# Supplementary material

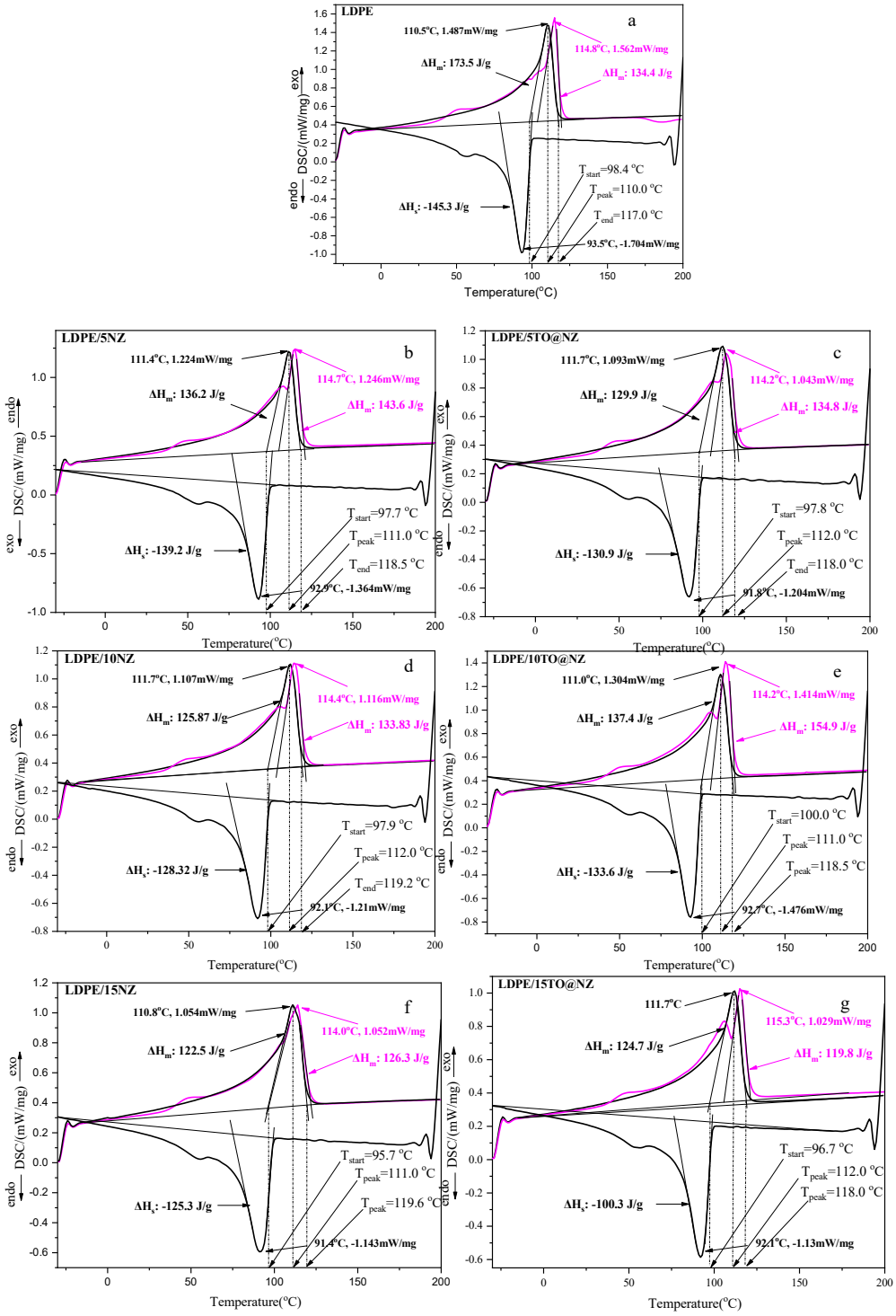


**Figure S1.** DSC plots of (a) pure LDPE, (b) LDPE/5NZ, (c) LDPE/5TO@NZ, (d) LDPE/10NZ, (e) LDPE/10TO@NZ, (f) LDPE/15NZ and (g) LDPE/15TO@NZ

