# **Summarised findings from Australian** poultry odour research (2005–2018)

by Mark Dunlop and Michael Atzeni
October 2020

AgriFutures® Chicken Meat

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# Foreword

Over the last few decades, the Australian chicken meat industry has invested significantly in research, development and extension (RD&E) on several topics related to odour, including:

- Measurement of odour emission rates from conventional and free-range farming systems
- The use of frontier and advanced instrumental techniques for odour assessment
- Odour chemistry
- The relationships between odour and dust
- The effect of environmental conditions and farm management on odour emissions
- Odour dispersion modelling and calculation of separation distances
- Odour management and mitigation, including diet modification.

RD&E related to odour is integral to addressing community concerns, reducing the potential for odour impacts and supporting sustainable growth of the chicken meat industry. By necessity, the industry is typically established on the urban fringe, which increases the potential for amenity impacts.

Odour RD&E has involved several research teams, including government agencies, universities, and consultancy businesses. The industry must now undertake the important tasks of broadly reviewing the overall knowledge that has been developed to date, taking stock of the achievements and challenges, and planning the path forward to address emerging and unresolved issues.

This project summarises the odour-related RD&E that has been supported by the Australian chicken meat industry (through AgriFutures Australia or the Poultry CRC) since 2005. It was funded by industry revenue, the Australian Government, and the Queensland Government Department of Agriculture and Fisheries.

This report for the AgriFutures Chicken Meat Program adds to AgriFutures Australia's diverse range of over 2,000 research publications. It forms part of our Growing Profitability arena, which aims to enhance the profitability and sustainability of our levied rural industries. RD&E supports the Australian chicken meat industry to provide quality, wholesome food to the nation.

Most of AgriFutures Australia's publications are available for viewing, free downloading or purchasing online at: www.agrifutures.com.au.

**John Smith**
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# About the authors

Michael Atzeni has been involved in various intensive livestock odour research projects as olfactometry supervisor, researcher and project leader. He has been involved in most of the poultry odour research projects involving the Queensland Department of Agriculture and Fisheries (DAF, formerly DPI&F) since 2005.

Mark Dunlop has led numerous poultry odour research projects completed by DAF since 2005. This research has focused on odour formation, release, dispersion, measurement and mitigation.

# Acknowledgments

We acknowledge the many researchers and organisations involved in the poultry odour projects covered by this report. We thank the funding bodies that supported the research, especially AgriFutures Australia (formerly RIRDC) and the Poultry CRC (2003–2017).

The Queensland Government, through the Department of Agriculture and Fisheries (DAF), also requires recognition for supporting this research summary and review.

# Definitions

**Olfactometry** is a technique used to measure the concentration of odour in the air. Samples of odorous air are collected in a specially prepared bags and transported to an olfactometry lab where they are diluted and presented to human panellists using an olfactometer. The olfactometer is a machine that dilutes odorous air by mixing it with fresh air. We affectionately refer to the panellists as ‘sniffers’, and they are tested to ensure they have a ‘normal’ sense of smell. The panellists take turns smelling the air from 2–3 ports, of which one will have the diluted odour and the remaining ports have fresh air. We record how much dilution is required for the odorous air to be only just detected with certainty. Stronger odours require more dilution to get them to the point where they can be only just detected.

**Odour units (ou)** are the units used to describe the concentration of an odour. At a concentration of one odour unit (1 ou), a person with a ‘normal’ sense of smell would be able to detect a minimal smell—that is, they will get ‘just a whiff of something’. In practical terms, if an odour has a concentration of 300 ou, we would need to dilute that odour by a factor of 300 to make it ‘just a whiff’. It must be noted that some people have a ‘strong’ sense of smell, while others have a ‘poor’ sense of smell. The amount of dilution required for different people to no longer smell an odour will be quite variable.

**Odorants** are the individual chemicals that combine to make air smell a particular way. Odorants are everywhere and are responsible for the smell in perfumes, food, manure, body odour and so on. If the proportion of odorants changes, the character and concentration of the smell will change. Coincidently, many of the dozens of odorants that create ‘poultry odour’ are the same odorants that are in the smell of our favourite foods, wines, and perfumes. We refer to the combination and study of individual odorants as **odour chemistry**. However, to understand how the combination of odorants affects what we perceive as smell with our nose, we use **instrumental odour analysis**, with techniques such as GC-MS/O, PTR-ToFMS, SIFT-MS or AOS (artificial olfaction systems/electronic nose).

# Abbreviations

| | |
|---|---|
| AOS | artificial olfaction system |
| DAF | Department of Agriculture and Fisheries, Queensland Government, Australia (formerly DPI—Dept. of Primary Industries; DPI&F—Dept. of Primary Industries and Fisheries; DEEDI—Dept. of Employment, Economic Development and Innovation; and DAFF—Dept. of Agriculture, Fisheries and Forestry) |
| DHS | dynamic headspace sampling |
| DPI, Vic | Department of Primary Industries, Victoria (currently: Agriculture Victoria) |
| EPA | Environmental Protection Agency |
| GC–MS | gas chromatography – mass spectrometry |
| GC–MS/O | gas chromatography – mass spectrometry with olfactometry port |
| FID | flame ionisation detector |
| FIDOL | frequency, intensity, duration, offensiveness, and location factors—of an odour |
| FSM | full scan mode |
| HS | headspace sampling |
| LOD | limit of detection |
| MS | mass spectrometer |
| NCD | nitrogen chemiluminescent detector |
| NMVOC | non-methane volatile organic compound |
| NZ | New Zealand |
| ou, OU | odour unit |
| pid, PID | photoionisation detector |
| ppb | parts per billion |
| ppm | parts per million |
| ppt | parts per trillion |
| PTR–MS | proton transfer reaction with quadrupole mass spectrometry |
| RD&E | research, development and extension |
| RIRDC | Rural Industries Research and Development Corporation, now trading as AgriFutures Australia |
| SCD | sulphur chemiluminescent detector |
| SEQ | south-east Queensland |
| SIFT–MS | selected ion flow tube – mass spectrometry |
| SIM | selected ion mode |
| SPME | solid-phase micro extraction |
| TD | thermal desorption |
| TD–GC–MS | thermal desorption – gas chromatography – mass spectrometry |
| ToF | time of flight mass spectrometer |
| UNE | The University of New England, Armidale, NSW |
| UNSW | The University of New South Wales, Sydney, NSW |
| VEB | vegetative environmental buffer |
| VIC | volatile inorganic compound |
| VOC | volatile organic compound |

# Contents

# Executive summary

### What the report is about

This report summarises odour-related RD&E investment by the Australian chicken meat industry since 2005. It includes details about the projects, funded by AgriFutures Australia and the Poultry CRC (2003–2017), by several research groups in government agencies, universities, and consultancy businesses. The research has addressed a variety of research topics, including:

- measurement of odour emission rates from conventional and free-range farming systems
- the use of frontier and advanced instrumental techniques for odour assessment
- odour chemistry
- the relationships between odour and dust
- the effect of environmental conditions and farm management on odour emissions
- odour dispersion modelling and calculation of separation distances
- odour management and mitigation, including diet modification.

With a broad range of people and organisations involved on a variety of odour-related topics, this report attempts to take a broad view of the RD&E. It describes how knowledge of poultry odour has evolved and how the topics relate to one another. Through this process, it has been possible to identify knowledge gaps and provide direction for future poultry odour RD&E.

### Who is the report targeted at?

The report is written for RD&E decision makers, researchers, producers, consultants, and regulators with interests in poultry odour measurement, assessment and management. The report provides recommendations on the future direction of odour-related research and development, as well as the need for targeted extension.

### Where are the relevant industries located in Australia?

The Australian chicken meat industry involves the participation of about 700 farms and 40,000 employees. Chicken meat is produced in all Australian states, typically near major metropolitan centres. According to the Australian Bureau of Agricultural and Resource Economics, Australians consume about 50 kg of chicken meat per annum, which is nearly twice as much as any other type of meat (ABARES, 2019). The strong and growing demand for chicken meat is a primary driver for industry growth.

