



Microbial competitiveness and risk of ochratoxin A in salami: *in situ* evaluation along maturation

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ABSTRACT

This study investigated interactions and competition between the starter culture *Penicillium nalgiovense* and the toxigenic fungus *Aspergillus westerdijkiae*, focusing on their effects on processing parameters and on ochratoxin A (OTA) production on the dry-fermented salami surface during ripening. The influence of *Lactococcus lactis*, incorporated into the meat matrix, was also assessed. Salami was produced in accordance with official technical standards in a controlled environment. Half of the meat batter was inoculated with *L. lactis*. Following stuffing, salami was treated with one of three inoculum solutions: (A) *P. nalgiovense*, (B) *P. nalgiovense* plus *A. westerdijkiae*, or (C) *A. westerdijkiae* alone. Samples ripened for 20 days under industry-standard conditions. At days 0, 4, 8, 12, 16, and 20, pH, water activity, total bacterial counts in the meat, total fungal counts on the casing, and OTA concentrations in both matrices were measured. *A. westerdijkiae* rapidly colonised and dominated the casing surface by day 4, even in the presence of *P. nalgiovense*, and reached peak growth between days 8 and 12. OTA concentrations increased significantly after day 12, reaching 69 µg/g in the casing and 16 µg/g in the meat by day 20. Indicating that the surface provides more favorable conditions for toxin production, so removing casing could reduce the exposure to the toxin. The addition of *L. lactis* accelerated early acidification and temporarily reduced bacterial load but did not significantly affect fungal growth or OTA biosynthesis. These findings demonstrate that, under favorable environmental conditions, toxigenic fungi represent a significant food safety risk during salami ripening. Starter cultures alone are insufficient to prevent mycotoxin contamination in dry-cured meat products.

1. Introduction

The occurrence of the mycotoxin ochratoxin A (OTA) in cured meat products, such as salami, has been documented by several authors (Sánchez-Montero et al., 2019; Andrade et al., 2019; Peromingo et al., 2019). In European studies, OTA contamination has predominantly been linked to *Penicillium nordicum* and *Penicillium verrucosum*, species favoured by temperate climatic conditions. However, more recent investigations conducted in Latin America, specifically in Brazil and Argentina, have reported the prevalence of *Aspergillus westerdijkiae* in salami (Parussolo et al., 2019; Villa et al., 2016). This species is also relevant in warmer European countries, such as Italy, Spain and

Portugal (Iacumin et al., 2020; Vipotnik et al., 2016; Álvarez Rubio et al., 2023), and it is important to highlight that some strains of *Aspergillus ochraceus* previously isolated from meat products may be *A. westerdijkiae* as indicated by recent taxonomic studies (Vipotnik et al., 2017). Despite this evidence, limited information is available on the competitive behaviour of *A. westerdijkiae* in complex food ecosystems, such as in dry-fermented meat products.

A. westerdijkiae is a known causative agent of “golden mould” in salami and exhibits a high capacity for OTA production under a range of environmental conditions. Temperature and water activity (a_w) are the primary factors influencing mycotoxin synthesis by this species (Gil-Serna et al., 2015; Li et al., 2021; Stefanello et al., 2024). Several studies

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have characterised the behaviour of *A. westerdijkiae* across various substrates and food matrices, reporting OTA levels that often exceed those produced by traditionally recognised mycotoxigenic species in cured meats, such as *P. nordicum* (Rodríguez et al., 2015; Vipotnik et al., 2017).

OTA is considered one of the most significant mycotoxins due to its high toxicity to both animals and humans. It has been classified by the International Agency for Research on Cancer (IARC) as a possible human carcinogen (Group 2B) (IARC, 1993). Given the potential health risks of OTA, the Joint FAO/WHO Expert Committee on Food Additives and the European Food Safety Authority (EFSA) set provisional tolerable weekly intakes of 100 and 120 ng/kg body weight, respectively (EFSA, 2006; JEFCA, 2007). However, following a recent reassessment of emerging evidence, EFSA concluded that this threshold can no longer be considered protective owing to OTA's genotoxic properties (EFSA, 2020). While the European Commission has set maximum limits for OTA in various food products (European Commission, 2023), only the Italian government has specifically established a regulatory limit for OTA in fresh pork and meat products, set at 1 µg/kg (Ministero della Sanità, 1999).

Various physical and chemical methods have been investigated for the detoxification of OTA in food products. However, these approaches often compromise nutritional value, texture, and overall product quality, and raise concerns about food safety due to the formation of chemical residues (Yang et al., 2022). In contrast, the use of biological agents capable of metabolising mycotoxins into non-toxic compounds has gained increasing attention as a promising alternative. Biodegradation involves the enzymatic transformation of toxic molecules by microbial metabolism, potentially leading to less harmful byproducts. Effective biological candidates must meet several safety and functional criteria, including non-pathogenicity and absence of toxigenic activity (Corrêa et al., 2022).

