Oral group medication in pig production: characterising medicated feed and drinking water systems

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ABSTRACT
Despite common use of oral group medication in pig rearing, the homogeneity, stability and carry-over of frequently used medicinal products in feed and drinking water are largely unknown. Therefore, a field study was performed on 52 Belgian pig farms, characterising preparation and administration of medicinal products via these systems, and farmers’ user experiences with medicated feed and medicated drinking water. The study showed that medicated drinking water is more commonly used than medicated feed, since 90.4 per cent of the farms sometimes use medicated drinking water and 69.2 per cent of the farms sometimes use medicated feed. The drinking water quality is evaluated at least once a year on only 30.7 per cent of the farms. Separate pipelines for medicated and non-medicated circuits were not present in any of the farms using medicated feed and in 27.7 per cent of the farms using medicated drinking water. With drinking water medication, 63.5 per cent of the farmers reported encountering practical problems, often related to solubility issues and precipitation of the active compounds. In contrast, medicated feed is bought ready-to-use from the feed manufacturer in 68.2 per cent of the cases, thus reducing the number of practical problems experienced by the farmer. This study shows room for improvement of oral group treatment, developing appropriate pharmaceutical formulations for drinking water medication, quality control of drinking water, using separate pipeline circuits, and cleaning and disinfecting protocols.

Introduction
Excessive and inappropriate use of antimicrobials in human and veterinary medicine has resulted in the emergence of resistant bacteria.1 2 The pig production sector is among the highest users of antimicrobials in intensive animal production, both in absolute values and in terms of treatment incidence.3–6 Oral administration of antimicrobials, by mixing medication into feed or drinking water, is the most frequently used administration route used in pig farms in Europe, where 91.2 per cent of the sold pharmaceutical formulations (milligram per population correction unit) are licensed for oral use.5 Oral group medication is often used because it is relatively easy to administer with less workload and with a decreased risk of needlestick injuries and drug residues present at the injection site, compared with parenteral therapy.7 Because of the threat of antimicrobial resistance, efforts are made to reduce the amount of antimicrobial drugs used in veterinary medicine, the number of animals treated and the duration of the treatment, resulting in a reduced use in the majority of the European countries.8

Feed medication can either be mixed in by the farmer or purchased from a feed mill with a licence to manufacture medicated feed. In the latter case, the formulation can be mixed in at the feed factory itself, or at the moment of delivery by a dosing system attached to the truck. When purchased from the feed factory, the concentration of the active compounds is checked by the feed manufacturer.9 At the farm, the medicated feed is stored in a silo before it passes through the

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feed pipelines and into the feeding troughs. If the formulation is mixed in by the farmer, this can be done by using a dosing system on the feed line, mixing a formulation into wet feed or strewing a formulation over the feed, the latter also known as top dressing.

Water medication involves the administration of medicinal products to the animals via the drinking water supply, by using suspensions or soluble powders. Medicated drinking water is always prepared at the farm, by mixing in a formulation in a small amount of water (a presolution), which is then added to a drinking water reservoir or to a bucket coupled to an electrical or mechanical dosing pump. The quality and characteristics of the drinking water are very important to keep the active compounds stable and homogeneously mixed, as well as ensuring sufficient water uptake. Drinking water quality depends on the source, filtration and water treatment (eg, acidification with organic acids to prevent infections by enteropathogenic bacteria), method of storage at the farm, water distribution pipelines (eg, pipeline materials, cleaning and disinfection protocol) and the surrounding environment. To prepare drinking water medication or feed medication, the bodyweight of the pigs and the drinking water/feeding uptake should be determined and taken into account.