### Background

The Australian chicken meat industry has invested significantly in RD&E about odour to address community concerns, reduce the potential for odour impacts, and support sustainable growth. A broad range of topics has been investigated, but there is a need to bring together all relative research, and summarise the achievements and challenges that have been encountered. With a concise overview of past research, it will be possible to provide direction for future poultry odour-related research. Consultation with industry stakeholders has identified more needs for targeted extension relating to odour.

### Aims and objectives

The aims and objectives of this report were to:

- summarise the key findings from poultry odour research funded by AgriFutures Australia and the Poultry CRC from 2005 to 2018

- determine the Australian chicken meat industry's needs for odour-related extension material
- provide direction for future poultry odour-related research based on current knowledge.

### Methods used

Key persons and stakeholders were consulted to develop the scope and direction of this summary, as well as identify needs for extension material. Research project reports, conference papers and journal articles relating to poultry odour research funded by AgriFutures Australia and the Poultry CRC from 2005 to 2018 were compiled into the summary. Important findings, implications and recommendations were also summarised. The evolutionary increase in poultry odour knowledge, the experience gained from on-farm and laboratory research using a variety of odour assessment methods (olfactometry, AOS/electronic nose/odour sensors, GC–MS/O, SIFT–MS, PRT–ToFMS), and linkages between projects were also identified and reported.

### Results/key findings

This report summarises the odour-related R&D supported by the chicken meat industry from 2005 to 2018. A key finding from this report was the need for improved odour monitoring methodology that is relevant for modern broiler production systems and endorsed by state planning and regulatory authorities.

The information and recommendations from this report will inform the development of the first planning and national environmental guidelines for the Australian chicken meat industry. These guidelines will ensure that future growth of the chicken meat industry occurs in an environmentally sustainable and socially responsible manner.

This report highlights the need for extension of odour research, and other issues impacting on the environmental and social license of the industry, to improve the communication of results and sharing of information between growers, integrators, environmental consultants, and regulators. A key focus of this extension should be to improve the understanding of current industry best practice for odour control.

### Implications for relevant stakeholders

R&D has focused on odour measurement, management, mitigation, and modelling. R&D findings have reduced the potential for odour impacts by supporting better planning for new farms, improving amenity, and reducing odour emissions from meat chicken farms. Adoption of odour-impact reduction strategies may improve with the addition of extension targeted at industry, regulators and consultants.

### Recommendations

The chicken meat industry should continue to invest in odour-related RD&E to:

- support improved planning of new farms, especially reliable and trusted methods to calculate separation distances
- reduce odour emissions by addressing the bio-chemical origins and transport mechanisms of odour, especially from fresh excreta and litter
- develop and test dietary formulations that reduce the potential for odour impacts, which should be a primary focus
- provide odour-management tools that can be voluntarily adopted on farms, as required, to address specific odour impact scenarios.

Olfactometry (according to the Australian/New Zealand Standard 4323.3:2001) should be used as the primary method for assessing odour concentration, but consideration should be given to assessing other characteristics of odour, such as hedonic tone, and chemical odorant profiles. The use of field odour panels also deserves consideration.

Extension of odour-related R&D should be directed toward regulators and consultants to open discussion, produce a broad consensus, endorsement, and acceptance of the findings, and to improve sentiment and trust of the Australian chicken meat industry.

# Introduction

> ***I should think we might fairly gauge the future of biological science, centuries ahead, by estimating the time it will take to reach a complete, comprehensive understanding of odour. It may not seem a profound enough problem to dominate all the life sciences, but it contains, piece by piece, all the mysteries.***
>
> Lewis Thomas (1913–1993, American physician, etymologist, poet, and essayist)

Concerns about the impacts of odour – real or perceived – are a constant obstacle to the growth and expansion of Australia's chicken meat industry. As such, odour has warranted substantial investment into research, development, and extension (RD&E) from industry, which was provided by AgriFutures Australia (formerly RIRDC) and the Poultry CRC (2003–2017). RD&E studies have included the measurement of odour emission rates from conventional and free-range farming systems using standard odour measurements (olfactometry), as well as frontier and advanced instrumental techniques to improve the understanding of odour chemistry (using AOS/electronic nose/odour sensors, GC–MS/O, SIFT–MS, PRT–ToFMS). Attempts have also been made to quantify the relationship between odour and dust, and to determine how environmental conditions and farm management affect odour emissions. Reducing the potential for odour impacts has been a common theme for much of this research, with studies dedicated to finding methods to reduce the amount of odour produced using technology and dietary/husbandry/management modifications. Research has also supported the development and improvement of tools to help with the planning, assessment, and approval of new meat chicken farms.

Results of the olfactory research have been communicated to industry, consultants, regulators and the scientific community through a variety of formal and informal extension pathways. Several government agencies, universities, consultants and companies have contributed to the odour RD&E since 2005. This summary represents the collective efforts of many people and is a tribute to them and their work.

Poultry odour research in Australia has been, and will continue to be, an intriguing journey of discovery through dry gullies and rich veins of endeavour. In this report, the story and main findings of poultry-related odour RD&E are presented in an easily accessible form, to facilitate discussions and provide industry and decision makers with a strategic direction to support future RD&E on odour.

# Objectives

The aims and objectives of this report were to:

- Summarise the key findings from poultry odour research funded by AgriFutures Australia and the Poultry CRC from 2005 to 2018
- Determine the Australian chicken meat industry's needs for odour-related extension material
- Provide direction for future poultry odour-related research based on current knowledge of odour measurement, chemistry and composition.

# Methodology

Key persons and stakeholders were consulted to develop the scope and direction of this summary, as well as identify needs for extension material to maximise the adoption of research outcomes.

This research summary required the identification and compilation of project reports, conference papers and journal articles relating to poultry odour research. Research reports were obtained from AgriFutures Australia and from the authors of the Poultry CRC research. The scope of the summary was limited to research between 2005 and 2018.

Research methods, objectives, important findings, implications and recommendations were summarised. By taking a broad view of the research, we identified and reported the evolutionary increase in knowledge about poultry odour, the experiences gained from on-farm and laboratory research using a variety of odour assessment methods (olfactometry, AOS/electronic nose/odour sensors, GC–MS/O, SIFT–MS, PRT–ToFMS), and linkages between projects.

# Consultation with industry and stakeholders

After discussions with industry and consultants, the following topics have been indicated as relevant:

- There is a tendency for all meat chicken farms to unfairly share the blame for odour impacts, and have their reputation tarnished, even though only a few meat chicken farms are responsible for most odour complaints. This has resulted in a perception that poor farming practices contribute to odour impacts.
- Odour-related RD&E has supported industry growth and public acceptance of operations by improving farm planning, design and management.
- Odour emission data from RD&E has **not** been well used by proponents of new or expanding poultry farm developments while undertaking odour modelling. Site-specific emission rates measured by odour consultants are typically used.
- Data and outcomes from RD&E are regarded as independent and trustworthy.
- Odour management strategies have been adopted as normal farming practice, primarily because they also contribute to health, productivity, welfare, and economic benefits, e.g. the use of high-powered vertical exhaust fans, proactive litter management strategies, and odour-reducing 'products'.
- Odour-related RD&E has helped improve the perception of the chicken meat industry, as seen by regulators and the community. This has been achieved by increasing their knowledge of industry practices, demonstrating improvement in practices, and managing their expectations of odour. Unfortunately, some environmental regulators have limited understanding of odour assessment and odour chemistry, especially how it relates to poultry production. Proactive engagement may be beneficial for increasing the acceptance of poultry production, and improving regulators' understanding of the contributing factors and likelihood of odour impacts from poultry farms.
- Odour modelling can be inconsistent in predicting odour impacts from meat chicken farms, which is partly attributed to the complexity of the real world.