**Table S1.** GC-MS analysis of thyme oil as received

| Peak | Label | Area Sum % |
|---|---|---|
| 1 | Cpd 1: .ALPHA.-PINENE, (-)-; C10 H16; 6.658 | 0.81 |
| 2 | Cpd 2: Camphene; C10 H16; 7.148 | 0.25 |
| 3 | Cpd 3: Sabinene; C10 H16; 8.171 | 0.11 |
| 4 | Cpd 4: .beta.-Myrcene; C10 H16; 8.864 | 0.56 |
| 5 | Cpd 5: Cyclohexene, 1-methyl-4-(1-methylethenyl)-, (R)-; C10 H16; 9.298 | 0.09 |
| 6 | Cpd 6: .ALPHA. TERPINENE; C10 H16; 9.802 | 0.72 |
| 7 | Cpd 7: Cyclohexane, 1-methyl-3-(1-methylethenyl)-, cis-; C10 H18; 9.998 | 0.12 |
| **8** | **Cpd 8: Benzene, 1-methyl-4-(1-methylethyl)-; C10 H14; 10.145 ή p-cymene** | **12.28** |
| **9** | **Cpd 9: D-Limonene; C10 H16; 10.341** | **16.54** |
| 10 | Cpd 10: .gamma.-Terpinene; C10 H16; 11.616 | 0.34 |
| 11 | Cpd 11: .alpha.-terpinolene; C10 H16; 12.890 | 0.23 |
| 12 | Cpd 12: Linalool; C10 H18 O; 13.497 | 1.67 |
| 13 | Cpd 13: Camphor; C10 H16 O; 15.292 | 0.11 |
| 14 | Cpd 14: Cyclohexanol, 1-methyl-4-(1-methylethenyl)-; C10 H18 O; 15.390 | 0.08 |
| 15 | Cpd 15: Bicyclo[2.2.1]heptan-2-ol, 1,7,7-trimethyl-, exo-; C10 H18 O; 15.845 | 0.1 |
| 16 | Cpd 16: endo-Borneol; C10 H18 O; 16.265 | 0.41 |
| 17 | Cpd 17: .ALPHA.-TERPINEOL; C10 H18 O; 17.462 | 4.21 |
| 18 | Cpd 18: Cyclohexanol, 1-methyl-4-(1-methylethylidene)-; C10 H18 O; 17.778 | 0.52 |
| 19 | Cpd 19: Fenchyl acetate; C12 H20 O2; 18.821 | 0.26 |
| 20 | Cpd 20: Cyclohexanol, 2-methylene-3-(1-methylethyl)-, acetate, cis-; C12 H20 O2; 20.228 | 0.12 |
| 21 | Cpd 21: Bicyclo[2.2.1]heptan-2-ol, 1,7,7-trimethyl-, acetate, (1S-endo)-; C12 H20 O2; 21.831 | 2.89 |
| **22** | **Cpd 22: Phenol, 5-methyl-2-(1-methylethyl)-; C10 H14 O; 22.273 OR THYMOL** | **32.54** |
| **23** | **Cpd 23: Phenol, 5-methyl-2-(1-methylethyl)-; C10 H14 O; 22.651 OR THYMOL** | **24.16** |
| 24 | Cpd 24: Tetradecane; C14 H30; 26.754 | 0.11 |
| 25 | Cpd 25: TRANS(.BETA.)-CARYOPHYLLENE; C15 H24; 27.251 | 0.36 |
| 26 | Cpd 26: Hexadecane; C16 H34; 34.638 | 0.17 |
| 27 | Cpd 27: Octadecane; C18 H38; 41.781 | 0.07 |
| 28 | Cpd 28: Hexadecanoic acid, 2-hydroxy-1-(hydroxymethyl)ethyl ester; C19 H38 O4; 60.105 | 0.19 |

**Table S2.** GC-MS analysis of the collected after the distillation process thyme oil rich in Limonene and p- Cymene fraction.