The application of bacterial species in food systems is already well-established, primarily due to their antimicrobial and antifungal properties (Barbosa et al., 2014). Moreover, several bacterial strains have been identified as potential agents for OTA degradation (Chen et al., 2018), highlighting a field of study that remains open to further exploration. In dry-fermented meat products, these microbial interactions are particularly relevant, as starter cultures may influence both fungal growth and mycotoxin production during ripening.

Lactic acid bacteria (LAB) are commonly used as starter cultures in fermented meat products to standardise fermentation, accelerate acidification, and improve product safety by outcompeting undesirable microorganisms (Laranjo et al., 2019). Starter cultures typically include LAB such as *Lactobacillus*, *Pediococcus*, and *Lactococcus* species, which lower pH through lactic acid production and may inhibit spoilage microbes through competitive exclusion and antimicrobial metabolites (Laranjo et al., 2019). In addition to these technological and biopreservative roles, several LAB strains can interact with OTA by physically adsorbing the toxin to bacterial cell wall components, thereby reducing OTA levels in contaminated media under controlled conditions (Piotrowska, 2014). Although the extent and mechanisms of LAB–OTA interactions in meat matrices remain poorly understood, these findings support the relevance of investigating LAB effects on OTA behaviour during salami ripening.

Removal of the casing of cured meat appears insufficient to ensure consumer safety, despite the observed reduction in metabolite concentration as they diffuse into the product matrix (Peromingo et al., 2019). Furthermore, there is a lack of studies investigating OTA production by *A. westerdijkiae* in the presence of starter cultures commonly used in cured meats, such as *P. nalgiovense*. *In situ* ripening models are therefore essential for capturing the complex interactions among toxigenic fungi, starter cultures, and the meat matrix under industrially relevant conditions.

Therefore, the objective of this study was to evaluate OTA production by the toxigenic species *A. westerdijkiae*, both in the presence and

absence of the starter culture *P. nalgiovense*, under simulated industrial salami manufacturing conditions. Additionally, this study aimed to assess the diffusion capacity of OTA through collagen casings and to investigate the potential degradation of this mycotoxin by *L. lactis* inoculated into the meat matrix.

2. Materials and methods

2.1. Strains used

For this study, a commercial strain of *P. nalgiovense* (S3), isolated from a starter culture (Lallemand specialty cultures), a strain of *A. westerdijkiae* (S1) OTA producer, isolated from Italian-type salami in southern Brazil (Parussolo et al., 2019; Stefanello et al., 2025), and a strain of *L. lactis* isolated from kefir included to represent the lactic acid bacteria component were used. The *L. lactis* strain was identified from a single pure colony using Matrix-Assisted Laser Desorption/Ionization-Time of Flight Tandem Mass Spectrometry (MALDI-TOF MS/MS) (Axima Confidence, Shimadzu Biotech, UK).

2.2. Salami preparation

The salami was manufactured in a previously cleaned and sanitised environment. The formulation consisted of 100% pork with 3% bacon fat, supplemented with 3% salt, special spices, refined sugar, sodium tripolyphosphate (INS 451i) as a stabiliser, sodium nitrate (INS 316) and sodium nitrite (INS 250) as preservatives, monosodium glutamate (INS 621) as a flavor enhancer, sodium nitrate (INS 251) as a preservative, and cochineal carmine dye (INS 120). Initially, the meat was ground to a particle size of 7 mm. Subsequently, salt and the other ingredients were incorporated, and the mixture was thoroughly blended until a homogeneous mass was achieved.

Two equal portions of meat were separated, and *Lactococcus lactis* was added at a concentration of 1.0×10^3 CFU/mL to one portion. The meat was then stuffed into collagen casings measuring 2.6 cm in diameter. Following stuffing, three immersion solutions were prepared: solution A contained 1.0×10^3 CFU/mL of *P. nalgiovense*; solution B contained 0.5×10^3 CFU/mL of *P. nalgiovense* combined with 0.5×10^3 CFU/mL of *A. westerdijkiae* and solution C contained 1.0×10^3 CFU/mL of *A. westerdijkiae*.

The solutions were maintained under constant stirring, and salami corresponding to each condition were submerged for 10 s, then stored in plastic boxes. To achieve specific a_w levels of 0.90, 0.80, and 0.73, saline solutions with sodium chloride concentrations of 165.6 g/L, 301.0 g/L, and 450 g/L, respectively, were prepared and added to the boxes according to the maturation stage of the salami. Each box (A, B, and C) contained 20 salamis, as detailed in Table 1.