It was also indicated that future odour-related RD&E should continue to focus on reducing the potential for odour impacts by refining odour management and modelling. Extension should support proponents of new or expanding poultry farms (and their consultants) to provide consistent information to assessment authorities (planning and environmental) to maintain trust, improve perceptions and reduce confusion. Specific suggestions for chicken meat industry RD&E included:

- More networking between odour regulators and odour researchers to improve the flow of information about the results of RD&E and industry practices, and to build trust between the regulators and industry
- Focusing on issues that might tarnish the industry's reputation or affect the sentiment of regulators
- Strategically supporting RD&E that focuses on investigating and validating:
    - The efficacy of high-powered vertical exhaust fans to reduce odour impacts
    - The performance of odour treatment systems that have been adapted from industrial odour control technologies to suit poultry production
    - The effectiveness of dietary modifications for reducing odour emissions
    - The effect of broad changes to industry production/husbandry/management practices (such as lower stocking density and more focus on litter and drinker management) to reduce odour emissions and the potential for odour impacts
    - Inputs to odour modelling, such as weather data in recognised growing regions, accurate source/farm representation, and the production of tools to accurately model odour plumes close to the sheds when affected by environmental parameters, such as thermal buoyancy.

It was also suggested that AgriFutures Australia, as the leading industry RD&E funder, should develop closer relationships with environmental regulators in the major meat chicken-growing jurisdictions to regularly update the industry's understanding of the contemporary environmental, social and political issues and perceptions related to poultry odour.

It was also requested that this current summary, as well as future RD&E, should be available as a single, easily accessible document that is regularly updated.

# Odour research summary

The Australian chicken meat industry supported a significant amount of odour-related RD&E between 2005 and 2018, and has involved multiple research organisations and researchers, with a focus on a variety of key themes and topics. These include:

- Measuring odour emission rates from conventional and free-range farming systems
- The effect of environmental conditions and farm management on odour emissions
- Odour management and mitigation (including diet modification)
- Odour chemistry
- Relationships between odour and dust
- Odour dispersion modelling and calculation of separation distances
- The use of frontier and advanced instrumental techniques for odour assessment.

Table 1 presents the individual projects and their relation to the key themes and topics identified by industry and stakeholders. Specific details of each project, key researchers, reports and publications, as well as key project objectives, findings, implications, and recommendations have been summarised in Appendix A.

The Australian chicken meat industry began to experience issues with odour before 2005 (Appendix B). Fortunately, foundation RD&E in the emerging field of odour science helped the industry focus on developing knowledge about the sources of poultry odour, the factors that affected odour emissions, and the underlying chemical pathways involved. Odour treatment technologies were also investigated, but there was little proof that they would be effective, affordable or compatible with meat chicken production. Before 2005, a database of odour emission rates compiled by industry was, unfortunately, no longer useful because of changes in olfactometry methodologies. Therefore, new data on emission rates were required for the odour impact assessment processes used for new and expanding meat chicken farms.

Since 2005, the growth and productivity of the chicken meat industry has accelerated because of an unprecedented increase in the popularity of and demand for chicken by Australian consumers (ACMF, 2018). By necessity, new meat chicken farms were built to meet this demand. To support the growing consumption of chicken meat and to improve industry sustainability, RD&E projects were designed to focus on:

- Collecting odour emission rate data that complied with the new olfactometry standard (AS/NZS 4323.3:2001)
- Identifying and evaluating odour-impact reduction strategies
- Improving the calculation of odour separation distances by refining odour dispersion modelling techniques
- Investing in new and novel ways to measure poultry odour using instrumental methods, to collect more odour data, and to improve knowledge of poultry odour.

This summary provides a brief overview of:

- Occurrences before 2005 that instigated the need for the chicken meat industry to start investing in odour-related RD&E
- The standardisation of odour measurement
- Advancements in knowledge and assessment of odour chemistry
- Efforts to improve odour dispersion modelling and calculation of separation distances when planning for new farms
- Lessons learned from each odour project
- The direction of future research.

**Table 1. Summary of projects that highlight the main research topics.**
**Dark green shading indicates a direct relationship; light green shading indicates some relevance.**

| Project and number | Research report/ main publication | Odour data collection | Factors affecting odour | Management & mitigation | Odorants and odour chemistry | Relationship: odour and dust | Dispersion modelling | Odour/odorant measurement techniques |
|---|---|---|---|---|---|---|---|---|
| Dust and odour from meat chicken and layer sheds (CRC 04-45) | Dunlop et al. (2011b) | | | | | | | |
| Windbreak walls (AgriFutures DAQ-321A) | Dunlop and Galvin (2013) | | | | | | | |
| Trials of odour control technologies (AgriFutures DAV-213A) | Simons (2010) | | | | | | | |
| Monitoring fan activity and ventilation rates (AgriFutures PRJ-000599) | Dunlop and Duperouzel (2014) | | | | | | | |
| AOS – Proof of concept (CRC 04-45) | *Reported in:* Dunlop et al. (2011b) | | | | | | | |
| Review of add-on technologies for odour control (AgriFutures DAQ-341A) | Dunlop (2009) | | | | | | | |
| Separation distances and thermal buoyancy (AgriFutures PRJ-002747) | Dunlop et al. (2010a) | | | | | | | |
| AOS – onsite continuous odour measurement (AgriFutures PRJ-002342) | Atzeni et al. (2016b) | | | | | | | |
| Vegetative environmental buffers (AgriFutures PRJ-007208) | Bielefeld et al. (2015b); Bielefeld et al. (2015a) | | | | | | | |
| Free-range odour and nutrients (AgriFutures PRJ-005044) | Brown and Gallagher (2015) | | | | | | | |

**Table 1 (cont.) Summary of projects that highlight the main research topics.**
**Dark green shading indicates a direct relationship; light green shading indicates some relevance.**

| Project and number | Research report/ main publication | Odour data collection | Factors affecting odour | Management & mitigation | Odorants and odour chemistry | Relationship; odour and dust | Dispersion modelling | Odour/odorant measurement techniques |
|---|---|---|---|---|---|---|---|---|
| Odour from spent-hen composting (Egg industry, CRC 2.2.4) | McGahan (2014) | | | | | | | |
| SIFT-MS odour analysis (AgriFutures PRJ-008767) | Atzeni et al. (2016a) | | | | | | | |
| Odour dispersion modelling: AERMOD, AUSPLUME & CALPUFF (AgriFutures PRJ-009544) | Featherston et al. (2014) | | | | | | | |
| Nutritional control of odour – Pilot study (CRC 2.2.8) | Sharma (2016) | | | | | | | |
| Litter properties and odour (CRC 2.2.2) | Dunlop (2017) | | | | | | | |
| PTR-ToFMS odour measurement (AgriFutures PRJ-009910) | Brown et al. (2018) | | | | | | | |

## Support provided by RD&E to improve planning and odour management

Reducing the risk of odour impact from a poultry farm starts at the planning and assessment stage before a farm is built. At this stage, the priority is to ensure that the poultry sheds and other sources of odour are located at an appropriate separation distance from neighbours and sensitive receptors. Once the farm is built, the separation distance established during planning and assessment should be sufficient to minimise odour impacts, although in some cases, changing farming practices or adopting odour mitigation technologies may be required for specific odour management. The themes listed in Table 1 have contributed to better planning and assessment of new farms, as well as reducing the potential for odour impacts from operational farms (Figure 1).

### Farm planning & assessment:
dispersion modelling and separation distances

**Dispersion modelling methods:**
standardisation of inputs, methods, and assessment criteria to improve consistency in farm approvals.

**Separation distances formulas:**
offer a standardised approach to enable low-risk farms to use a simple and consistent method for calculating separation distances.

**Odour data collection:**
odour emission rates are an input to dispersion modelling, and data collection is imperative.

**Investigating and quantifying the multiple factors affecting odour emission:**
because they affect how odour emission rates need to be adjusted for input into dispersion modelling (e.g. litter conditions/management, weather, ventilation, stocking density, exhaust air temperature).

