Supplementary materials for:

Novel Carvacrol or *trans*-Cinnamaldehyde@ZnO/Natural Zeolite Ternary Nanohybrid for Poly-L-lactide/tri-ethyl Citrate Based Sustainable Active Packaging Films

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Table S1. Data used for the statistical analysis and the calculation of CV or *t*CN %wt. adsorption Capacity mean values.

CV or *t*CN %wt. Adsorption Capacity

Nanohybrid	Value 1	Value 2	Value 3
CV@ZnO/NZ1.0	61.9	62.0	62.1
CV@ZnO/NZ0.5	63.9	64.0	64.1
CV@ZnO/NZ0.25	65.9	66.0	66.1
***t*CN@ZnO/NZ1.0**	59.9	60.0	60.1
***t*CN@ZnO/NZ0.5**	61.9	62.0	62.1
***t*CN@ZnO/NZ0.25**	63.9	64.0	64.1

Table S2. Data used for the statistical analysis and the calculation of k_2 mean values of nanohybrids.

k_2 Values ($\times 10^{-5}$)

Nanohybrid	Value 1	Value 2	Value 3
CV@ZnO/NZ1.0	5.954	6.480	7.006
CV@ZnO/NZ0.5	1.584	1.710	1.836
CV@ZnO/NZ0.25	1.134	1.230	1.326
***t*CN@ZnO/NZ1.0**	0.990	1.030	1.070
***t*CN@ZnO/NZ0.5**	2.140	2.240	2.340
***t*CN@ZnO/NZ0.25**	11.450	11.870	12.290

Table S3. Data used for the statistical analysis and the calculation of q_e mean values of nanohybrids.

q_e Values

Nanohybrid	Value 1	Value 2	Value 3
CV@ZnO/NZ1.0	0.97	0.98	0.99
CV@ZnO/NZ0.5	0.92	0.93	0.94
CV@ZnO/NZ0.25	0.86	0.87	0.88
***t*CN@ZnO/NZ1.0**	0.80	0.82	0.84
***t*CN@ZnO/NZ0.5**	0.74	0.76	0.78
***t*CN@ZnO/NZ0.25**	0.55	0.57	0.59

Table S4. Data used for the statistical analysis and the calculation of EC_{50} mean values of all ternary nanohybrids.

EC_{50},DPPH Values (mg/mL)

Nanohybrid	Value 1	Value 2	Value 3
CV@ZnO/NZ1.0	17.26	20.09	22.92
CV@ZnO/NZ0.5	7.43	7.89	8.35
CV@ZnO/NZ0.25	5.39	6.02	6.65
***t*CN@ZnO/NZ1.0**	23.41	23.64	23.87
***t*CN@ZnO/NZ0.5**	23.07	26.48	29.89
***t*CN@ZnO/NZ0.25**	29.09	33.24	37.39

