Supporting information

Molecular Mechanisms of CeO_2 Nanomaterials Improving Tomato Yield, Fruit Quality, and Postharvest Storage Performance

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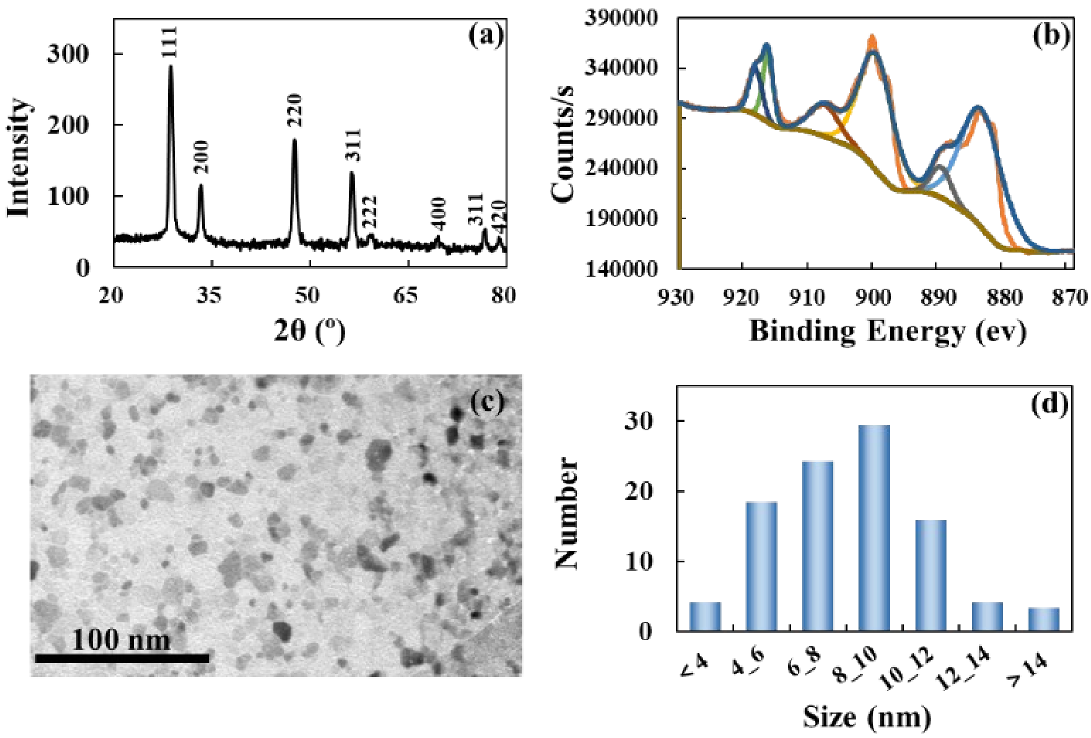

Fig. S1 XRD analysis (a), XPS measurement (b), TEM image (c) and size distribution (d) of CeO_2 NMs.

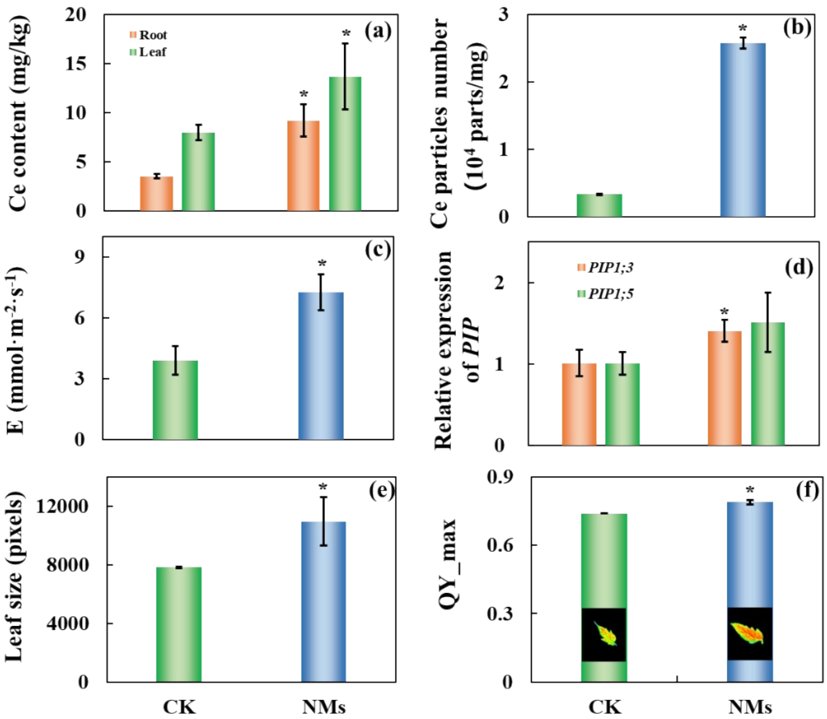

Fig. S2 Ce content in roots and leaves (a), Ce particles number in leaves (b), transpiration rate (E) (c), relative expression of *PIP* (c), leaf size (e) and photosystem II photochemistry (QY_max) (d). The significant differences between control and CeO_2 NMs are marked with "*" (p < 0.05). Values are mean ± standard deviation (t test, n = 5).