The salami was aged under conditions commonly employed in the food industry. During the first 24 h, the temperature was maintained at 26 °C with 88–90% relative humidity (RH). For the subsequent 48 h, the

Table 1
Experimental design and sampling scheme for dry-fermented salami maturation.

Box	Fungal inoculum on casing	<i>Lactococcus lactis</i> in meat	Total salamis per box	Salamis per sub-condition
A	<i>Penicillium nalgiovense</i>	Present / Absent	20	10 with <i>L. lactis</i> / 10 without
B	<i>P. nalgiovense</i> + <i>Aspergillus westerdijkiae</i>	Present / Absent	20	10 with <i>L. lactis</i> / 10 without
C	<i>A. westerdijkiae</i>	Present / Absent	20	10 with <i>L. lactis</i> / 10 without

Analyses of pH, water activity, fungal counts, bacterial counts, and ochratoxin A (OTA) were performed destructively at 0, 4, 8, 12, 16, and 20 days of maturation.

temperature was set between 22 and 24 °C with 80% RH. Thereafter, aging continued at 12–15 °C and 70–75% RH for the remainder of the 20-day period. All analyses were conducted at days 0, 4, 8, 12, 16, and 20.

2.3. Microbiological analysis

Microbiological analyses were conducted on both the meat and the surface of the salami. Surface sampling was performed using a sterile swab moistened with Ringer's solution. The swab was applied to a defined 10 cm² area, which was then homogenised in a tube containing 10 mL of saline solution. Serial dilutions were prepared, and 100 µL aliquots were inoculated in duplicate onto Petri dishes containing malt extract agar (MEA; 15 g/L agar, 30 g/L malt extract). Plates were incubated at 25 °C for 7 days prior to colony counting. Results were expressed as CFU/cm².

For meat analysis, 10 g of sample was aseptically weighed into a sterile bag, and 90 mL of saline solution was added. The mixture was homogenised in a Stomacher® 400 Circulator for 30 s at 230 rpm. Serial dilutions were prepared, and 100 µL aliquots were inoculated in duplicate onto Petri dishes containing Nutrient Agar (15 g/L agar, 1 g/L meat extract, 5 g/L peptone, 5 g/L sodium chloride, 2 g/L yeast extract). Plates were incubated at 37 °C for 24 h before colony counting. Results were expressed as CFU/mL. Additionally, the initial microbiota of the raw materials including meat, casing, and the salami mixture was assessed.

2.4. Analysis of hydrogen potential (pH) and water activity (a_w)

To measure pH, 1 g of meat was weighed and diluted at a 1:10 ratio with distilled water. The sample was homogenised and the pH was determined using Orion Lab Star PH111 electrodes (Thermo Scientific) following the methodology described by Terra and Brum (1988). The a_w was measured using an Aqualab PAWKIT portable a_w meter.

2.5. Extraction and quantification of Ochratoxin A (OTA) and Ochratoxin α (OTα)

OTA extraction was performed using the same protocol for both casing and meat samples. For meat, 5 g of each sample was weighed, while for casing, the entire available fraction was used. Extraction was carried out with 40 mL of Milli-Q methanol: water (80:20 v/v) containing 2% acetic acid, and 0.5 g of sodium chloride (NaCl). Samples were ground for 5 min using an electric grinder (George Home 300 W hand blender). The homogenate was transferred to a 50 mL Falcon tube and agitated on a shaker at 300 rpm for 30 min at room temperature. Subsequently, the samples were centrifuged at 7830 rpm for 10 min. Then, 10 mL of the supernatant was collected and mixed with 20 mL of phosphate-buffered saline (PBS) solution.

The extract of all samples in duplicate was passed through a 25-well immunoaffinity column (2 mL/min) designed for OTA sample preparation (LgtECH). The column was washed with 10 mL of PBS (1×) in two aliquots of 5 mL each. OTA was then eluted using 1.5 mL of acetic acid: methanol (2: 98 v/v) in two fractions of 0.75 mL. The eluates were concentrated under a nitrogen stream using a Techne Dri-Block DB-3D at 40 °C for approximately 2 h and 30 min. After drying, samples resuspended in 200 µL of acetic acid: acetonitrile (2: 98 v/v) and transferred to vials for analyses.