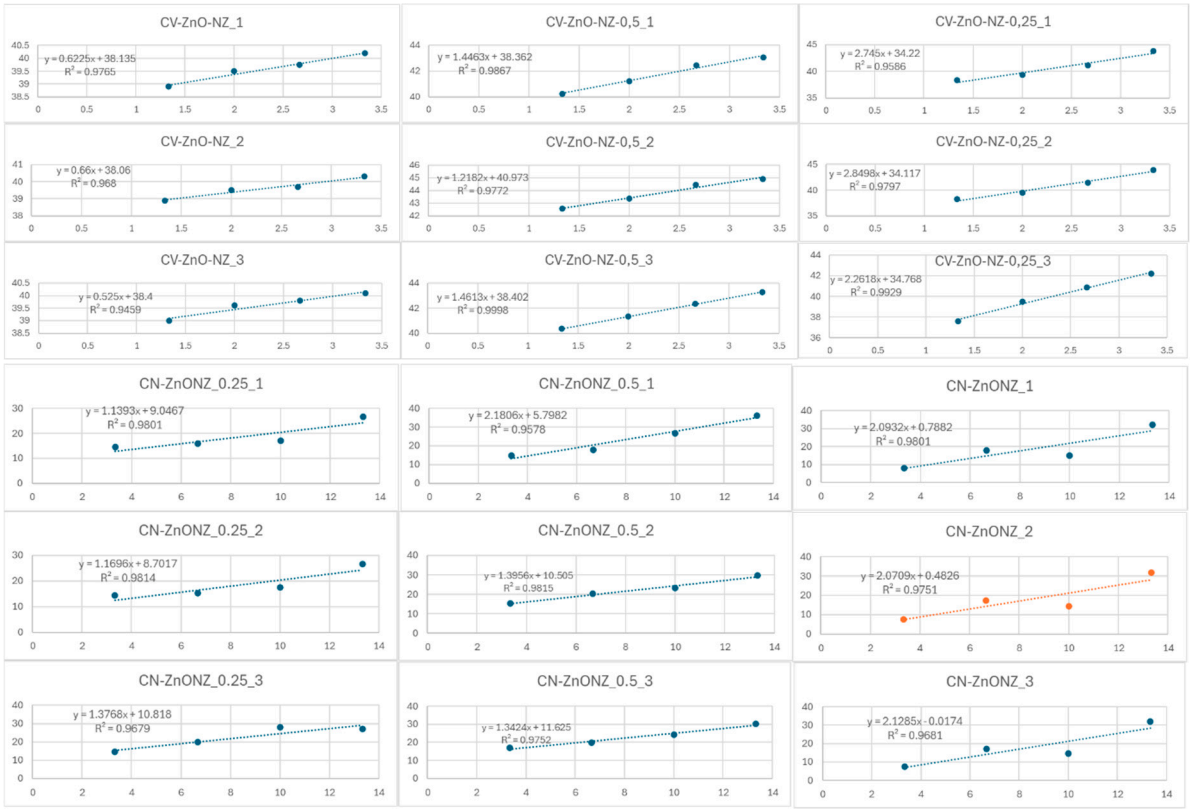


Figure S1. Obtained Absorbance = f (mg of nanohybrid) plots and calculated equations used for the calculation of EC_{50} mean values of all ternary nanohybrids.

Table S5. Data used for the statistical analysis and the calculated mean values of tensile properties.

Sample	E (MPa)	σ_uts (MPa)	%ε	σ_break (MPa)
PLA/TEC	520, 580, 594, 650, 670	16.5, 18.5, 20.0, 21.5, 23.5	132, 145, 157, 170, 182	10.0, 12.5, 15.0, 17.5, 20.0
PLA/TEC/10CV@ZnO/NZ0.25	840, 875, 896, 920, 950	32.4, 33.8, 34.7, 35.6, 37.0	20.0, 23.5, 26.7, 30.0, 33.4	19.8, 21.0, 22.3, 23.5, 24.8
PLA/TEC/10CV@ZnO/NZ0.5	646, 680, 714, 748, 782	21.6, 23.8, 25.5, 27.2, 29.4	141, 158, 175, 192, 209	16.2, 17.8, 19.5, 21.2, 22.8
PLA/TEC/10CV@ZnO/NZ1.0	611, 650, 690, 730, 768	17.0, 20.0, 24.0, 28.0, 31.0	161, 175, 190, 205, 219	11.1, 15.0, 20.3, 25.6, 29.5
PLA/TEC/10CN@ZnO/NZ0.25	985, 1020, 1051, 1080, 1116	29.4, 31.0, 32.0, 33.0, 34.6	15.2, 16.0, 16.7, 17.4, 18.2	18.2, 19.3, 20.3, 21.3, 22.4
PLA/TEC/10CN@ZnO/NZ0.5	585, 605, 621, 635, 656	19.6, 21.0, 22.7, 24.4, 25.8	28.8, 33.0, 37.3, 41.6, 45.8	11.7, 13.5, 15.7, 17.9, 19.7
PLA/TEC/10CN@ZnO/NZ1.0	295, 320, 354, 390, 414	7.5, 8.5, 9.6, 10.7, 11.7	192, 205, 227, 249, 262	9.0, 10.0, 11.0, 12.0, 13.0

Table S6. Data used for the statistical analysis and the calculated O.T.R. mean values.