**Odour mitigation:**
Changing the farm design or adding mitigation technologies and strategies (e.g. altering the position of exhaust fans or establishing vegetative environmental buffers) can reduce the risk of odour impacts, and may be used to demonstrate to regulators that risk of odour nuisance has been sufficiently reduced, so that the farm can be approved and licensed.

### Operational farms:
odour management while growing meat chickens

**Odour mitigation:**
achieved by understanding the multiple factors affecting odour emission, and the assessment, development and adoption of odour-reducing technology to minimise odour production and emission, or increase odour dispersion and dilution before it leaves the farm boundary.

**Odour data collection:**
to adapt 'standard' sampling methods to poultry shed applications; develop knowledge of the greatest sources of odour to prioritise future RD&E; and to improve the understanding of poultry odour, including the contribution of **odorants and odour chemistry**.

**Development of techniques for advanced instrumental odour measurement:**
using technology such as GC-MS/O, PTR-ToFMS, SIFT-MS or artificial olfaction systems (AOS, electronic nose). These instruments provide a different dimension of understanding about odour: whether it be objective measurement of dominant odorants; continuous measurement of odour (to understand dynamic changes in odour emissions; or downwind odour assessment.

**Relationships between odour and dust:**
to identify possible mitigations that may reduce risks associated with both pollutants or to better understand how dust filtering may reduce odour nuisance.

**Figure 1: Contribution of RD&E to planning, odour assessment and odour management.**

## Project summaries

The projects listed in Appendix A and Table 1 addressed specific, topical, emerging and anticipated issues raised by industry, coinciding with better scientific knowledge and technology. The following information is a summary of the projects that primarily relate to odour measurement, odour management and odour modelling.

### Measurement of odour emission rates

#### *Dynamic olfactometry*

One of the first requirements identified by the chicken meat industry was the need for updated data on odour emission rates to enable industry-specific odour modelling for new and expanding farm developments. A review by Pollock and Anderson (2004) defined the need for the industry to partly fund the extensive costs associated with measuring odour emission rates, to reduce the costs for new farm developments to conduct their own measurements. Projects by Simons (2010) and Dunlop et al. (2011b) initiated the expensive and challenging process of measuring odour emission rates from representative farms (at the time) in Queensland and Victoria, with the expectation that the data collected would be made publicly available, accepted by EPAs, and improve the understanding of the factors that affect odour emissions. Following this, research by Brown and Gallagher (2015) measured odour emission rates from free-range farms, including emissions from the range area and the poultry sheds. Since those publications, there have been many changes to shed design, husbandry practice, bird genetics, litter management and nutrition that can potentially reduce odour emissions. Consequently, proponents of new meat chicken farms are likely to, once again, do their own odour measurements to support their development application.

#### *The use of artificial olfaction systems (AOS) to measure odour*

The research on odour measurement demonstrated the highly dynamic nature of odour emissions from meat chicken sheds. Odour emission rates were found to vary between farms, throughout each day, over the grow-out cycle, and seasonally. Completely characterising odour emissions from meat chicken farms with the method of collecting discrete odour samples combined with olfactometry would be prohibitively expensive as well as logistically and technically challenging. This led to the ambitious attempt to develop an AOS (electronic nose) to measure the strength of poultry odour. Sohn et al. (2008) (and subsequent research by Sohn et al. (2010)) indicated that measuring poultry odour using AOS was achievable. When combined with continual ventilation rate monitoring, the AOS produced a continuous odour emission rate record for meat chicken sheds, which confirmed the highly variable nature of meat chicken farm odour emissions. It also provided a new perspective on the times of day when odour impacts are more likely to occur, especially when combined with weather data, such as atmospheric stability class, which greatly affects odour dispersion and is known to contribute to odour impacts (Dunlop et al., 2013b).

One of the biggest challenges to the development of AOS is the need to train the sensors to mimic the human sense of smell. The research by Sohn et al. (2008; 2010) had the benefit of coinciding with hundreds of odour emissions measurements from meat chicken sheds, which provided a substantial dataset for training the AOS on several different farms. Subsequent research by Atzeni et al. (2016b) did not have a similar training opportunity, and was unable to replicate the AOS performance of the earlier research. These projects concluded that until the sensitivity of odour sensors and training methods for AOS improved, it was unlikely that AOS would replace olfactometry, which subsequently ended this area of research into AOS development.

#### *Instrumental analysis of odorants*

Research to identify and quantify odorants was undertaken to:

- Increase knowledge about the primary odorants that contribute to poultry odour

- Contribute knowledge about the origins of the odorants (birds, litter, biological)
- Support strategic odour mitigation (by targeting highest priority odorants).

One advantage of instrumental measurements is that there is less inherent variability than olfactometry, which is partly associated with the involvement of human panellists for odour assessment. However, there are challenges to relying on technology, including a substantial calibration process and the need to collect and/or pre-concentrate odorant samples, which can selectively include or exclude odorants, depending on the method. Odours researchers have not yet been able to relate odorant concentration data to odour concentration.

The development of real-time, mass spectrometry instruments, such as SIFT-MS and PTR-ToFMS, has provided new opportunities to directly analyse odour from poultry farms and their surrounding environment. Despite the benefit of sampling directly from the odour source and quantifying minute concentrations of presumably odorous chemicals (at ppb and ppt levels), these instruments are not truly portable, and the requirements for data processing are quite complex. Uncertainty exists about whether compounds indicated by the instrument are actually the target odorant, or another compound with similar chemical properties. It is also not currently possible to explain, with certainty, how the measured odorant concentrations contribute to the intensity and character of an odour and to its likelihood to cause impacts.

Despite the promising opportunities expected with instrumental odorant measurement, odour concentration measurement still requires dynamic olfactometry.

### *Relationships between dust and odour*

Odorants adhere to dust particles, which can result in a higher concentration than in the air surrounding the dust particles. It is generally believed that the accumulation of odorants on dust can trigger a strong smell when breathed in through the nose. As a result, there is an internationally inferred belief that dust can contribute to odour impacts. Researchers and entrepreneurs have attempted to develop dust mitigation strategies to reduce odour.

Simons (2010) and Dunlop et al. (2011b) investigated relationships between odour and dust. Simons (2010) performed olfactometry on unfiltered and filtered odour samples collected simultaneously, and found that there was no significant difference (NB: unfiltered is the normal practice; filtered samples were collected through a 1-micron filter). This study also suggested that sample bags may exclude the dust, but it was not confirmed. Subsequent research by Dunlop et al. (2011b) had the benefit of a multi-disciplinary research team that included environmental dust specialists who had real-time dust particle monitors. Through a series of experiments, this research team observed that dust particles collected into odour sample bags (while collecting odour samples) quickly adhered to the plastic bag material, likely due to electrostatic attraction, and most dust was effectively removed from the sample air within a timeframe of a few minutes to a few hours. This observation confirmed the suggestion by Simons (2010) that current methods effectively exclude dust from the olfactometry process.

In other experiments, Dunlop et al. (2011b) performed olfactometry on filtered and unfiltered odour samples and, like Simons (2010), found no significant difference. The researchers also attempted to regenerate odour from the dust collected in the dust filters, with inconclusive results. Therefore, it can be reasonably concluded that the current odour sample collection processes and olfactometry exclude the contribution of dust from odour concentration measurement, and only the gas-phase odorants are assessed. The relationship between dust and odour concentration, and the potential for odour impacts, requires more investigation by industry.

## Odour management and mitigation strategies

The Australian chicken meat industry needs affordable and effective odour management strategies that can reduce the potential of odour impacts from existing farms. Other odour mitigation strategies may also be applied to proposed farms to support their approval for development. Odour mitigation strategies exist in several forms, including:

- **Capture and treat** – filters, scrubbers, biofilters, vegetative/tree screens/buffers
- **Odour-neutralising agents** (mixed into the airstream) – chemical deodorants, ozone, active oxygen
- **Odour source controls** – adsorbent materials, litter amendments, litter drying, litter aeration
- **Dietary control** – feed additives, lower protein diets, altered feed ingredients
- **Dispersion enhancement** – fan stacks, windbreak walls, vegetative/tree screens/buffers.