| Label | Area Sum % |
|---|---|
| Cpd 1: l-Phellandrene; C10 H16; 6.462 | 0.15 |
| Cpd 2: .ALPHA.-PINENE, (-)-; C10 H16; 6.658 | 3.7 |
| Cpd 3: Camphene; C10 H16; 7.141 | 1.52 |
| Cpd 4: 2-.BETA.-PINENE; C10 H16; 8.171 | 0.35 |
| Cpd 5: .beta.-Myrcene; C10 H16; 8.864 | 1.68 |
| Cpd 6: Cyclohexane, 1-methylene-4-(1-methylethenyl)-; C10 H16; 9.263 | 0.18 |
| Cpd 7: 3-Carene; C10 H16; 9.522 | 0.1 |
| Cpd 8: .ALPHA. TERPINENE; C10 H16; 9.809 | 0.33 |
| ***Cpd 9: Benzene, 1-methyl-4-(1-methylethyl)-; C10 H14; 10.194-p cymene*** | **31.98** |
| ***Cpd 10: D-Limonene; C10 H16; 10.397*** | **31.83** |
| Cpd 11: .gamma.-Terpinene; C10 H16; 11.623 | 0.07 |
| Cpd 12: 12.918 | 0.15 |
| Cpd 13: Linalool; C10 H18 O; 13.499 | 2.09 |
| Cpd 14: D-Fenchyl alcohol; C10 H18 O; 13.940 | 0.08 |
| Cpd 15: 3-Cyclohexen-1-ol, 1-methyl-4-(1-methylethyl)-; C10 H18 O; 14.935 | 0.22 |
| Cpd 16: Cyclohexanol, 1-methyl-4-(1-methylethenyl)-; C10 H18 O; 15.390 | 0.12 |
| Cpd 17: 15.845 | 0.19 |
| Cpd 18: endo-Borneol; C10 H18 O; 16.258 | 0.3 |
| Cpd 19: 3-Cyclohexen-1-ol, 4-methyl-1-(1-methylethyl)-; C10 H18 O; 16.825 | 0.06 |
| Cpd 20: .ALPHA.-TERPINEOL; C10 H18 O; 17.453 | 1.77 |
| Cpd 21: Cyclohexanol, 1-methyl-4-(1-methylethylidene)-; C10 H18 O; 17.777 | 0.23 |
| Cpd 22: Fenchyl acetate; C12 H20 O2; 18.814 | 0.14 |
| Cpd 23: Isobornyl acetate; C12 H20 O2; 21.762 | 0.63 |
| **Cpd 24: Phenol, 5-methyl-2-(1-methylethyl)-; C10 H14 O; 22.210** | **13.31** |
| **Cpd 25: Phenol, 5-methyl-2-(1-methylethyl)-; C10 H14 O; 22.574** | **8.32** |
| Cpd 26: Tetradecane; C14 H30; 26.754 | 0.09 |
| Cpd 27: Hexadecane; C16 H34; 34.638 | 0.15 |
| Cpd 28: Hexadecanoic acid, 2-hydroxy-1-(hydroxymethyl)ethyl ester; C19 H38 O4; 60.105 | 0.23 |