Sample	OTR Value 1	OTR Value 2	OTR Value 3	Mean
PLA/TEC	195	196	197	**196**
PLA/TEC/CV@ZnO/NZ0.25	45	46	47	**46**
PLA/TEC/CV@ZnO/NZ0.5	51	52	53	**52**
PLA/TEC/CV@ZnO/NZ1.0	79	80	81	**80**
PLA/TEC/*t*CN@ZnO/NZ0.25	68	69	70	**69**
PLA/TEC/*t*CN@ZnO/NZ0.5	88	89	90	**89**
PLA/TEC/*t*CN@ZnO/NZ1.0	78	79	80	**79**

Table S7. Data used for the statistical analysis and the calculated P_{eO2} mean values.

Sample	P_{eO2} ($cm^2 \cdot s^{-1}$) × 10^{-9}			P_{eO2}
	P_{eO2}_1	P_{eO2}_2	P_{eO2}_3	$P_{eO2}_average$
PLA/TEC	5.19097E-09	5.21759E-09	5.24E-09	5.22 ± 0.025E-09
PLA/TEC/CV@ZnO/NZ0.25	9.375E-10	9.58333E-10	9.79E-10	2.10 ± 0.027E-09
PLA/TEC/CV@ZnO/NZ0.5	1.23958E-09	1.26389E-09	1.29E-09	1.85 ± 0.026E-09
PLA/TEC/CV@ZnO/NZ1.0	1.8287E-09	1.85185E-09	1.88E-09	1.75 ± 0.019E-09
PLA/TEC/*t*CN@ZnO/NZ0.25	1.41667E-09	1.4375E-09	1.46E-09	1.26 ± 0.025E-09
PLA/TEC/*t*CN@ZnO/NZ0.5	1.73148E-09	1.75116E-09	1.77E-09	1.44 ± 0.022E-09
PLA/TEC/*t*CN@ZnO/NZ1.0	2.07639E-09	2.10301E-09	2.13E-09	9.58 ± 0.021E-10

Table S8. Data used for the statistical analysis and the calculation of EC_{50} mean values of all active nanocomposite films.

EC_{50},DPPH Values for Films (mg/mL)

Film	Value 1	Value 2	Value 3
PLA/TEC	-	-	-
PLA/TEC/CV@ZnO/NZ0.25	30.95	34.43	37.91
PLA/TEC/CV@ZnO/NZ0.5	45.13	46.87	48.61
PLA/TEC/CV@ZnO/NZ1.0	59.47	64.27	69.07
PLA/TEC/*t*CN@ZnO/NZ0.25	202.32	209.12	215.92
PLA/TEC/*t*CN@ZnO/NZ0.5	168.44	181.83	195.22
PLA/TEC/*t*CN@ZnO/NZ1.0	80.68	82.78	84.88