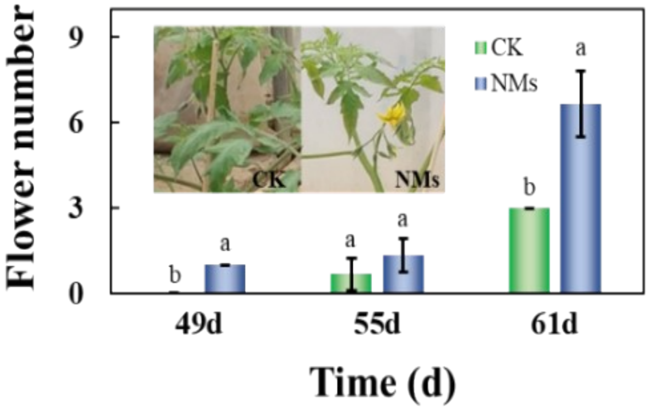

Fig. S3 Phenotype of early flowering and flower number in control and CeO_2 NMs. Different letters indicate significant differences among treatments ($p < 0.05$). Values are mean ± standard deviation (t test, n = 5).

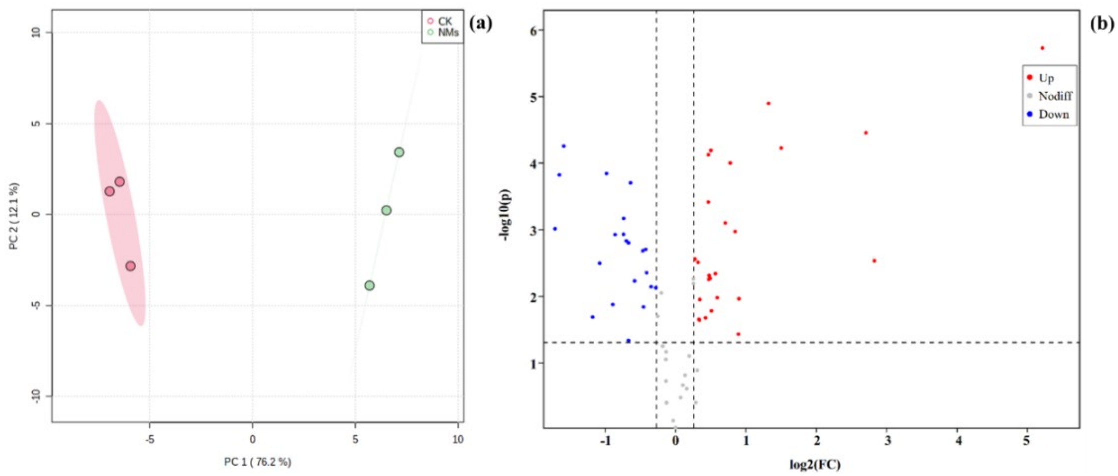

Fig. S4 Partial least squares-discriminate analysis score plots of profiles (a), and volcano plot metabolites (b) of tomato fruits between un-exposed control and CeO_2 NMs.

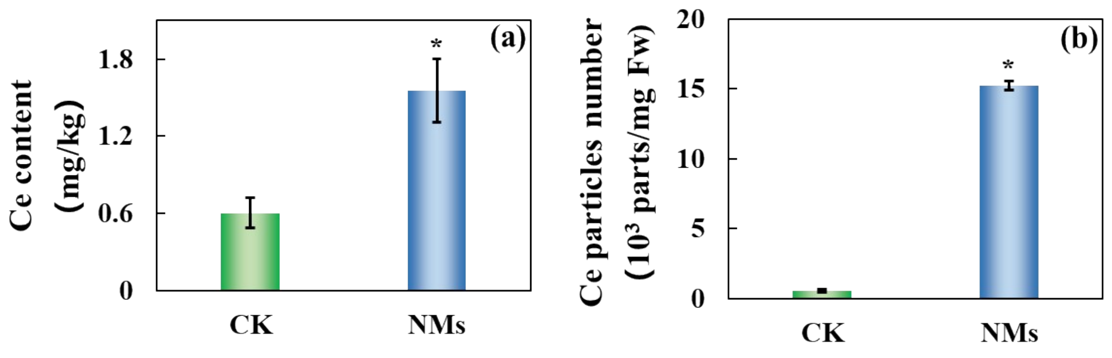

Fig. S5 Ce content (a) and Ce particles number (b) in tomato fruit. The significant differences between control and CeO_2 NMs are marked with “*” ($p < 0.05$). Values are mean ± standard deviation (t test, n = 5).