**Table S3.** GC-MS results of the remaining after the distillation process thyme oil rich in thymol (TO) fraction

| Peak | Label | Area Sum % |
|---|---|---|
| 1 | Cpd 1: Camphene; C10 H16; 7.142 | 0.18 |
| 2 | Cpd 2: Benzene, 1-methyl-4-(1-methylethyl)-; C10 H14; 10.131 | 0.99 |
| 3 | Cpd 3: D-Limonene; C10 H16; 10.292 | 0.97 |
| 4 | Cpd 4: Linalool; C10 H18 O; 13.492 | 0.69 |
| 5 | Cpd 5: 3-Cyclohexen-1-ol, 1-methyl-4-(1-methylethyl)-; C10 H18 O; 14.942 | 0.21 |
| 6 | Cpd 6: Camphor; C10 H16 O; 15.278 | 0.15 |
| 7 | Cpd 7: Cyclohexanol, 1-methyl-4-(1-methylethenyl)-; C10 H18 O; 15.383 | 0.17 |
| **8** | Cpd 8: 15.838 | 0.19 |
| **9** | Cpd 9: Bicyclo[2.2.1]heptan-2-ol, 1,7,7-trimethyl-, exo-; C10 H18 O; 16.258 | 0.54 |
| 10 | Cpd 10: 3-Cyclohexen-1-ol, 4-methyl-1-(1-methylethyl)-; C10 H18 O; 16.825 | 0.11 |
| 11 | Cpd 11: .ALPHA.-TERPINEOL; C10 H18 O; 17.463 | 1.65 |
| 12 | Cpd 12: Cyclohexanol, 1-methyl-4-(1-methylethylidene)-; C10 H18 O; 17.778 | 0.54 |
| 13 | Cpd 13: 18.611 | 0.09 |
| 14 | Cpd 14: Fenchyl acetate; C12 H20 O2; 18.821 | 0.54 |
| 15 | Cpd 15: Ascaridole; C10 H16 O2; 20.249 | 0.19 |
| 16 | Cpd 16: Isobornyl acetate; C12 H20 O2; 21.748 | 0.36 |
| 17 | Cpd 17: Bicyclo[2.2.1]heptan-2-ol, 1,7,7-trimethyl-, acetate, (1S-endo)-; C12 H20 O2; 21.867 | 3.38 |
| 18 | **Cpd 18: Phenol, 5-methyl-2-(1-methylethyl)-; C10 H14 O; 22.294** | **46.61** |
| 19 | **Cpd 19: Phenol, 5-methyl-2-(1-methylethyl)-; C10 H14 O; 22.679** | **40.09** |
| 20 | Cpd 20: 25.592 | 0.18 |
| 21 | Cpd 21: Tetradecane; C14 H30; 26.747 | 0.15 |
| **22** | Cpd 22: TRANS(.BETA.)-CARYOPHYLLENE; C15 H24; 27.251 | 0.33 |
| **23** | Cpd 23: 29.282 | 0.18 |
| 24 | Cpd 24: CARYOPHYLLENE OXIDE; C15 H24 O; 33.672 | 0.1 |
| 25 | Cpd 25: Hexadecane; C16 H34; 34.639 | 0.21 |
| 26 | Cpd 26: 48.132 | 0.37 |
| 27 | Cpd 27: 48.426 | 0.39 |
| 28 | Cpd 28: 60.105 | 0.43 |

**Table S4.** Mass changes of LDPE/15NZ films as a function of time for temperature variation from 0 to 85 °C to calculate the water vapor content of the control film.

| | LDPE/15NZ_1 | | LDPE/15NZ_2 | | LDPE/15NZ_3 | | LDPE/15NZ |
|---|---|---|---|---|---|---|---|
| | average film thickness l 0.061 mm | | average film thickness l 0.119 mm | | average film thickness l 0.0781 mm | | - |
| Time (s) | $m_t$ (mg) | $\Delta m$ ($m_t$-$m_0$) | $m_t$ (mg) | $\Delta m$ ($m_t$-$m_0$) | $m_t$ (mg) | $\Delta m$ ($m_t$-$m_0$) | average $\Delta m$ / water vapor |
| 0 | 520 | 0 | 690 | 0 | 605 | 0 | 0 |
| 120 | 517 | 3 | 688 | 2 | 603 | 3 | 3 |
| 240 | 516 | 4 | 688 | 2 | 602 | 3 | 3 |
| 360 | 516 | 4 | 687 | 3 | 602 | 4 | 4 |
| 480 | 516 | 4 | 686 | 4 | 601 | 4 | 4 |
| 600 | 516 | 4 | 685 | 5 | 601 | 5 | 5 |
| 720 | 516 | 4 | 685 | 5 | 601 | 5 | 5 |
| 840 | 516 | 4 | 684 | 6 | 600 | 5 | 5 |
| 960 | 516 | 4 | 683 | 7 | 600 | 6 | 6 |
| 1080 | 516 | 4 | 683 | 7 | 600 | 6 | 6 |
| 1200 | 516 | 4 | 683 | 7 | 600 | 6 | 6 |
| 1320 | 516 | 4 | 683 | 7 | 600 | 6 | 6 |
| 1440 | 516 | 4 | 683 | 7 | 600 | 6 | 6 |
| 1560 | 516 | 4 | 683 | 7 | 600 | 6 | 6 |
| 1680 | 516 | 4 | 683 | 7 | 600 | 6 | 6 |
| 1800 | 516 | 4 | 683 | 7 | 600 | 6 | 6 |
| 1920 | 516 | 4 | 683 | 7 | 600 | 6 | 6 |
| 2040 | 516 | 4 | 683 | 7 | 600 | 6 | 6 |
| 2160 | 516 | 4 | 683 | 7 | 600 | 6 | 6 |

