



SMALL RUMINANTS AS PRIORITY SENTINEL SPECIES FOR SOIL-MEDIATED PCDD/F AND PCB CONTAMINATION IN RAW MILK: EVIDENCE FROM A TEN-YEAR PERI-INDUSTRIAL SURVEILLANCE PROGRAM

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Scope. Small ruminants in peri-industrial agropastoral systems are systematically underrepresented in food safety surveillance despite their demonstrated vulnerability to soil-mediated contamination by persistent organic pollutants (POPs). This study aimed to quantify the inter-species hierarchy of polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) and polychlorinated biphenyls (PCBs) in raw milk from bovine, ovine, and caprine farms reared within 20 km of the Taranto industrial complex (Apulia, Southern Italy), to identify the most sensitive sentinel species for monitoring purposes, and to assess regulatory compliance against Commission Regulation (EU) 2023/915.

Methods. A total of 671 raw bulk milk samples were collected between 2016 and 2025 under the Extraordinary Monitoring Plan implemented by the Local Health Authority of Taranto, in compliance with Regulation (EC) No 854/2004 for the period preceding December 2019 and Regulation (EU) 2017/625 thereafter. Samples were analysed by high-resolution gas chromatography coupled with high-resolution mass spectrometry (GC-HRMS) at the Italian National Reference Laboratory for halogenated POPs in food and feed (IZS Teramo), with results expressed as upper-bound WHO-TEQ concentrations, as recommended by the EFSA CONTAM Panel. Inter-species differences were modelled using linear mixed-effects regression (LMM), with cattle as the baseline reference group, farm distance from the industrial perimeter and sampling year as covariates, and individual holding as a random effect.

Results. Caprine and ovine milk consistently and substantially exceeded bovine concentrations across all contaminant

classes throughout the entire study period, after controlling for spatial and temporal confounders. The inter-species hierarchy was most pronounced for pure PCDD/Fs, caprine exceeding bovine by more than twofold ($p < 0.001$), ovine by approximately twofold ($p < 0.001$), and persisted for combined contamination ($p < 0.001$), consistent with the higher feed-to-milk transfer efficiency of PCDD/Fs in small ruminants. For NDL-PCBs alone, the hierarchy was inverted, with ovine milk exceeding caprine ($p < 0.001$), reflecting species-specific differences in accumulation rate and depuration kinetics. Between-farm variance was near zero across all models, confirming landscape-driven contamination. Non-compliance with EU maximum levels was predominantly concentrated in small ruminant, particularly caprine, holdings.

Conclusions. Small ruminants, goats above all, represent the most sensitive sentinel species for soil-mediated PCDD/F and PCB contamination in peri-industrial dairy systems, in line with evidence from analogous European industrial sites. Their elevated contamination relative to cattle reflects a combination of species-specific traits: soil ingestion up to 20% of daily dry matter intake due to ground-proximate foraging behaviour, versus 2-5% in cattle; greater feed-to-milk transfer efficiency for lipophilic compounds; and higher milk fat content promoting PCDD/F and PCB sequestration. The predominance of caprine over ovine exceedances is consistent with goats' more selective soil-proximate foraging and their higher milk fat-to-bodyweight ratio. These findings support species-differentiated sampling intensity in official monitoring plans, with small ruminants assigned priority sentinel status in territories with legacy industrial soil contamination.