Samples were injected into an high-performance liquid chromatography (HPLC) system coupled to a fluorescence detector. The mobile phase consisted of acetonitrile, water, and acetic acid (57:41:2, v/v/v), and quantification was based on the fluorescence response of OTA and OTα (excitation at 330 nm; emission at 460 nm) (García-Cela et al., 2015). Standards were obtained from Romer Labs (Tulln, Austria). The limits of detection and quantification were 0.05 and 0.15 ng/g for OTA, and 0.2 and 0.5 ng/g for OTα, respectively. Calibration curves showed

good linearity ($R^2 > 0.99$). Retention times were 5.5 min for OTA and 3.2 min for OTα.

2.6. Statistical analysis

Initially, the Shapiro-Wilk test was conducted to assess the normality of the data. As the assumption of normality was rejected ($p < 0.05$), non-parametric analyses were performed. The Kruskal-Wallis test was applied to compare medians across groups, considering two different variables grouped by time and experimental condition. For comparisons yielding statistically significant differences ($p < 0.05$), *post hoc* pairwise comparisons were conducted using Dunn's test with Holm's correction to identify specific group differences.

3. Results and discussion

3.1. Changes in pH and water activity

Fig. 1 illustrates the pH changes in salami during maturation with and without the addition of *L. lactis* culture. No significant differences in pH were observed between the tested conditions ($p > 0.05$), indicating that the addition of *L. lactis* did not significantly affect pH variation throughout the maturation process.

The initial average pH of all salami was 5.70. After 4 days of maturation, the pH decreased to an average of 5.10 in salami inoculated with *L. lactis* and to 5.30 in those without *L. lactis*. Subsequently, the pH increases after day 12 of maturation may result from surface fungal metabolism that reduces product acidity by consuming organic acids and producing alkaline compounds. At the end of maturation (day 20), pH values of approximately 6.80 were observed across all conditions. These results are consistent with Barbosa et al. (2015), who reported a similar pH trend during salami maturation without the addition of *Lactobacillus curvatus* MBSa2 or *Listeria monocytogenes* AL602/08. In their study, salami pH decreased to 5.15 during the first 4 days of fermentation and increased to 5.45 by the end of the 30-day maturation period.

Changes in salami pH may be influenced by several factors, including fungal proliferation on the surface. Mould presence can induce deacidification of the product. The observed pH increase in mouldy salami is likely attributable to intense oxidative deaminase activity, particularly by strains inoculated at the onset of ripening (Di Cagno et al., 2008). Insufficient pH reduction can impair colour development and hinder fat-protein binding, resulting in a product with poor consistency (Magistá et al., 2016).

The consistency of fermented sausages is largely determined by both pH and a_w. These parameters during salami ripening serve as critical indicators of product safety, with the combination of low pH and reduced a_w effectively inhibiting the growth of pathogenic microorganisms (Brugnini et al., 2024).

Fig. 1 presents a_w values throughout the salami maturation process. No significant differences were observed between the treatment conditions, while significant differences occurred across maturation times ($p < 0.05$). Initial a_w values ranged from 0.96 to 0.97 for all conditions. The value of a_w was not changed between days 4 and 8. As expected, a_w decreased progressively during maturation, reaching 0.93 in boxes A (1.0×10^3 CFU/mL of *P. nalgiovensis*) and C (1.0×10^3 CFU/mL of *A. westerdijkiae*), and 0.90 in Box B (0.5×10^3 CFU/mL of *P. nalgiovensis* + 0.5×10^3 CFU/mL of *A. westerdijkiae*) at the end of the process. These findings align with those of Parussolo et al. (2019), who inoculated *A. westerdijkiae* on salami surfaces and incubated them at 20 °C for 35 days, observing a reduction in a_w from 0.98 at day 0 to 0.95 after maturation.