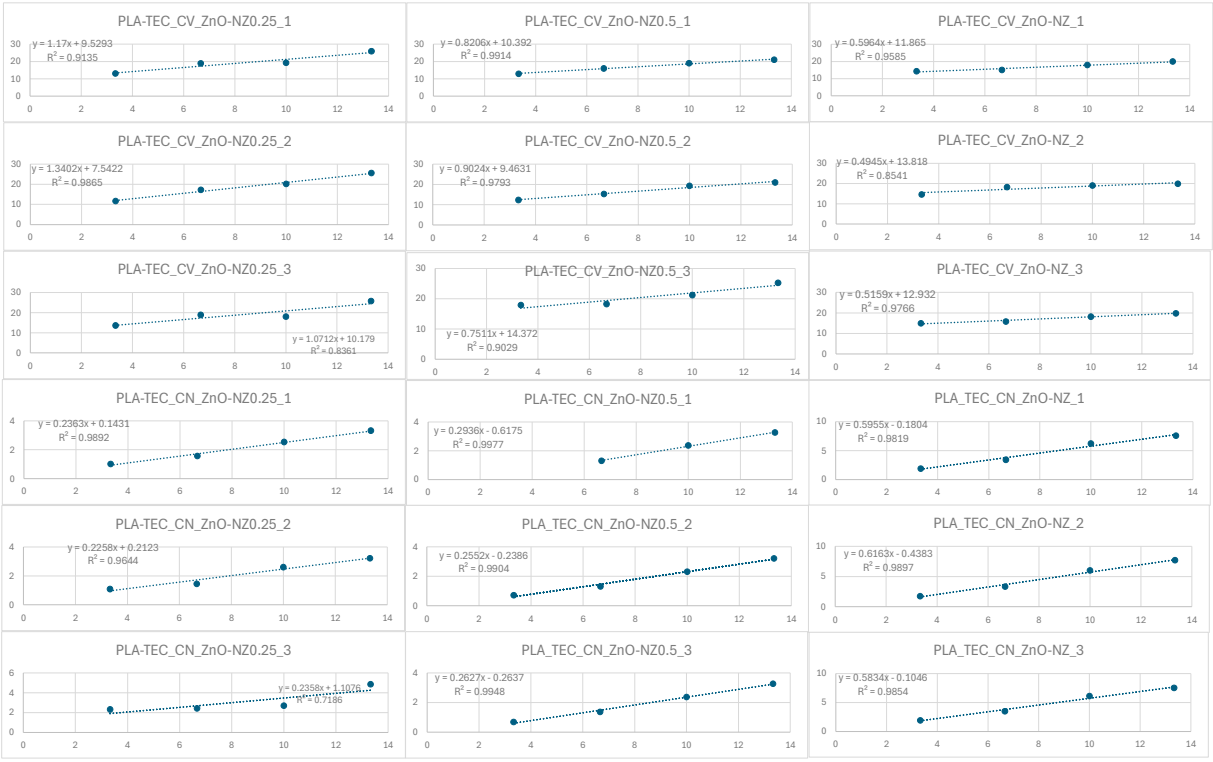


Figure S2. Obtained Absorbance = f (mg of nanohybrid) plots and calculated equations used for the calculation of EC_{50} mean values of all active nanocomposite films.

Table S9. Values used for the statistical analysis and the calculation of TBARS mean values.

TBARS Values (mg/kg) - Three Replicates Each
CONTROL
• Day 0: 0.40, 0.41, 0.42
• Day 2: 0.57, 0.59, 0.61
• Day 4: 0.71, 0.73, 0.75
• Day 6: 0.80, 0.82, 0.84
PLA/TEC/CV@ZnO/NZ0.25
• Day 0: 0.40, 0.41, 0.42
• Day 2: 0.53, 0.54, 0.55
• Day 4: 0.64, 0.65, 0.66
• Day 6: 0.73, 0.74, 0.75
PLA/TEC/10*t*CN@ZnO/NZ1.0
• Day 0: 0.40, 0.41, 0.42
• Day 2: 0.55, 0.56, 0.57
• Day 4: 0.66, 0.67, 0.68
• Day 6: 0.76, 0.77, 0.78

Table S10. Values used for the statistical analysis and the calculation of TBARS mean values.

Heme Iron Values (μg/g) -
CONTROL
• Day 0: 7.53, 7.65, 7.77
• Day 2: 5.89, 6.25, 6.61
• Day 4: 5.33, 5.51, 5.69
• Day 6: 4.33, 4.66, 4.99
PLA/TEC/CV@ZnO/NZ0.25
• Day 0: 7.53, 7.65, 7.77
• Day 2: 7.03, 7.15, 7.27
• Day 4: 5.95, 6.16, 6.37
• Day 6: 4.97, 5.24, 5.51
PLA/TEC/10*t*CN@ZnO/NZ1.0
• Day 0: 7.53, 7.65, 7.77
• Day 2: 7.01, 7.13, 7.25
• Day 4: 5.92, 6.13, 6.34
• Day 6: 4.94, 5.21, 5.48

Table S11. Values used for the statistical analysis and the calculation of TVC mean values.

TVC Values (log CFU/g) - Three Replicates Each
CONTROL
• Day 0: 4.29, 4.32, 4.35
• Day 2: 5.46, 5.59, 5.72
• Day 4: 6.73, 6.79, 6.85
• Day 6: 8.13, 8.14, 8.15
PLA/TEC/CV@ZnO/NZ0.25
• Day 0: 4.29, 4.32, 4.35
• Day 2: 4.96, 5.09, 5.22
• Day 4: 6.33, 6.39, 6.45
• Day 6: 7.40, 7.41, 7.42
PLA/TEC/10*t*CN@ZnO/NZ1.0
• Day 0: 4.29, 4.32, 4.35
• Day 2: 4.97, 5.01, 5.05
• Day 4: 6.25, 6.32, 6.39
• Day 6: 7.32, 7.37, 7.42