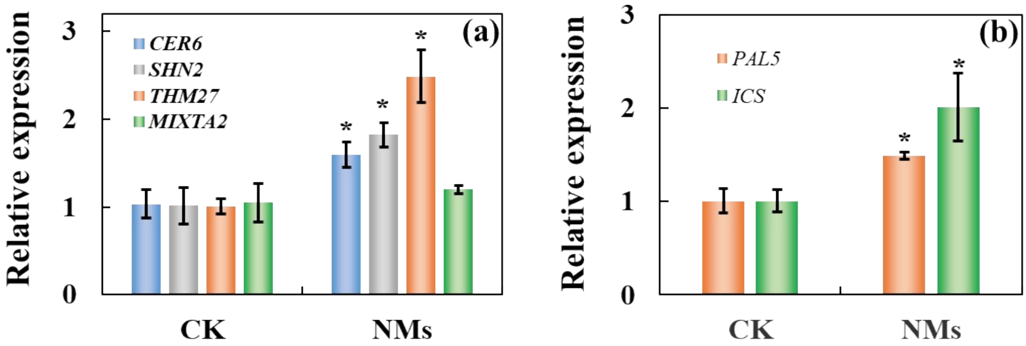

Fig. S6 Relative expressions of waxy layer synthesis genes (*CER6*, *SHN2*, *THM27* and *MXTA*) (a) and salicylic acid synthesis genes (*PAL5* and *ICS*) (b). The significant differences between control and CeO_2 NMs are marked with "*" ($p < 0.05$). Values are mean ± standard deviation (t test, n = 5).

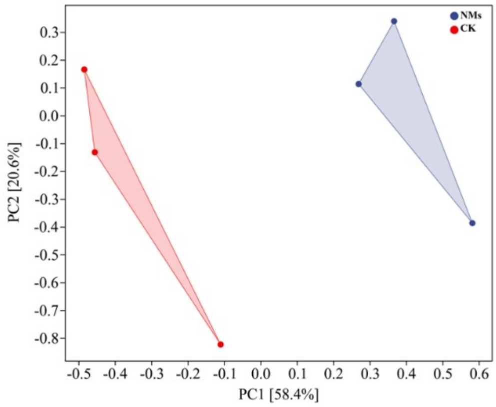

Fig. S7 Principal coordinates analysis in postharvest soil upon CeO_2 NM exposure as compared to un-exposed control.

Table S1 The properties of soil used in this research.

pH	Total carbon (g kg^{-1})	Total nitrogen (g kg^{-1})	Ce Content (g kg^{-1})	Available phosphorus (g kg^{-1})	Available potassium (g kg^{-1})
7.5	18.7	1.9	0.086	0.1	0.5

Table S2 Primer sequences for qRT-PCR.

Gene	Primer	Sequence (5' to 3')
Actin	Forward	ATGATAACTCGACGGATCGC
	Reverse	CTTGGATGTGGTAGCCGT
PIP1;3	Forward	TTTAACAAAGACGAGGCATGGGA
	Reverse	AAACAACAGCACCAGACAGGG
PIP1;5	Forward	TATCTGTCTTTAAACAATGGGATTCT
	Reverse	GAACCTTCATTGATAAGGTACATTAC
SPS	Forward	CGGTGGATGGCAAAACG
	Reverse	GGCAATCGGCCTCTGGT
SFT	Forward	CACCGATATTCCAGCTACCA
	Reverse	TGTTTGCCGACCTAATTGTC
LeSUT1	Forward	TTCCATAGCTGCTGGTGTTC
	Reverse	TACCAGAAATGGGTCCACAA
LeSUT2	Forward	CCTACAGCGTCCCTTTCTCT
	Reverse	GGATACAACCATCTGAGGTACAA
PIF4	Forward	GGCTTAGGTTCACATACAG
	Reverse	TGATGGTGTCGTTGTCTC
PAL5	Forward	AACAGCAACATTACCCCGTGTT
	Reverse	GCAATGTATGACAACGGGACAA
CER6	Forward	ACAAGAAGATCCACAAGGGAAAGT
	Reverse	CGGACCGATCGTAGTGATGTT
SHN2	Forward	ATGCAAAGCTGAGGAAATGTTG
	Reverse	GATGTTTTTTGCCACACTCCAA
THM27	Forward	GTAAAGATTGCAGTTGTGGAAGTGA
	Reverse	TTCAAGCCCAAAAAGTCATAACC
MIXTA2	Forward	GCGAGCGCTAGTGCTGGTAT
	Reverse	TAATATGTTGCGCATTTTCGAAA
ICS	Forward	TCATTAGACGATTGGCGTGCTA
	Reverse	GCTGTTGCATCAAATCGGATT