3.2. Fungal proliferation on the surface of salami during maturation

Fig. 2 presents photographs taken throughout the 20-day salami

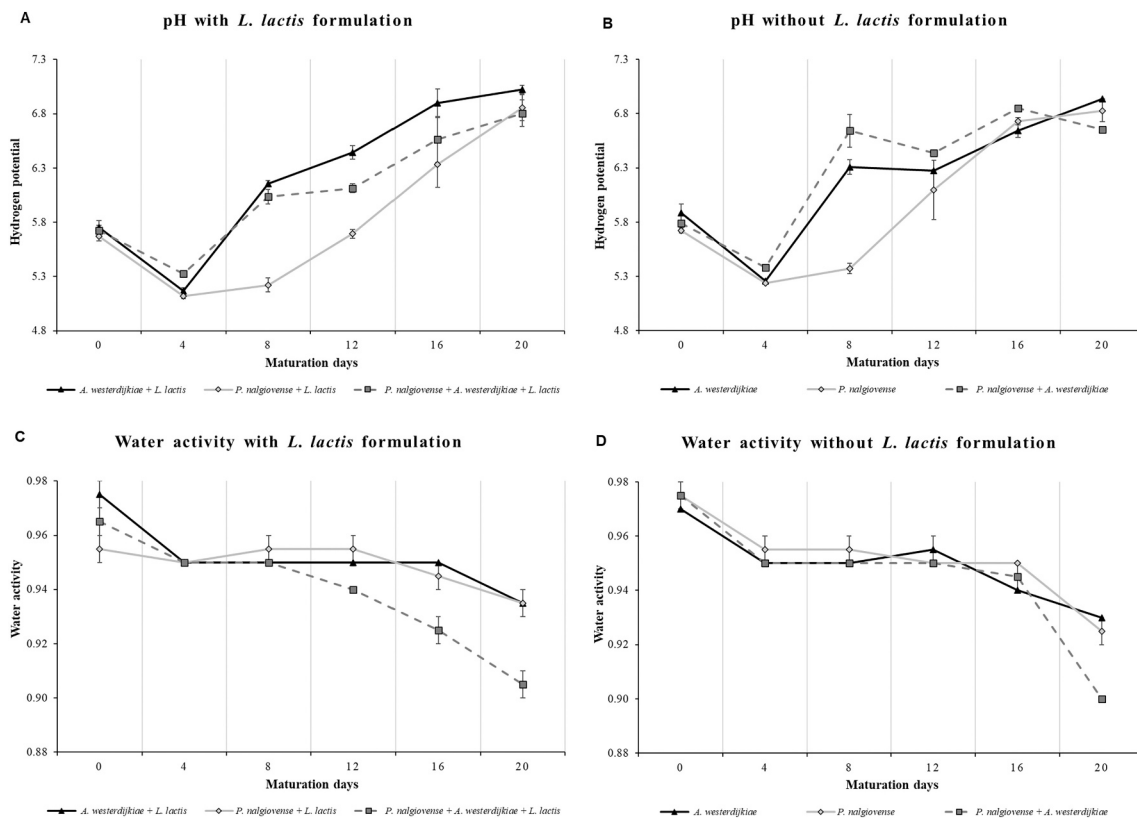


Fig. 1. Evolution of pH (A, B) and water activity (C, D) during 20-day maturation of dry-cured salami in the presence or absence of *Lactococcus lactis*.

maturation period. Images corresponding to day 0 were captured immediately after salami production. By day 4 of maturation, salami from boxes B (0.5×10^3 CFU/mL of *P. nalgiovense* + 0.5×10^3 CFU/mL of *A. westerdijkiae*) and C (1.0×10^3 CFU/mL of *A. westerdijkiae*) exhibited rapid proliferation of the *A. westerdijkiae* strain. In contrast, salami from box A (1.0×10^3 CFU/mL of *P. nalgiovense*), the starter culture, showed growth limited to a few localised points.

The dominance of this toxigenic strain over the starter culture has been previously demonstrated *in vitro* by Stefanello et al. (2025), with a rapid growth of *A. westerdijkiae* during the first 7 days under initial salami ripening conditions (*aw* 0.93).

Due to the efficient adaptation of *A. westerdijkiae* to these early ripening parameters, salami in Box B exhibited complete surface colonisation by *A. westerdijkiae* by day 8, preventing visual detection of the starter culture on the salami surface. Surface growth of *A. westerdijkiae* peaked between days 8 and 12, followed by stabilisation, as illustrated in Fig. 3. Similarly, Ferrara et al. (2016) observed that *Penicillium nordicum* (0.25%, quantity of the spore mixture applied to the surface of the salamis) could colonise sausage surfaces and grow even in the presence of *P. nalgiovense* (97.25%).

Visually, the fungal proliferation on the surface of salami in Box B, containing both the toxigenic species and the starter culture, was comparable to that observed in Box C, which contained only the toxigenic species. This observation was supported statistically, as no significant differences ($p > 0.05$) were found in the fungal colony-forming units (CFU) on the casing between these conditions, as detailed in Table 2. In contrast, Box A, which contained only the starter culture, exhibited substantial yeast proliferation alongside the starter culture. Notably, increased surface growth of the starter culture was observed only after 16 days of maturation. However, complete fungal coverage of the surface was not achieved until the end of the 20-day maturation period.

3.3. Bacterial evaluation of salami meat during maturation

The initial microbial count in the meat was 5.63 Log CFU/g prior to processing. During salami maturation, bacterial counts in the meat were monitored under both conditions, as shown in Fig. 3. At time 0, the average bacterial load was 7.30 Log CFU/g in salami with *L. lactis* addition and 7.00 Log CFU/g in those without. The elevated initial microbial counts were likely associated with hygienic and sanitary conditions during slaughter. After 4 days of maturation, bacterial counts increased in all conditions. By day 8, a decrease in bacterial counts was observed across all treatments, which may be attributed to the pH reduction recorded at day 4.