**Table S5.** Mass changes of LDPE/15TO@NZ films as a function of time for temperature variation from 0 to 90 °C in order to calculate the TO content released from the film.

| | LDPE/15TO@NZ_1 | | | | LDPE/15TO@NZ_2 | | | | LDPE/15TO@NZ_3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | average film thickness l 0.075 mm | | | | average film thickness l 0.074 mm | | | | Average film thickness l 0.086 mm | | | |
| **Time (s)** | **$m_t$ (mg)** | **$m_t$ + water vapor** | **$m_t / m_\infty$** | **$(m_t / m_\infty)^2$** | **$m_t$ (mg)** | **$m_t$ + water vapor** | **$m_t / m_\infty$** | **$(m_t / m_\infty)^2$** | **$m_t$ (mg)** | **$m_t$ + water vapor** | **$m_t / m_\infty$** | **$(m_t / m_\infty)^2$** |
| 0 | 591 | 591 | 1.037 | 1.075 | 545 | 545 | 1.036 | 1.074 | 665 | 665 | 1.037 | 1.076 |
| 120 | 580 | 583 | 1.022 | 1.044 | 534 | 537 | 1.020 | 1.040 | 654 | 657 | 1.024 | 1.049 |
| 240 | 579 | 582 | 1.021 | 1.043 | 533 | 536 | 1.019 | 1.038 | 652 | 655 | 1.022 | 1.044 |
| 360 | 579 | 583 | 1.022 | 1.044 | 532 | 536 | 1.018 | 1.036 | 651 | 655 | 1.021 | 1.043 |
| 480 | 578 | 582 | 1.021 | 1.043 | 532 | 536 | 1.019 | 1.038 | 650 | 654 | 1.020 | 1.041 |
| 600 | 578 | 583 | 1.022 | 1.044 | 532 | 537 | 1.020 | 1.040 | 649 | 654 | 1.020 | 1.039 |
| 720 | 578 | 583 | 1.022 | 1.044 | 531 | 536 | 1.018 | 1.036 | 648 | 653 | 1.018 | 1.036 |
| 840 | 577 | 582 | 1.021 | 1.043 | 531 | 536 | 1.019 | 1.038 | 648 | 653 | 1.019 | 1.038 |
| 960 | 577 | 583 | 1.022 | 1.044 | 531 | 537 | 1.020 | 1.040 | 648 | 654 | 1.020 | 1.039 |
| 1080 | 577 | 583 | 1.022 | 1.044 | 531 | 537 | 1.020 | 1.040 | 647 | 653 | 1.018 | 1.036 |
| 1200 | 576 | 582 | 1.020 | 1.041 | 531 | 537 | 1.020 | 1.040 | 647 | 653 | 1.018 | 1.036 |
| 1320 | 576 | 582 | 1.020 | 1.041 | 531 | 537 | 1.020 | 1.040 | 647 | 653 | 1.018 | 1.036 |
| 1440 | 576 | 582 | 1.020 | 1.041 | 531 | 537 | 1.020 | 1.040 | 647 | 653 | 1.018 | 1.036 |
| 1560 | 576 | 582 | 1.020 | 1.041 | 531 | 537 | 1.020 | 1.040 | 646 | 652 | 1.016 | 1.033 |
| 1680 | 575 | 581 | 1.018 | 1.037 | 531 | 537 | 1.020 | 1.040 | 646 | 652 | 1.016 | 1.033 |
| 1800 | 575 | 581 | 1.018 | 1.037 | 531 | 537 | 1.020 | 1.040 | 646 | 652 | 1.016 | 1.033 |
| 1920 | 575 | 581 | 1.018 | 1.037 | 531 | 537 | 1.020 | 1.040 | 646 | 652 | 1.016 | 1.033 |
| 2040 | 575 | 581 | 1.018 | 1.037 | 531 | 537 | 1.020 | 1.040 | 646 | 652 | 1.016 | 1.033 |
| 2160 | 575 | 581 | 1.018 | 1.037 | 531 | 537 | 1.020 | 1.040 | 646 | 652 | 1.016 | 1.033 |

