In addition, Sardar et al. (2022) found that SeNPs promoted the alleviation of Cd toxicity via enriching leaf relative water content, total soluble sugars and chlorophyll content, improving gas-exchange parameters and modulating the antioxidant system of coriander (*Coriandrum sativum* L.) plants in response to Cd stress.

Due to the invasion of various pathogens including fungi and bacterial strains, food security and yield are seriously threatened (Bramhanwade et al. 2015). Among various nanoparticles, SeNPs have become powerful antibacterial agents and bio-enhancers to reduce the catastrophic effects of plant pathogenic species. Hashem et al. (2021) demonstrated that biogenic SeNPs improved *Vicia faba* (Faba Bean) morphological and metabolic determinants, yield and seed germination. Moreover, SeNPs have promising antifungal activity against *Rhizoctonia solani*, which can markedly enhance morphological and metabolic determinants as well as growth and yield compared to the infected controls. In summary, SeNPs have important potential applications in reducing biotic and abiotic stresses of plants (Zohra et al. 2021).

8.2.3 Zinc Oxide Nanoparticles

Zinc (Zn) is an important micronutrient necessary for adequate plant growth. It is a vital element for the production of chlorophyll, protein synthesis and carbohydrate metabolism, and is the key to biomass production (Anita 2021). Many reports have demonstrated that zinc-oxide nanoparticles (ZnONPs) may improve plant productivity and growth. Therefore, research related to the application of ZnONPs is of great significance to sustainable agriculture (Rizwan et al. 2017). ZnONPs can be used as nano-fertilizers to reduce the amount of fertilizer used without affecting crop yields and maximize crop productivity (Palacio-Márquez et al. 2021). Sadak et al. (2020) found that ZnONPs have beneficial effects on the growth and yield of flax (*Linum uitatissimum* L.) plants, which are manifested in improving the levels of carbohydrates, free amino acids and photosynthetic pigments of flax plants. Zhao and co-workers (2014) showed that ZnONPs (800 mg/kg of soil) could alter the carbohydrate quality of cucumbers (*Cucumis sativus*). The results indicated that ZnONPs might not influence the content of reducing and non-reducing sugars, but increased the content of starch on cucumber fruit. Sun et al. (2020a) found that ZnONPs (100 mg/L) significantly improved the activities of SOD, CAT and APX, and reduced lipid peroxidation in the maize (*Zea mays* L.) cell membrane system due to drought. In addition, ZnONPs enhance the biosynthesis of starch and sucrose in maize under drought stress by elevating the levels of UDP-glucose pyrophosphorylase (17.8%), glucose phosphate isomerase (391.5%) and cytoplasmic invertase (126%) (Sun et al. 2020b). Recently, Salam et al. (2022) demonstrated that ZnONPs improved the plant growth, biomass, and photosynthetic machinery in maize (*Zea mays* L.) under cobalt (Co) stress by reducing ROS and MDA. However, the accumulation of a high dosage of NPs in plants can affect their growth. Studies have confirmed that a high dosage of ZnONPs causes oxidative stress in wheat (*Triticum aestivum*) by increasing the level of lipid peroxidation and oxidizing glutathione in roots (Dimkpa et al. 2012). Salehi et al. (2022) found that aerially applied ZnONPs negatively affect fully developed bean plants (*Phaseolus vulgaris* L.). ZnONPs could induce tapetum abnormality, abnormal deposition of carbohydrates, and eventually apoptosis.