Table S3 Zeta potential and hydrodynamic diameter of CeO_2 NMs in deionized water. Values are mean ± standard deviation (t test, n = 5).

NMs	Zeta potential (mV)	Hydrodynamic diameter (nm)
50 mg L^{-1} CeO_2	17.4 ± 0.5	131.5 ± 3.2

Table S4 Elemental concentration (mg kg^{-1}) in tomato root and leaf. The significant differences between control and CeO_2 NMs are marked with "*" (p < 0.05). Values are mean ± standard deviation (t test, n = 5).

		Elemental concentration (mg kg^{-1})										
		Na	**Mg**	**P**	**S**	**K**	**Ca**	**Mn**	**Fe**	**Cu**	**Zn**	**Mo**
Root	**CK**	11473.5	3309.0	2629.4	3692.9	2041.1	8511.6	167.7	1552.7	15.3	39.2	0.8
	NMs	11709.27*	4663.9*	4348.8*	5829.1*	2570.6*	9441.6*	377.2*	4367.1*	21.5*	34.7	1.5*
Leaf	**CK**	9241.2	4204.7	7480.1	2262.6	13528.9	11243.9	227.8	1381.7	11.1	31.2	1.0
	NMs	11866.9*	45593.8	8231.1*	2410.5*	14969.7	18030.8*	267.8*	2061.7*	13.5*	35.2	1.1

Table S5 Relative content of metabolites in tomato leaves altered by CeO_2 NMs. The significant differences between control and CeO_2 NMs are marked with "*" ($p < 0.05$). Values are mean ± standard deviation (t test, n = 5).

Metabolites	CK	NMs
Serine	269729599.4	315286363.0
Leucine	1108489665.0	1291215185.0
Alanine	10393409.9	13550901.8*
Aspartate	44558883.9	82056517.2
Threonine	65792673.5	66842905.5
Tyrosine	38736469.6	31728401.6
Tryptophane	1501767.2	1179298.6
Arginine	17850356.6	22565715.9*
Glutamine	181122916.9	489312983.2*
Glutamate	811434449.6	783386400.4
Citrulline	27321339.9	38954250.1*
Proline	391525319.6	1260413970.0*
Caffeic acid	498700100.0	768801796.1*
Malic acid	10299664010.0	13138488670.0*
Citric acid	1154445353.0	1280078645.0*

Table S6 Relative content of main metabolites in tomato fruits altered by CeO_2 NMs. The significant differences between control and CeO_2 NMs are marked with "*" ($p < 0.05$). Values are mean ± standard deviation (t test, n = 5).

Metabolites	CK	NMs
L-Malic acid	54740066.8	155198564.5*
Quercetin	4644754.6	22509350.3*
Fructose	1239063191.0	2428121936.0*
Ascorbic acid	43501587.2	394332653.5*
Coumaric acid	1494851267.0	3669602269.0*
L-Phenylalanine	16543050.2	24252566.1*

Table S7 Nutrient element concentration (mg kg^{-1}) in tomato fruits as affected by CeO_2 NMs. The significant differences between control and CeO_2 NMs are marked with "*" ($p < 0.05$). Values are mean ± standard deviation (t test, n = 5).

Elemental concentration (mg kg^{-1})						
		Na	**K**	**Fe**	**Cu**	**Zn**
Fruit	**CK**	1624.1	24504.4	109.6	5.4	15.7
	NMs	2352.7*	34627.0*	145.4*	6.2*	18.6*

Table S8 Relative content of changed metabolites involved in salicylic acid metabolic pathways of tomato fruits by CeO_2 NMs. The significant differences between control and CeO_2 NMs are marked with "*" ($p < 0.05$). Values are mean ± standard deviation (t test, n = 5).

Metabolites	**CK**	**NMs**
Glutamate	3154016749.0	5413813957.0*
L-Phenylalanine	1494858126.0	3794122207.0*
Salicylic acid	25056885.2	51432736.6*