**Table S6.** Calculated values of: slope of equation (5), diffusion coefficient of TO released in mm2/s and m2s, total film mass loss or total mass of TO released and % Film total weight loss or % total TO content released.

| sample | Slope ($4\frac{D.t}{\pi.l^2}$) | D ($mm^2/s$) | D($cm^2/s$) | Total film mass loss $m_0 - m_\infty$ or total mass of TO released (mg) | % Film total weight loss $(m_0 - m_\infty)/m_0*100$ or % total TO content released |
|---|---|---|---|---|---|
| LDPE/15TO@NZ_1 | $10^{-4}$ | 4.42E-07 | $4.42.10^{-10}$ | 10.0 | 1.69 |
| LDPE/15TO@NZ_2 | $10^{-4}$ | 4.29866E-07 | $4.30.10^{-10}$ | 8.0 | 1.47 |
| LDPE/15TO@NZ_3 | $10^{-4}$ | 5.80586E-07 | $5.81.10^{-10}$ | 13.0 | 1.95 |
| average | - | - | $4.84.10^{-13}$±$0.84.10^{-13}$ | 10.3±2.5 | 1.70±0.24 |

# Pearson's Correlations

**Table S7**. pure LDPE control sample

| Confidence Intervals | | | | |
|---|---|---|---|---|
| | Pearson Correlation | Sig. (2-tailed) | 95% Confidence Intervals (2-tailed)[a] | |
| | | | Lower | Upper |
| DAY0 - DAY2 | ,998 | ,000 | ,976 | 1,000 |
| DAY0 - DAY4 | ,998 | ,000 | ,977 | 1,000 |
| DAY0 - DAY6 | ,995 | ,000 | ,939 | ,999 |
| DAY0 - DAY8 | ,992 | ,000 | ,905 | ,999 |
| DAY0 - DAY10 | ,998 | ,000 | ,971 | 1,000 |
| DAY0 - DAY12 | ,818 | ,047 | -,062 | ,976 |
| DAY2 - DAY4 | 1,000 | ,000 | 1,000 | 1,000 |
| DAY2 - DAY6 | ,998 | ,000 | ,975 | 1,000 |
| DAY2 - DAY8 | ,997 | ,000 | ,963 | 1,000 |
| DAY2 - DAY10 | ,995 | ,000 | ,942 | ,999 |
| DAY2 - DAY12 | ,839 | ,037 | ,004 | ,979 |
| DAY4 - DAY6 | ,998 | ,000 | ,975 | 1,000 |
| DAY4 - DAY8 | ,997 | ,000 | ,963 | 1,000 |
| DAY4 - DAY10 | ,995 | ,000 | ,943 | ,999 |
| DAY4 - DAY12 | ,838 | ,037 | ,000 | ,979 |
| DAY6 - DAY8 | 1,000 | ,000 | ,994 | 1,000 |
| DAY6 - DAY10 | ,987 | ,000 | ,860 | ,998 |
| DAY6 - DAY12 | ,815 | ,048 | -,072 | ,975 |
| DAY8 - DAY10 | ,984 | ,000 | ,826 | ,998 |
| DAY8 - DAY12 | ,823 | ,044 | -,048 | ,976 |
| DAY10 - DAY12 | ,843 | ,035 | ,015 | ,979 |

a. Estimation is based on Fisher's r-to-z transformation with bias adjustment.