8.2.4 Copper Oxide Nanoparticles

Copper (Cu) is an essential micronutrient for plants, directly involved in the synthesis of oxidoreductase and the metabolism of protein and carbohydrates (Wang et al. 2019). Due to the antibacterial properties of copper oxide nanoparticles (CuONPs), they are being used commercially for wood preservation, agricultural fungicides and antifouling coatings (Yuan et al. 2016). The application of CuONPs in agriculture is relatively new, but interest in its use as plant protection products and nano-fertilizers is increasing (Verma et al. 2018). CuONPs can be used as nutrients for plants but can have phytotoxicity depending on its application concentration, particle size, administration method and exposure time (Liu et al. 2016). There are facts that at low concentrations CuONPs have beneficial effects on plants. Pelegrino et al. (2021) found that spraying spherical CuONPs on lettuce (*Lactuca sativa* L.) leaves had a positive effect on its growth and promoted the dry weight, total phenol content and flavonoid content of lettuce. The CuONPs synthesized by green tea at concentrations between 0.2 and 20 μg/mL are non-phytotoxic and might enhance lettuce radicle growth (Pelegrino et al. 2020). Zuverza-Mena and co-workers (2015) found that compared with the control, application of CuONPs improved the biomass yield of cilantro (*Coriandrum sativum*). Zhao et al. (2017) found that compared with the control, administration of CuONPs significantly increased the accumulation of metabolites (e.g., sugars, fatty acids, amino acids and organic acids) in cucumbers (*Cucumis sativus*). Recently, Kadri et al. (2022) reported that enhancement of *Hordeum vulgare* L. seed germination parameters, and seedling growth parameters (shoots and roots' lengths, dry biomass and fresh biomass) by decreasing the concentration of CuONPs. However, at present, most researches have focused on the toxicity of CuONPs to crops. Exposure to CuONPs can cause membrane lipid damage, increased ROS and proline accumulation, and decreased seed germination in rice (*Oryza sativa* L.) seedlings (Shaw et al. 2013). Nair et al. (2015) reported that CuONPs reduced the shoot elongation, carotenoids and chlorophyll content of *Indian mustard*. Therefore, in order to take advantage of the benefits of CuONPs on plant growth and development as well as disease control of various crops, further research especially optimal dosage is needed.

8.2.5 Magnesium Oxide Nanoparticles

Magnesium (Mg) is the fourth most important element after potassium (K), phosphorus (P), and nitrogen (N) among the important elements for plant development.

It participates in many physiological and biochemical reactions during plant growth and development (Cakmak 2013). Mg is essential for the formation of plant carbohydrates and protein. 75% of the Mg in plant leaves is used for the synthesis of plant protein, 20% is involved in the synthesis of chlorophyll, and is used as an enzyme cofactor to participate in the carbon fixation and metabolism process of photosynthesis (Cakmak et al. 2008). Mg deficiency can inhibit the synthesis of chlorophyll, cause different morphological and physiological changes in plants, and regulate its secondary metabolic pathways (Guo et al. 2016). Magnesium oxide nanoparticles (MgONPs) are easily absorbed by the soil, improve fertilizer utilization, and can be used as an element supplement to increase the Mg content in the soil. When *Macrotyloma uniforum* was treated with MgONPs, the above-ground length, chlorophyll content and fresh biomass increased significantly, and the accumulation of carbohydrates and proteins increased by 4–20% and 18–127% (Sharma et al. 2021a). However, some studies have found that exposure to MgONPs negatively regulates plant growth. Sharma et al. (2021b) found that treatment with MgONPs resulted in reductions in total chlorophyll, biomass and carbohydrate content of mungbean (*Vigna radiata* L.) by 24–75%, 40% and 41%, respectively. These studies indicated that responses to MgONPs are largely dependent on the type of plants.