3.4. Production of Ochratoxin A

OTA levels during salami maturation are shown in Fig. 4. Control samples, without toxigenic species and analysed at time 0, did not show OTA production. No significant differences ($p < 0.05$) were observed in OTA production with or without the presence of the starter culture. OTA levels differed significantly between initial and final maturation times. Elevated OTA concentrations were detected from day 12 onward, coinciding with the increased fungal counts observed on the salami surfaces at the same time points. The highest OTA concentration was measured on day 20, reaching 69.31 $\mu\text{g/g}$ in the casing where both the toxigenic species and starter culture were inoculated, while the corresponding level in the meat was 10.96 $\mu\text{g/g}$.

On the 16th–20th day of aging, higher values of OTA production were obtained mainly in the salami casing, but the toxin also migrated to the internal part of the product. Similar results were described by Parussolo et al. (2019), where high concentrations of OTA were observed in the sausage casing, with diffusion to the outer layers of the meat.

The starter culture used in this study was ineffective in controlling OTA production by the toxigenic species. Similar findings were reported by Merla et al. (2018) in a salami monitoring study conducted in



Fig. 2. Representative photographs of salami during maturation from day 0 and every 4 days up to day 20. Salami inoculated with *P. nalgiovensis*; salami inoculated with *P. nalgiovensis* and *A. westerdijkiae*; and salami inoculated with *A. westerdijkiae* alone.

northern Italy, where *A. westerdijkiae* produced OTA despite the presence of *P. nalgiovensis*. OTA production was detected from the 4th day of maturation. Ferrara et al. (2016) also observed early expression of the OTA biosynthesis gene and toxin detection by *P. nordicum* on day 4 during small-scale salami production. *P. nalgiovensis* failed to ensure a protective effect.

Meftah et al. (2018) evaluated the effects of starter cultures and yeast on the growth and OTA production of *P. nordicum* and *A. westerdijkiae*. In that study, the four native yeasts used in salami production significantly reduced the growth of both species. No OTA production was detected for *P. nordicum* in the salami-type matrices (industrial and traditional), regardless of the presence of yeasts or starter culture. For *A. westerdijkiae*, however, there was a significant stimulation of OTA production in all conditions tested, whether in the presence of yeast or starter culture, and irrespective of the matrix. The highest OTA concentration in this study was also observed in the presence of protective culture, reinforcing that microorganisms involved in fermentation or biocontrol can exert variable effects on different ochratoxigenic fungi,

potentially leading to unforeseen food safety issues (Meftah et al., 2018).

Perrone et al. (2019) emphasised the need to explore alternative strains for controlling toxigenic fungi on salami surfaces, such as combinations of *P. salamii* and *P. chrysogenum*. Protective cultures combining atoxigenic fungi and yeasts, such as *Debaryomyces hansenii*, have demonstrated improved control over *P. nordicum* and OTA production in cured hams (Cébrían et al., 2019).

Strains of the genera *Lactobacillus* and *Lactococcus* were also evaluated for sensitivity to OTA and their ability to reduce it in liquid medium (Piotrowska and Zakowska, 2005). Most strains were insensitive to the presence of OTA at a concentration of 5 µg/disc, and all were able to reduce, to varying degrees, the amount of OTA in the medium. Luz et al. (2018) describe that the reduction of OTA by lactic acid bacteria occurs predominantly through adsorption where OTA binds to cell wall components and enzymatic biotransformation, leading to less toxic compounds.

None of the conditions tested in the present study presented the mycotoxin OTA-α. No studies reporting the presence of OTA-α in cured