To address odour issues, significant investment has been put into investigating a variety of odour mitigations for meat chicken production (Bielefeld et al., 2015a; Bielefeld et al., 2015b; Dunlop and Galvin, 2013; Dunlop and Duperouzel, 2014; Dunlop, 2009, 2017; Kolominskas et al., 2002; Pillai et al., 2012; Sharma, 2016; Simons, 2010).

'Best bet' strategies and technologies were identified by Kolominskas et al. (2002), including:

- **Shed insulation** – to reduce condensation and prevent wet litter
- **Ventilation** – enough to dry the litter and provide temperature control
- **Waste management** – to remove excess waste and manage litter moisture
- **Dietary manipulation** – decreasing crude protein and increasing amino acids
- **Litter management** – strategies to minimise anaerobic decomposition
- **Floor design** – internal and external, engineered to ensure drainage, and minimise litter moisture and anaerobic decomposition
- **Short chimney stacks** – added to fans to increase vertical dispersion of odour plumes
- **Windbreak walls** – to increase vertical dispersion of odour plumes
- **Active oxygen** or '**ozone'** – to oxidise odorants and to neutralise smell
- **Biofiltration** – using microbes to convert odorants to less odorous gases
- **Odour-neutralising agents** – using chemicals to neutralise odorants.

In a later review, Dunlop (2009) recommended that the following strategies deserved more investigation:

- **Dry dust filtration** – of shed exhaust air
- **Litter aeration** – currently known as litter conditioning, or tilling to 'work' the litter
- **Electrostatic particulate ionisation** – to settle dust within the poultry shed
- **Odour-neutralising agents –** assuming effective products could be found
- **Dust control structures** – including windbreak walls and fan hoods
- **Wet scrubbing** – of shed exhaust air with water or chemical solutions.

Some odour management strategies required no further research investment and have been adopted by industry as good practice. These adoptions include the following: the proper insulation of all new poultry sheds; better ventilation; engineered floors; and litter management practices that minimise litter moisture and keep litter aerated and 'working'.

Research investments were focused on the strategies and technologies considered to be affordable and adaptable to meat chicken sheds. Results of these studies included the following:

- Odour-neutralising agents and biological litter treatments were unable to significantly reduce odour emissions (Simons, 2010).
- Odour filtering/scrubbing devices have not been specifically tested in Australia because there is currently no technology considered to be affordable, effective, reliable, resistant to dust clogging, and able to treat large volumes of air. To support the design of 'capture and treat' technologies, Dunlop and Duperouzel (2014) recorded fan activity on meat chicken sheds to

improve the understanding of the dynamic nature of ventilation rates, and to specifically identify the ventilation rates that occur during times of higher potential for odour impacts, for example, at night and in the early morning when stable atmospheric conditions limit odour dispersion.

- A strategy to treat a fraction of the air exhausted from poultry sheds was identified by Dunlop (2009) during a review of add-on odour control technologies. It was, therefore, suggested as a possible method to reduce capital and operating costs of odour technologies, while remaining effective at reducing odour impacts.
- Windbreak walls and short stacks evaluated by Dunlop and Galvin (2013) were found to reduce downwind odour concentrations, but the effectiveness of this method depended on weather conditions and the separation distance between the sheds and receptors.
- Recommendations for the design of vegetative environmental buffers (VEB) using trees, grasses, bamboo and shrubs were outlined by Bielefeld et al. (2015a).
- The combination of dietary manipulation and litter moisture, pH and water activity can be used to reduce odour (based on measurement of odorant concentrations) (Sharma, 2016). Dietary manipulation included the use of different protein sources, reducing crude protein levels by adding amino acids, controlled salt levels, and the use of probiotics and other in-feed additives. Certain dietary manipulation was found to reduce odour emissions from fresh excreta and reduce litter moisture, which contributed to lower odour emissions.
- The maintenance of dry litter conditions reduced the formation of characteristic odorants (Dunlop, 2017). Calculating the odour activity value (OAV), which is a numerical calculation of odour strength based on the concentration of odorants and their odour threshold value, showed that dry litter had lower OAV than wet and caked litter. Actively maintaining dry and friable litter is likely to reduce odour formation in the litter. This research also identified that fresh excreta had high OAV, which therefore requires further investigation as a primary odour source, with attention to odour control through dietary manipulation or active litter management.

The assessment of odour management strategies can be technically challenging. In some cases, these strategies may:

- Need longer treatment time than occurs within the shed (may be as short as 30–40 s) and samples may need to be collected away from the shed, which could affect the integrity of the sample after being subjected to environmental interactions (or the plume could travel vertically so that it is impossible to collect samples).
- Produce their own, but less offensive odour (e.g. perfumed masking agents), which cannot be assessed using only olfactometry to determine odour concentration.
- Treat the odour in a location that is difficult to define (e.g. VEB), which makes it difficult to collect meaningful samples of the ‘treated’ odour.
- Have variable effectiveness, for example, litter conditioning may initially release odour (depending on the litter conditions, and is why it is performed at a time of day that is unlikely to contribute to odour impacts), although the effect of litter drying and aeration may have long-term effects of reducing odour emissions for days or weeks.

Improvements in shed design, farm design and landscaping, shed and ventilation management, husbandry practices and litter management have all contributed to reducing the potential for odour impacts from meat chicken farms. Unfortunately, there is currently no recognised mitigation strategy that is guaranteed to reduce odour impacts from meat chicken farms. Future evaluation of odour management strategies will need to be carefully planned to ensure measurements of efficacy are meaningful.

## Odour modelling

### *Assessing odour impacts*

It is extremely difficult to predict the potential odour impact risk of a new meat chicken farm because of complex human, social and economic factors. It is equally difficult to produce odour impact criteria to determine whether new developments should be approved or not (DES, 2013). In general, consideration must be given to the frequency, intensity, duration, offensiveness, and location of an odour, commonly referred to as the FIDOL factors, which also include the characteristics of the receptor (DES, 2013). Conventionally, farm planning can reduce the potential of future odour impacts by ensuring that there is sufficient separation distance between the farm and neighbours (or other sensitive locations). Methods of determining the separation distance can involve a relatively simple mathematical formula, or more complex odour dispersion modelling.

### *Separation distance formulas (s-factor formulas)*

Separation distance formulas (often referred to as 's-factor' formulas) calculate separation distances quickly (a few minutes), but they usually give 'conservative' values that could be greater than needed. S-factor formulas are empirically derived from dispersion modelling of a variety of theoretical scenarios. Recognised s-factor formulas can be used in most Australian state jurisdictions for 'simple' farm scenarios (e.g. single farm, flat terrain, no unusual weather patterns) and where the number of chickens on the farm is below established limits. Each Australian state has its own s-factor formula methodology. Attempts have been made with R&D to improve and standardise s-factor formulas for meat chicken farms by using the most sophisticated odour dispersion models available (Dunlop et al., 2010a).

### *Odour dispersion modelling*

Odour dispersion modelling is a complex method for estimating separation distances for meat chicken farms, but it enables modelling to be tailored to individual farms. Details about dispersion models and their associated challenges for accurately modelling the risk of odour impacts from poultry farms have previously been reported by Ormerod (2011) and D'Abreton (2011). Odour dispersion modelling is performed with computational software, such as AUSPLUME, CALPUFF or AERMOD, with the support of other software, such as TAPM, CALMET and odour emission models. These software packages are used to model the emission and dispersal of odour plumes from poultry sheds into the environment, to estimate the likely intensity, frequency, and duration of odour exposure in the surrounding landscape. The dispersion models produce site-specific estimations for poultry farms by using site-specific inputs, such as farm layout, odour concentration, ventilation rates, weather data, terrain information (hills and valleys) and surface roughness for the landscape surrounding the farm (usually related to vegetation coverage, e.g. grass or trees). Odour concentration and ventilation rate data is required to be on an hourly time-step (or more frequent).