8.2.6 Silicon Dioxide Nanoparticles

Silicon (Si), the second most abundant element on Earth's crust, is abundantly found in the soils. Si can facilitate plants to cope with abiotic and biotic stresses (de Moraes et al. 2021). Sharifi-Rad co-workers (2016) studied the effects of silicon dioxide nanoparticles (SiO_2NPs) on two field crops (*Phaseolus vulgaris* L. and *Zea mays* L.) and two medicinal plants (*Nigella sativa* L. and *Hyssopus officinalis* L.) on the morphological and biochemical characteristics. The results showed that 400 mg/L SiO_2NPs remarkably improved shoot and root lengths, dry weight and fresh weight (except for *Hyssopus officinalis* L.), photosynthetic pigments, seed germination, total amino acid (except for *Hyssopus officinalis* L.) and total protein, but total carbohydrates appeared to reduce. Zahedi et al. (2020) found that spraying a solution containing SiO_2NPs improved the growth of strawberry (*Fragaria* × *ananassa* Duch.) plants under normal and drought stress conditions. Compared to the control group, the plants treated with SiO_2NPs retained more photosynthetic pigments and exhibited higher levels of key permeates, such as carbohydrates and proline. In addition, exogenous spraying of SiO_2NPs improves the drought tolerance by elevating the activities of antioxidant enzymes and reducing the degree of lipid peroxidation. Siddiqui et al. (2014) reported that SiO_2NPs can significantly reduce cellular oxidative damage by enhancing antioxidant enzyme activity, reducing MDA and H_2O_2 levels, and alleviating the decrease in pumpkin (*Cucurbita pepo* L.) seed germination rate, vitality, and growth caused by salt stress. Recently, Khattab et al. (2022) found that SiO_2NPs enhanced the growth and multiplication of *Lavandula officinalis* in vitro plantlets and modified its essential oil bioactivities and phytochemical compositions.

Mesoporous silica nanoparticles (MSNs), as a kind of SiO_2NPs, are widely used in various fields of agriculture because of their large specific surface area, uniform particle size, high stability, easy to modify internal and external surfaces and good biocompatibility (Popat et al. 2012; Abdelrahman et al. 2021). Sun and co-workers (2016) found that the photosynthesis efficiency of wheat (*Triticum aestivum*) and lupin (*Lupinus angustifolius*) plants exposed to MSNs was significantly improved, the germination of seeds was enhanced, and the plant biomass, total protein and chlorophyll content increased.

8.3 Green Synthesis of Nanoparticles Using Plant Carbohydrates

NPs have been prepared by various approaches, including biological, chemical and physical methods. Compared to chemical and physical methods, biological entities, especially plants, provide an environment-friendly, safe and efficient method for the synthesis of NPs (Nayantara et al. 2018). Recently, plant extracts (phenolic acids, bioactive alkaloids, polyphenols, terpenoids, sugars and proteins) have been demonstrated to serve as reducing, stabilizing, and/or complexing agents for the green synthesis of NPs (Ettadili et al. 2022). Carbohydrates with different functional groups (e.g., amino, carboxylate, ester, hydroxyl and sulfate) can bind with metal precursors via non-covalent or van der Waals interaction, leading to the decreased levels of metals and stabilization of metal NPs (Majhi et al. 2021). As the main carbohydrate, polysaccharides contain various functional groups, including hydroxyl groups capable of reducing precursor salts and hemiacetal reducing ends (Fig. 8.3). The carbonyl groups oxidized from polysaccharide hydroxyl groups play a vital role in the reduction process of inorganic salts. The reducing ends of polysaccharides have been applied to introduce amino functional groups that can compound and stabilize NPs (Park et al. 2011).

The synthesis of NPs from carbohydrates has attracted more and more attention because of its non-toxic, safe, stable, good biocompatibility, environmental friendliness and strong availability of carbohydrates (Boddohi et al. 2010). The use of natural polysaccharides as reducing agents and stabilizers for NPs synthesis is a simple green synthesis technology, which does not require any other chemical reducing agents (Mohammadlou et al. 2016). Kumar et al. (2019) used *Arabidopsis thaliana* as a model plant for the biosynthesis of AgNPs *in vitro* and systematically revealed the biochemical components required for the production of AgNPs. The results showed that carbohydrates, polyphenols and glycoproteins are the basic factors for stimulating the synthesis of AgNPs. Yugay et al. (2020) isolated polysaccharides (alginate, fucoidan, and laminaran) from the seaweed *Fucus evanescens* and *Saccharina cichorioides*, and found that all polysaccharides can be used as reducing agents to convert silver nitrate into AgNPs, and their catalytic activities may vary as follows: laminaran > fucoidan > mayalginate. Tippayawat et al. (2016) used aloe