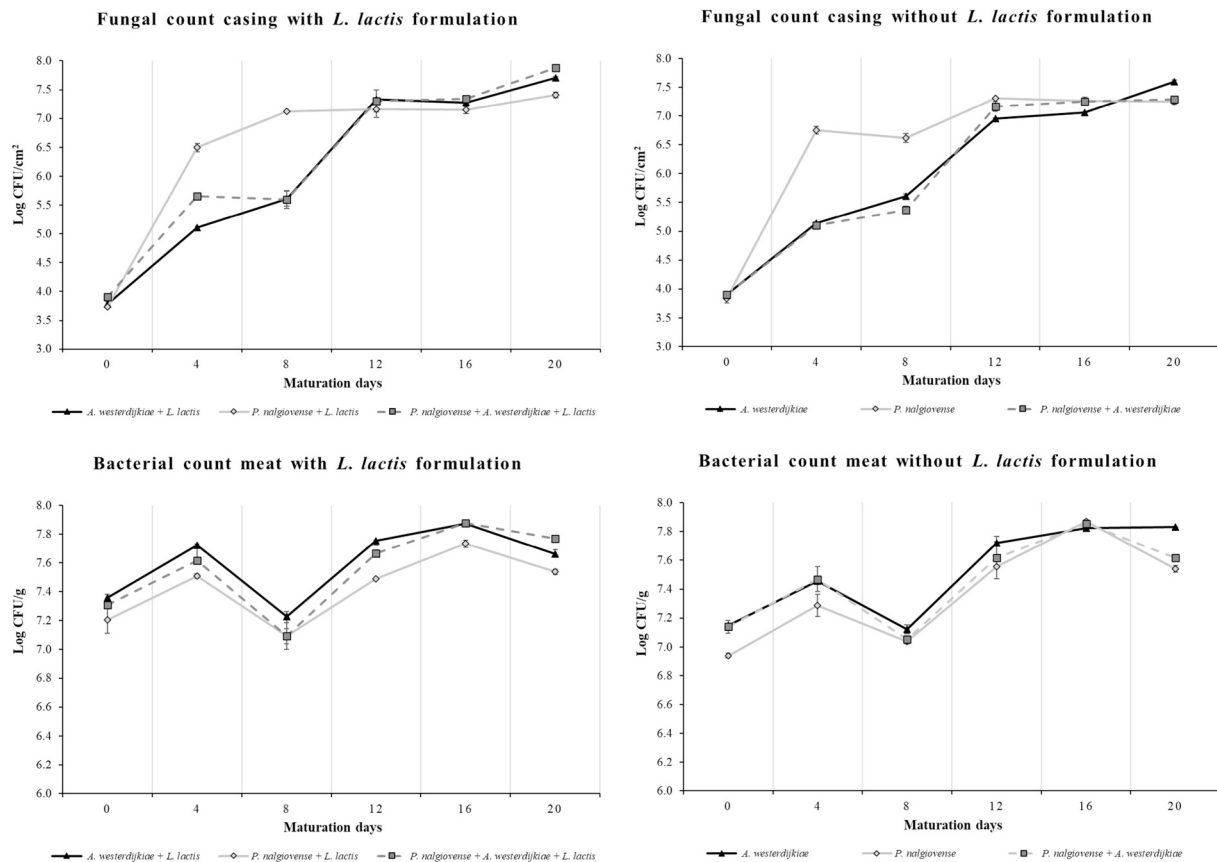


Fig. 3. Evolution of microbial counts during 20-day maturation of dry-cured salami. Fungal counts in the casing (A, B) and bacterial counts in the meat (C, D) in the presence or absence of *Lactococcus lactis*.

Table 2

Kruskal–Wallis H test results for the effects of microbial conditions and maturation time on physicochemical parameters, microbial counts, and ochratoxin A (OTA) levels during dry-fermented salami maturation.

Name	Condition		Time	
	H Statistic	p-value	H Statistic	p-value
pH	5.816	0.325	56.636	0.000 ^a
Water activity (a_w)	3.597	0.609	54.681	0.000 ^a
CFU - casing	1.977	0.852	60.347	0.000 ^a
CFU - meat	5.635	0.343	58.362	0.000 ^a
OTA - casing	50.023	0.000 ^a	5.017	0.414
OTA - meat	37.016	0.000 ^a	18.796	0.002 ^a
OTA - meat vs casing	86.473	0.000 ^a	14.753	0.011 ^a

^a Indicates significant difference at 5% confidence interval.

meat products were found, possibly due to the lack of research focused on this specific aspect. Most studies concentrate on the detection and quantification of OTA, given its toxicological relevance.

4. Conclusion

This study demonstrated that the toxigenic species *A. westerdijkiae* exhibits high adaptability and dominance under initial salami ripening conditions, surpassing the growth of the starter culture *P. nalgiovense*, particularly between days 4 and 12. The rapid fungal colonisation of isolated and non-isolated *A. westerdijkiae* directly impacted on OTA production, with significantly elevated concentrations observed from day 12 onwards, peaking at day 20, especially in the casing. The presence of *L. lactis* influenced pH dynamics during the early ripening stages, promoting a more pronounced acidification until day 4, which may have

contributed to a temporary reduction in bacterial load. However, *L. lactis* did not exert a significant effect on OTA production. These findings underscore the critical importance of rigorously controlling fungal species during the ripening of fermented meat products, as microbial competition can substantially influence food safety. Although starter cultures are beneficial for the technological and sensory development of the product, they may be insufficient to inhibit mycotoxin production under favorable conditions to toxigenic fungal growth. Therefore, implementing effective prevention and environmental control strategies is essential to mitigate colonisation by undesirable fungi. Measures such as rigorous sanitation of maturation chambers, continuous monitoring of humidity and temperature, the use of competitive starter cultures well-adapted to initial maturation conditions, and maintaining good manufacturing practices are essential to reducing the environmental microbial load and minimising the risk of cross-contamination.