Odour modelling consultants have developed their own odour emission models to predict hourly odour emission rates (for example, the model described by Ormerod and Holmes (2005) and used by Featherston et al. (2014)). Odour emission models can be based on odour concentration data from odour measurements, such as the odour measurement projects outlined in Table 1, or independent odour measurements by consultants. These models are generally based on factors considered to affect odour emissions, such as batch start dates, temperature (from weather data), stocking density, ventilation rates, and an adjustment factor ('k-factor') that considers farm design and operation. The relationship between the variable factors and their effect on odour emissions is complex and not well understood, and the predicted odour emission rates can vary significantly.

### *Contributions of research to improve odour modelling*

Research projects have contributed to the knowledge of odour emission rates and the many factors that affect emission rates and odour impacts. One of the primary goals of AOS R&D and the trialling of instrumental odour analysis technologies (SIFT-MS and PTR-MS) was to develop the capacity to continually measure odours that would reduce the need for predictive odour emission rate modelling. While this capability has not been developed for general and ongoing use, continuous odour monitoring was briefly achieved during several studies (Dunlop et al., 2011b; Sohn et al., 2008; Sohn et al., 2010).

Featherston et al. (2014) compared the odour impact predictions of three different dispersion models, and the impacts of prescriptive odour modelling methodologies stipulated by an environmental regulator. The study showed significant differences in predicted odour impacts by different dispersion models and that are also due to the selection and pre-processing requirements of meteorological data and other inputs. The authors made several recommendations, including ground-truthing of meteorological data, modifying stipulated requirements for the quantity of meteorological data, and modifying some dispersion modelling practices.

The research projects outlined in this current summary have compiled data based on visual observations, physical measurements, and CFD modelling that contributes to an increase in knowledge about the shape, movement, air temperature and thermal buoyancy of odour plumes as they are exhausted from poultry sheds (Dunlop et al., 2010a; Dunlop and Galvin, 2013), as well as detailed data of ventilation rates (Dunlop and Duperouzel, 2014).

# Future directions for odour RD&E

Future odour-related R&D should focus on supporting better odour modelling and planning for new poultry farms. It should also focus on developing and testing strategies to reduce odour emissions from existing farms that will reduce the potential of odour impacts and enable the Australian chicken meat industry to grow sustainably and maintain social licence.

Extension of these research projects should be based on better communication of results to integrators, growers, environmental consultants and regulators. Extension to industry should focus on information sharing and, where appropriate, adoption of beneficial strategies. Extension to regulators and consultants should focus on building professional relationships and improving their understanding of industry practices and improvements. Extension should improve public perception by demonstrating innovative practices, industry improvements and great environmental custodianship. Industry practices are considerably different from what they were 5–10 years ago, which must be reflected in the information shown to stakeholders so that they can understand the new methods available for reducing the potential of odour impacts from chicken meat production.

Industry must continue to fund the measurement of odour emissions to demonstrate the effect of recently adopted industry practices on odour emission rates, such as litter conditioning. Understanding the short-, medium- and long-term effects of better practices that reduce odour emission rates will contribute to enhanced odour modelling and management practices.

More RD&E is required for odour migration strategies, with priority given to reducing odour from fresh excreta and litter (i.e. the primary source of the odour) through the modification of poultry diets and the optimisation of litter management and intervention strategies. Development of autonomous technologies in other industries should be investigated to determine whether they can be transferred and adapted to automate litter conditioning in chicken meat production. This could potentially reduce labour inputs and associated costs while simultaneously reducing odour emissions. Odour-neutralising agents should be a continued consideration for RD&E, and as promising products and technologies emerge, focus should be on confirming their efficacy.

Odour dispersion modelling will likely continue as the primary tool for assessing the potential of odour impacts caused by new and expanding meat chicken farms in Australia. RD&E should focus on improving input data to predictive models, especially those regarding odour emissions and ventilation rates. Further, the results from odour modelling R&D must be actively communicated to regulators and consultants, through targeted extension events and forums to get broad consensus and endorsement of the findings that improve sentiment and trust in odour modelling.

# Implications

Odour RD&E is a relatively new field of research in the chicken meat industry compared to traditional research related to nutrition, health, vaccine development, welfare, housing, product quality and food safety. Since the mid-1990s, odour has emerged as an important issue because of urban encroachment, industry intensification, and changes to environment and planning legislation. In the last few decades, RD&E projects funded by the chicken meat industry have aimed to reduce and resolve odour-related issues by supporting better planning of new farms and developing strategies to reduce odour impacts. The results of these research projects have been used and adopted to varying degrees by industry and stakeholders.

The perception of meat chicken farming by regulators and the community has been impaired by odour impacts, especially those from the late 1990s and early 2000s. Recent changes in industry practices relating to farm locations, production intensity, litter management, farm layout and landscaping, and nutritional refinement have undoubtedly reduced the potential of odour impacts from meat chicken farms in Australia. Future odour-related RD&E should focus on more reductions to odour emissions from meat chicken farms, with an active demonstration and communication of these improvements to consultants and regulators.

# Recommendations

We recommend that the Australian chicken meat industry continues to support odour-related RD&E, particularly for topics that:

- Support better planning of new farms, including reliable and trusted methods to calculate separation distances
- Reduce odour emissions by addressing the bio-chemical origins and transfer/transport of odour, especially from fresh excreta and litter
- Develop and test dietary formulations to reduce the potential of odour impacts
- Provide evidence to support odour management strategies or mitigation tools that can be voluntarily adopted by individual farms to address odour impact scenarios specific to that property.

Olfactometry complying with the Australian/New Zealand Standard (AS/NZS 4323.3:2001) should be the primary method for assessing odour concentration, although consideration should also be given to assessing hedonic tone (pleasantness of an odour) and chemical odorants. Field-based odour assessments that have not been used in R&D projects may also be necessary to evaluate the reduction in the potential for odour impacts downwind from a farm.

Extension of odour-related R&D should be directed at regulators and consultants to get broad consensus, endorsement, and acceptance of the findings, and to improve sentiment and trust toward the Australian chicken meat industry.

# Appendices

## Appendix A. Summary of odour research projects 2005–2018

| Project | Year | Lead investigators | Research organisation | Funder & project code | Publications and presentations | Objectives | Main findings | Implications and recommendations |
|---|---|---|---|---|---|---|---|---|
| Dust and odour emissions from meat chicken & layer sheds | 2005-2009 | Dunlop, M.<br>Gallagher, E.<br>Stuetz, R.M.<br>Ristovski, Z.<br>McCauley, I. | DAF<br>UNSW<br>QUT<br>DPI, Vic | Poultry CRC<br><br>04-45 | *Reports*<br>*Dunlop et al. (2011a); Dunlop et al. (2011b)*<br><br>*Other publications*<br>Dunlop et al. (2013b); Dunlop et al. (2013c); Dunlop et al. (2010b); Modini et al. (2010); Murphy et al. (2012); Pillai et al. (2010); Pillai et al. (2012) | Develop a database of odour and dust emission rates.<br>Explore relationships for dust and odour, and measurement methods.<br>Identify and quantify key odorant chemicals. | Odour and dust emission rates were quantified.<br>Odour samples decay rapidly and need to be analysed within 6-12 hours of collection.<br>Odour emission rate model could not be developed.<br>Odour chemistry was affected by many factors. Several compounds appeared to contribute to odour concentration. | Odour and dust emission rates available for assessing new developments.<br>Improved knowledge about chemical odorants.<br>Development of improved sampling methods. |
| Control of Odour and Dust from Chicken Sheds – Evaluation of windbreak walls | 2004-2006 | Dunlop, M.<br>Galvin, G. | DAF | Agri-Futures Aust.<br><br>DAQ-321A | *Report*<br>Dunlop and Galvin (2013)<br><br>*Other publications*<br>Dunlop et al. (2013a) | Assess potential for odour impact reduction by windbreak walls and short stacks (field measurements and CFD modelling). | Odour dilution is increased near the shed.<br>Likely effectiveness is only for close receptors (less than 150 m from the poultry sheds). | Windbreak walls and short stacks may not be a reliable odour reduction strategy in all situations. Both technologies may have other benefits. |
| Trials of Odour Control Technologies on Broiler Farms | 2004-2006 | Simons, J. | DPI, Vic. | Agri-Futures Aust.<br><br>DAV-213A | *Report*<br>Simons (2010) | Develop protocols and database for evaluating odour reduction technologies and test their effectiveness. | Odour control technologies were not found to be effective.<br>Odour emission rates were found to be influenced by multiple factors. | At the time, there were no ‘superior technologies’ found for odour control.<br>Odour control products need to provide evidence of how well they work. |