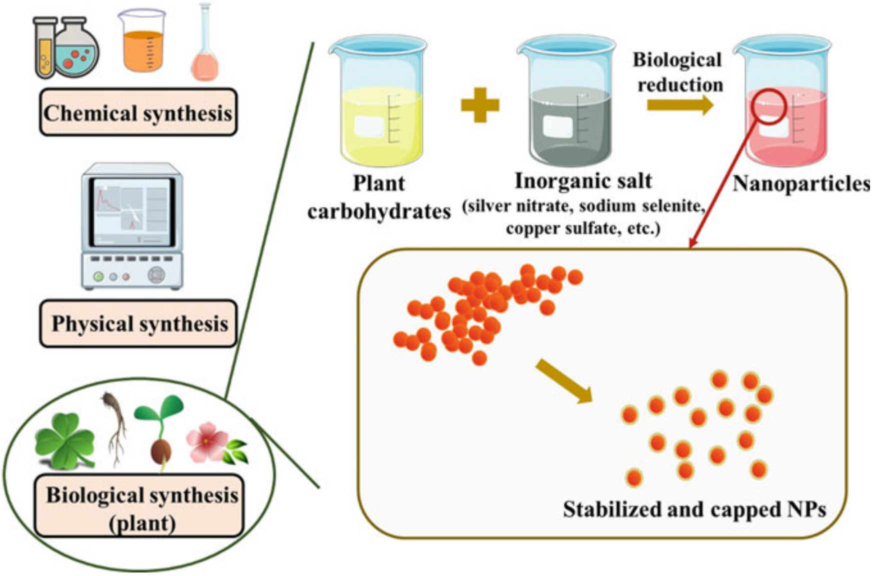

Fig. 8.3 Green synthesis of nanoparticles using plant carbohydrates. Graph by Lei Qiao

plant extracts rich in pectin, lignin and hemicellulose to synthesize spherical AgNPs, in which the aloe vera extract functions as both capping and reducing agents. Zhou et al. (2021) synthesized stable and individual spherical SeNPs with a mean diameter of ~ 79 nm using the *Citrus limon* L.-extracted polysaccharides as the decorator and stabilizers and SeNPs exhibited good dispersion and high stability in water for at least 3 months. Jonn et al. (2017) reported an environmentally friendly synthesis of platinum nanoparticles (PtNPs) using water hyacinth (*Eichhornia crassipes*) plant extracts as effective reducing agents and stabilizers. Fourier transform infrared spectroscopy (FTIR) showed that the extracts hydroxyl, nitrogen and carbohydrate groups are responsible for the reduction and capping of PtNPs. Patil and co-workers (2016) developed cerium oxide (CeO_2) NPs with a mean particle size of < 40 nm using a pectin extracted from the peel of red pomelo (*Citrus maxima*). In general, the synthesis of nanoparticles using carbohydrates has more advantages than traditional approaches in terms of cost, eco-friendly and biocompatibility.

8.4 Conclusion and Prospects

NPs have become a research hotspot in the field of agriculture due to their special physical and chemical properties. This article mainly reviews the application of NPs in sustainable agriculture, such as promoting plant growth and improving stress resistance, from the perspective of plant macromolecules (carbohydrates and lipids).

In addition, the use of plant macromolecules to biosynthesize nanoparticles is cost-effective, environmentally friendly and can improve the performance of NPs. Many researchers have confirmed that biosynthetic NPs are an effective strategy to replace traditional nanoparticles and agrochemicals. Therefore, the biosynthesis of NPs can inevitably become an emerging trend in the sustainable development of agriculture. Natural products, such as plant carbohydrates, can serve as promising candidate materials for the green synthesis of NPs, which are abundantly available in nature. While developing nanotechnology in the future, the safety of NPs, especially their toxicity, should be considered, and their safe use range and use environment should be studied to improve their utilization and stability, and promote the application of NPs in sustainable agriculture.

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