**Table S8.** LDPE/15NZ sample

| Confidence Intervals | | | | |
|---|---|---|---|---|
| | Pearson Correlation | Sig. (2-tailed) | 95% Confidence Intervals (2-tailed)[a] Lower | Upper |
| DAY0 - DAY2 | ,999 | ,000 | ,986 | 1,000 |
| DAY0 - DAY4 | ,998 | ,000 | ,980 | 1,000 |
| DAY0 - DAY6 | ,997 | ,000 | ,969 | 1,000 |
| DAY0 - DAY8 | ,999 | ,000 | ,983 | 1,000 |
| DAY0 - DAY10 | ,998 | ,000 | ,980 | 1,000 |
| DAY0 - DAY12 | ,979 | ,001 | ,783 | ,997 |
| DAY2 - DAY4 | 1,000 | ,000 | ,999 | 1,000 |
| DAY2 - DAY6 | ,999 | ,000 | ,993 | 1,000 |
| DAY2 - DAY8 | ,999 | ,000 | ,989 | 1,000 |
| DAY2 - DAY10 | ,995 | ,000 | ,946 | ,999 |
| DAY2 - DAY12 | ,973 | ,001 | ,726 | ,997 |
| DAY4 - DAY6 | ,999 | ,000 | ,993 | 1,000 |
| DAY4 - DAY8 | ,999 | ,000 | ,985 | 1,000 |
| DAY4 - DAY10 | ,994 | ,000 | ,933 | ,999 |
| DAY4 - DAY12 | ,972 | ,001 | ,717 | ,996 |
| DAY6 - DAY8 | ,999 | ,000 | ,993 | 1,000 |
| DAY6 - DAY10 | ,994 | ,000 | ,936 | ,999 |
| DAY6 - DAY12 | ,965 | ,002 | ,659 | ,996 |
| DAY8 - DAY10 | ,997 | ,000 | ,968 | 1,000 |
| DAY8 - DAY12 | ,968 | ,002 | ,683 | ,996 |
| DAY10 - DAY12 | ,975 | ,001 | ,747 | ,997 |

a. Estimation is based on Fisher's r-to-z transformation with bias adjustment.

**Table S9.** LDPE/15TO@NZ sample

| Confidence Intervals | | | | |
|---|---|---|---|---|
| | Pearson Correlation | Sig. (2-tailed) | 95% Confidence Intervals (2-tailed)[a] Lower | Upper |
| DAY0 - DAY2 | ,999 | ,000 | ,983 | 1,000 |
| DAY0 - DAY4 | ,999 | ,000 | ,986 | 1,000 |
| DAY0 - DAY6 | ,999 | ,000 | ,983 | 1,000 |
| DAY0 - DAY8 | ,997 | ,000 | ,969 | 1,000 |
| DAY0 - DAY10 | ,998 | ,000 | ,972 | 1,000 |
| DAY0 - DAY12 | ,940 | ,005 | ,474 | ,992 |
| DAY2 - DAY4 | ,999 | ,000 | ,994 | 1,000 |
| DAY2 - DAY6 | 1,000 | ,000 | 1,000 | 1,000 |
| DAY2 - DAY8 | 1,000 | ,000 | ,995 | 1,000 |
| DAY2 - DAY10 | ,999 | ,000 | ,991 | 1,000 |
| DAY2 - DAY12 | ,956 | ,003 | ,583 | ,994 |
| DAY4 - DAY6 | ,999 | ,000 | ,992 | 1,000 |
| DAY4 - DAY8 | ,998 | ,000 | ,978 | 1,000 |
| DAY4 - DAY10 | ,998 | ,000 | ,972 | 1,000 |
| DAY4 - DAY12 | ,948 | ,004 | ,524 | ,993 |
| DAY6 - DAY8 | 1,000 | ,000 | ,996 | 1,000 |
| DAY6 - DAY10 | ,999 | ,000 | ,993 | 1,000 |
| DAY6 - DAY12 | ,956 | ,003 | ,587 | ,994 |
| DAY8 - DAY10 | 1,000 | ,000 | ,997 | 1,000 |
| DAY8 - DAY12 | ,962 | ,002 | ,635 | ,995 |
| DAY10 - DAY12 | ,961 | ,002 | ,624 | ,995 |

a. Estimation is based on Fisher's r-to-z transformation with bias adjustment.