| Project | Year | Lead investigators | Research organisation | Funder & project code | Publications and presentations | Objectives | Main findings | Implications and recommendations |
|---|---|---|---|---|---|---|---|---|
| Monitoring mechanical ventilation rates in poultry buildings | 2006-2007 | Dunlop, M. Duperouzel, D. | DAF | Agri-Futures Aust.<br><br>PRJ-000599 | *Report*<br>Dunlop and Duperouzel (2014) | Collect data on fan activity and ventilation rate for tunnel ventilated sheds (QLD, NSW & VIC) to:<br>Quantify daily, seasonal and batch age trends (e.g. use in odour modelling). Assist the design of odour/dust treatment tech. | Ventilation rates reduced during times of the day when odour impacts are commonly thought to occur. | Data is available to improve estimation of ventilation rates during odour dispersion modelling.<br>Reduction in ventilation rates at times of likely odour impacts means that odour treatment systems can be sized for lower than maximum ventilation. |
| Artificial olfaction system proof-of-concept<br>(electronic nose) | 2007-2008 | Sohn, J.H. | DAF | Poultry CRC<br><br>04-45 | *Reported in*<br>Dunlop et al. (2011b)<br><br>*Other publications*<br>Sohn et al. (2008); Sohn et al. (2010) | Develop a novel electronic nose, AOS, or odour-sensing array to measure odour concentration. | A sensor-based instrument with matching mathematical models could predict odour concentration. | Sensor array and mathematical algorithms needed to be matched.<br>Training required dozens of odour samples. Training is site-specific. |
| Control of Odour and Dust from Chicken Sheds – Review of “add-on” technologies | 2007-2008 | Dunlop, M. | DAF | Agri-Futures Aust.<br><br>DAQ-341A | *Report*<br>Dunlop (2009) | Information search for technologies and strategies to reduce odour and dust. | Many technologies were unsuitable, had no proof of effectiveness or were expensive. | Some technologies require independent testing for effectiveness.<br>Litter aeration recommended for further investigation as an odour control strategy. |
| Separation Distances for Broiler Farms – Verifying methods and investigating the effects of thermal buoyancy | 2008-2009 | Dunlop, M. Duperouzel, D. Pott, L. | DAF | Agri-Futures Aust.<br><br>PRJ-002747 | *Report*<br>Dunlop et al. (2010a)<br><br>*Other publications*<br>Dunlop et al. (2013a) | Develop simple ways to calculate separation distances for new farms.<br>Investigate how thermal buoyancy affects how odour plumes move after exiting the shed. | Separation distance formulas were developed.<br>Thermal buoyancy causes odour plumes to rise very close to the exhaust fans. | Thermal buoyancy should be included in odour modelling.<br>Separation distance formulas should be acceptable as a first-level odour impact assessment.<br>Odour modelling results should be verified with complaint data. |

| Project | Year | Lead investigators | Research organisation | Funder & project code | Publications and presentations | Objectives | Main findings | Implications and recommendations |
|---|---|---|---|---|---|---|---|---|
| Artificial olfaction systems for on-site odour measurement | 2010 | Atzeni, M.<br>Lobsey, C.<br>Mayer, D.<br>Parcsi, G. | DAF<br>UNSW | Agri-Futures Aust.<br><br>PRJ-002342 | *Report*<br>Atzeni et al. (2016b) | Develop a tool or proxy for measuring poultry odour concentration for on-site and continuous measurement. | An artificial olfaction system with trained mathematical model was able to predict 'ballpark' odour concentrations. Problems existed with retraining new sensors and lack of sensor sensitivity to known odorants. | AOS is not likely to be a viable odour measurement technology for the foreseeable future. |
| Vegetative environmental buffers (VEB) for meat chicken farms | 2011-2012 | Bielefeld, E.N.<br>McGahan, E.J.<br>Watts, P.J.<br>Prentice, E. | FSA Consulting | Agri-Futures Aust.<br><br>PRJ-007208 | *Literature review*<br>Bielefeld et al. (2015b)<br><br>*Farmer's guide*<br>Bielefeld et al. (2015a) | Produce a guide to assist Australian meat chicken farmers in adopting VEBs. | Establishing VEBs is likely to be effective for reducing odour and amenity impacts, but correct design and plant selection is critical. | Establish VEBs around meat chicken farms by following the information in the farmer's guide. |
| Free range chickens – odour emissions and nutrient management | 2012-2013 | Brown, G.<br>Gallagher, E. | DAF | Agri-Futures Aust.<br><br>PRJ-005044 | *Report*<br>Brown and Gallagher (2015) | Measure odour emissions from free-range poultry sheds and range area.<br>Measure soil nutrients in range areas and runoff. | Odour emissions from free-range sheds were similar to conventional sheds, and odour from range areas was negligible.<br>Soil N and K were slightly higher, with P lower, in the range areas than in controls. | Range areas are not hotspots for nutrient accumulation.<br>Range areas do not need to be included in odour assessments. |

| Project | Year | Lead investigators | Research organisation | Funder & project code | Publications and presentations | Objectives | Main findings | Implications and recommendations |
|---|---|---|---|---|---|---|---|---|
| Free range chickens – odour emissions and nutrient management | 2012-2013 | Brown, G.<br>Gallagher, E. | DAF | Agri-Futures Aust.<br><br>PRJ-005044 | *Report*<br>Brown and Gallagher (2015) | Measure odour emissions from free-range poultry sheds and range area.<br>Measure soil nutrients in range areas and runoff. | Odour emissions from free-range sheds were similar to conventional sheds, and odour from range areas was negligible.<br>Soil N and K were slightly higher, with P lower, in the range areas than in controls. Runoff nutrients were lower than a golf course. | Range areas are not hotspots for nutrient accumulation.<br>Range areas do not need to be included in odour assessments. |
| Odour measurement and impact from spent hen composting<br>(Egg Industry) | 2012-2013 | McGahan, E. | FSA Consulting | Poultry CRC<br><br>2.2.4 | *Report*<br>McGahan (2014) | Quantify odour emissions and possible impacts from composting spent hens.<br>Determine the effect of cover materials, moisture levels and compost age. | Odour from composting windrows has a negligible impact on the farm's overall emissions.<br>Consideration needs to be given to when and how often windrows are turned. | Industry can confidently compost spent hens, but composting areas and windrow need to be appropriately prepared and managed. |
| Rapid continuous chemical analysis of meat chicken shed emissions by SIFT-MS | 2013 | Atzeni, M.<br>Langford, V.<br>Prince, B.<br>Mayer, D. | DAF<br><br>SYFT Technologies | Agri-Futures Aust.<br><br>PRJ-008767 | *Report*<br>Atzeni et al. (2016a) | Evaluate the feasibility of using SIFT-MS for poultry odour assessment, and if it can substitute olfactometry.<br>Validate with GC-MS measurements. | SIFT-MS showed potential as a research tool for poultry odour assessment.<br>In-field application requires refinement. | Further research required to relate SIFT-MS data with odour concentrations.<br>Other MS technologies should also be evaluated. |