CRedit authorship contribution statement

Andrieli Stefanello: Writing – original draft, Investigation, Funding acquisition, Formal analysis, Data curation. **Alessandra Marcon Gasperini:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Dámaris Cristine Landgraf:** Investigation. **Antoine Thiollot:** Investigation. **Marina Venturini Copetti:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Esther Garcia-Cela:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence

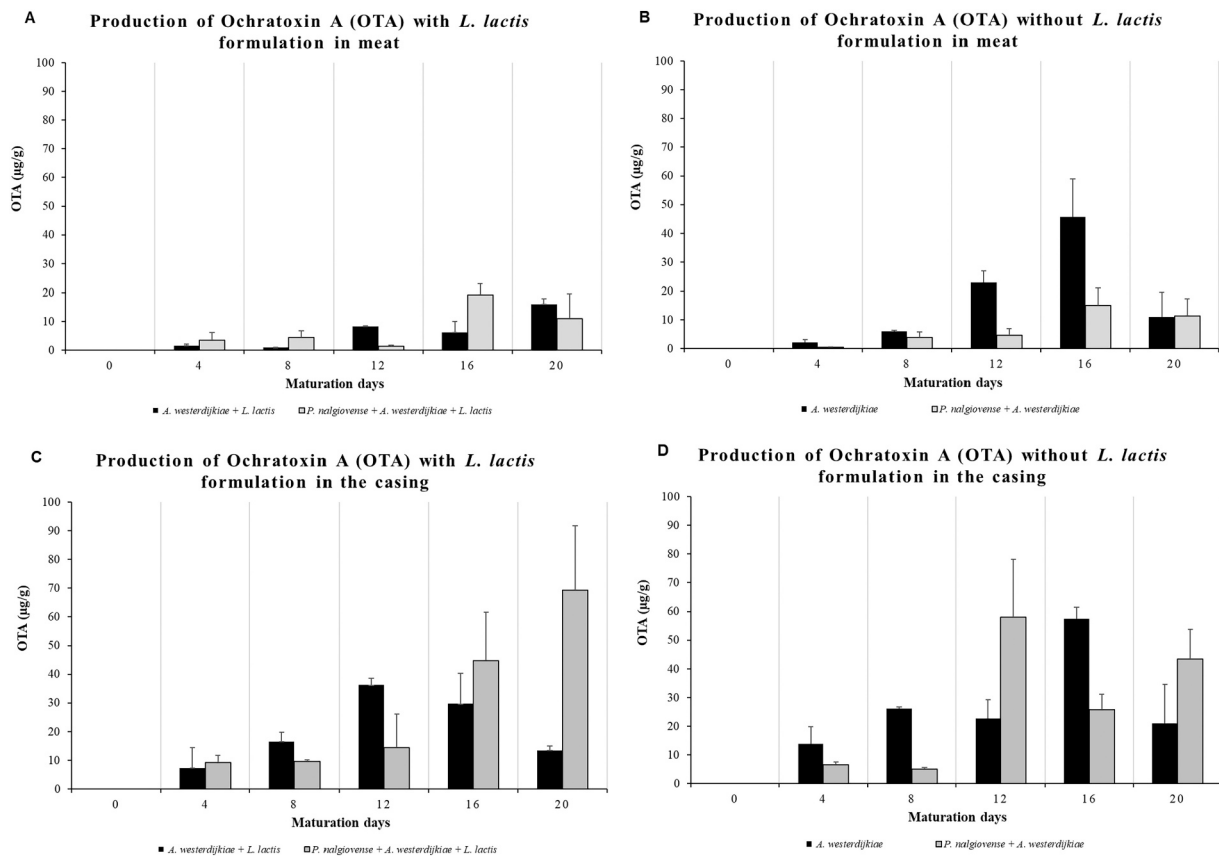


Fig. 4. Quantification of ochratoxin A levels during maturation of dry-fermented salami in the meat (A, B) and in the casing (C, D) in the presence or absence of *Lactococcus lactis*.

the work reported in this study on the interaction of fungal cultures and ochratoxin A production during salami ripening.

Data availability

Data will be made available on request.

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