| Project | Year | Lead investigators | Research organisation | Funder & project code | Publications and presentations | Objectives | Main findings | Implications and recommendations |
|---|---|---|---|---|---|---|---|---|
| Odour Dispersion Modelling of Meat Chicken Farms – Comparison of AERMOD, AUSPLUME and CALPUFF models | 2014 | Featherston, D.<br>Pollock, T.<br>Power, M. | GHD | Agri-Futures Aust.<br><br>PRJ-009544 | *Report*<br>Featherston et al. (2014) | Investigate the differences between air dispersion models AUSPLUME, CALPUFF, and AERMOD using fictitious poultry farm scenarios.<br>Investigate the effects of new odour modelling protocols in Victoria. | AERMOD, the newer model, calculates greater separation distances than AUSPLUME.<br>The new modelling protocols will increase costs, require larger separation distances, and require more skilled and knowledgeable modellers. | Ground truth is required to evaluate the accuracy of models to predict odour nuisance.<br>Discrepancies between models need to be investigated.<br>Odour criteria should be reviewed. |
| Pilot study on nutritional manipulation of odour emissions from poultry | 2013-2016 | Swick, R.<br>Sharma, N. (PhD) | UNE | Poultry CRC<br><br>2.2.8 | Report/PhD Thesis Sharma (2016)<br><br>*Other publications*<br>Sharma et al. (2015); Sharma et al. (2016); Sharma et al. (2017a); Sharma et al. (2017b); Sharma et al. (2017c); Sharma et al. (2018) | Determine the role of diets on odour emissions, feed intake, litter quality and productivity measures.<br>Investigate the generation of odour by cultured *Clostridium perfringens (Cp)*. | Dietary additives, ingredients, formulations, and protein content affected litter conditions and formation of some odorous compounds.<br>*Cp* produces a number of odorants that impart noxious smell. | 'Low odour' diets are likely to be possible, but yet to be realised commercially.<br>Maintaining dry litter is beneficial for reducing odour formation. |
| Reducing odour from litter and improving understanding about litter properties | 2013-2016 | Stuetz, R.<br>Dunlop, M. (PhD) | UNSW<br>DAF | Poultry CRC<br><br>2.2.2 | Report/PhD Thesis Dunlop (2017)<br><br>*Other publications*<br>Dunlop et al. (2015, 2016a); Dunlop et al. (2016b); Dunlop et al. (2016c) | Focus on the litter and investigate how litter conditions affect odour emissions.<br>This was to support litter management strategies. | Litter conditions are highly variable diurnally, spatially and within the profile. Odour emissions are affected by multiple factors. Dry litter produces fewer unpleasant odorants. | Keep litter 'working' to prevent cake formation and to maximise drying. This should be effective in reducing odour formation and reducing the potential for impacts. |

| Project | Year | Lead investigators | Research organisation | Funder & project code | Publications and presentations | Objectives | Main findings | Implications and recommendations |
|---|---|---|---|---|---|---|---|---|
| Odour Dispersion Modelling of Meat Chicken Farms – Comparison of AERMOD, AUSPLUME and CALPUFF models | 2014 | Featherston, D.<br>Pollock, T.<br>Power, M. | GHD | Agri-Futures Aust.<br><br>PRJ-009544 | *Report*<br>Featherston et al. (2014) | Investigate the differences between air dispersion models, AUSPLUME, CALPUFF, and AERMOD using fictitious poultry farm scenarios.<br>Investigate the effects of new odour modelling protocols in Victoria. | AERMOD, the newer model, calculates greater separation distances than AUSPLUME.<br>The new modelling protocols will increase costs, require larger separation distances, and require more skilled and knowledgeable modellers. | Ground truth is required to evaluate the accuracy of models to predict odour nuisance.<br>Discrepancies between models need to be investigated.<br>Odour criteria should be reviewed. |
| Addressing odour abatement and assessment knowledge gaps using PTR-ToFMS | 2015-2017 | Brown, G.<br>Atzeni, M.<br>Mayer, D.<br>Maleknia, S. | DAF<br>UNSW | Agri-Futures Aust.<br><br>PRJ-009910 | *Report*<br>Brown et al. (2018) | Evaluate PTR-ToFMS for assessing poultry odours in field and laboratory situations, and relate the efficacy of odour reduction strategies to changes in key odorants (especially downwind from poultry sheds). | PTR-ToFMS was useful as a research tool for poultry odour assessment. A suite of characteristic poultry odorants were reliably detected and measured.<br>In-field application requires refinement. | Routine measurement of poultry odours will remain laboratory-based in the foreseeable future. Using the PTR-ToFMS to analyse dynamic odour plumes in the field is logistically difficult. Olfactometry and PTR-ToFMS methods are complementary. |

# Appendix B. Snapshot of pre-2005—an era of rapid change

### *Industry changes contributing to odour issues*

The period from 1995 to 2005 was an era of many changes in chicken meat industry practices, which included:

- Broader adoption of tunnel ventilation (including conversion of naturally ventilated/conventional sheds)
- Higher productivity made possible by better housing technology combined with new poultry genetics.

These changes, combined with urban expansion and encroachment into peri-urban and agricultural areas, coincided with an increase in the number of complaints relating to odour received by councils and environmental agencies. This prompted the industry to look for options to reduce the potential for odour impacts, beginning with better farm planning for new and expanding farms, but also looking for methods to reduce odour emissions.

### *Foundations of odour-related RD&E*

RD&E on poultry odour started before 2005 to address growing conflicts and concerns between meat chicken farms and surrounding community, as well as working towards formalising and improving odour assessment methodology and environmental management practices. The chicken meat industry was not alone in these endeavours, with similar research being undertaken by the other intensive animal industries. Early research by Kolominskas et al. (2002) (presented at industry conferences by McGahan et al. (2002), and McGahan and Nicholas (2004)), Pollock and Anderson (2004), and Jiang and Sands (2000) established a foundation of knowledge about:

- Odour emission rates
- How odour is produced and what odorous chemical are involved
- Effects of the environment, diet and management practices on odour emissions
- Odour sampling and analysis methodologies
- Relationships between odour, dust, and ammonia
- Odour dispersion, dispersion models, modelling techniques, source/poultry-shed/farm characterisation and impact criteria (of the various Australian states)
- Odour mitigation strategies.

### *Standardisation of olfactometry*

In addition to industry changes, the 1995–2005 period was also a time of rapid change, advancement and standardisation for odour measurement (olfactometry) and odour science. One of the biggest changes occurred in 2001, with the introduction of an Australian/New Zealand standard for odour concentration measurement using dynamic olfactometry (AS/NZS 4323.3:2001). This new olfactometry standard was based on a draft European Standard (now EN13725:2003) and superseded previous olfactometry standards, including NVN2820:1996 and EPA Victoria Method B2 (1985). The new Standard had a different methodology to previous standards that produced data, was incomparable to previous measurements (e.g. values measured by Jiang and Sands (2000)), but delivered better repeatability and consistency (Bardsley, 2002). The change in standards made it necessary for the chicken meat industry to invest in new odour measurements.

### *Instrumental analysis of odour chemistry*

Instrumental analysis techniques (e.g., with GC-MS and other mass spectrometry instruments) also advanced rapidly during this era, allowing researchers to more thoroughly explore the chemistry of poultry odour by identifying odorants and quantifying odorant concentrations. This opened new possibilities to develop knowledge based on how farming practices and odour mitigation strategies affect the formation and concentration of specific odorants, and therefore target the reduction of the most important odorants that may contribute to odour impacts. Improvements with instrumental analysis during this era included affordability, accessibility, reliability, and ease of operation. GC instruments could be more reliably paired with various detectors (MS, FID, SCD, NCD, ToF), and sample delivery techniques (HS, DHS, SPME, TD) (Stuetz, R., personal communication, 27 October 2018). Rapid improvements in computing power during this time were also important to enable processing of large chemical databases and advanced data processing (for example, the use of artificial neural networks).

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