When feed and/or water medications are used, several potential problems can arise. An example is the reduced palatability of medicated feed and drinking water, resulting in a reduced uptake of the medication by the treated animals. Moreover, clinically ill pigs tend to stop eating and drink less, also resulting in less uptake of the medication and considerable variability in exposure between animals. Also, cross-contamination of compound feed due to carry-over of remaining residues can occur, which may result in antimicrobial residues in animal products. The cleaning products and disinfectants could also interact with medicinal products used for drinking water medication (eg, olofoxacin and ornidazole can interact with cetyltrimethylammonium bromide, a quaternary ammonium surfactant). Other problems concern the potential carry-over of residues in feed and water, insufficient homogeneity and stability of the active compounds in water and feed, segregation/precipitation of the active compounds and feed/water at the farm (in the feeders/feed pipelines) which could result in clogging of different parts of the drinking water system, and issues of solubility of the drug in the drinking water. Moreover, the materials from which the pipelines are made of can interact with the active compounds and excipients present in feed/water medication or disinfectants. To prevent these problems, the active compounds should ideally be mixed homogeneously in the feed and drinking water, remain stable until the moment of ingestion, and their carry-over should be limited as much as possible. The identification and control of the factors influencing the homogeneity, stability and formation of residues are therefore crucial for the successful pharmacological treatment of pigs and the protection of public health. However, to identify these factors at the farm level, and to estimate the magnitude of their importance, the process of mixing-in medication at the farm needs to be understood and information needs to be collected on various aspects of use and preparation of medicated feed and drinking water. This information should cover the drinking water and feeding systems at pig farms, materials of pipelines, protocols for cleaning and disinfection, methods of mixing medication in feed and water, as well as pig farmers’ user experiences with the different types of medication.

To the authors’ knowledge, this information is currently not available in public literature. Therefore, the aim of this study is to investigate the use of medicated feed and medicated drinking water in pig farming and the problems that might be associated with it.

**Materials and methods**

**Farm selection**

Farms were included through the herd veterinarians, who were contacted via the Belgian branch of the International Pig Veterinary Society. First, an email was sent (n=67) followed by a phone call to explain the study objectives and to verify the veterinarian’s willingness to participate. Veterinarians who were willing to collaborate were accompanied during their planned routine farm visits. The farms were randomly selected and not specifically for the purpose of this study. When arriving on a farm, the purpose of the study was explained to the pig farmer and agreement to collaborate was requested. It was emphasised that questionnaires would be processed anonymously. The interview was combined with a visit of the pig stables. All visits and interviews were conducted between February and October 2017.

**Questionnaire**

On the selected farms, a questionnaire containing 12 open-ended and 34 closed questions was conducted. The questionnaire was divided into eight sections: (1) general farm information; (2) construction of the feeding/drinking water systems; (3) drinking water purification, water quality control and acidification; (4) cleaning and disinfection in case no treatment is given; (5) group treatment via feed and drinking water with respect to production categories, use of combination treatment, size of treated group and presence of separate pipelines; (6) preparation of feed and water medication; (7) cleaning and disinfection before and after medication; and finally (8) the farmer’s experience with ease of use and practical problems with drinking water/feed medication, as well as their perception about the efficacy of treatment. A pretest was conducted on four farms to assess the clarity and consistency of the
Table 1  Descriptive statistics for the pig farms participating in the field study

<table>
<thead>
<tr>
<th>Pig production stage</th>
<th>Number of farms keeping pigs in each production stage</th>
<th>Number of pigs in a production stage in all types of farms keeping pigs in this production stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Median</td>
</tr>
<tr>
<td>Sows</td>
<td>20</td>
<td>315</td>
</tr>
<tr>
<td>Piglets</td>
<td>16</td>
<td>1156</td>
</tr>
<tr>
<td>Fattening pigs</td>
<td>44</td>
<td>1866</td>
</tr>
<tr>
<td>Total number of farms</td>
<td>52</td>
<td></td>
</tr>
</tbody>
</table>

Note: For presentation purposes, the mean values of the number of pigs are rounded.
*Eleven of these farms are closed farms keeping pigs of all three production stages.

questions. The full questionnaire (in Dutch and French) is available upon request.

Data processing and analysis
All information from the survey, coded numerically to assist analysis, was entered into Microsoft Excel 2010 and recoded into categorical data for further analysis in SPSS 24.0 (SPSS, Chicago, Illinois). Descriptive statistics were obtained. To compare the mean ranks of farmers’ perception about the efficacy of treatment via medicated feed and drinking water, a Mann-Whitney U test was performed.

Results
Eleven out of 67 veterinarians expressed their willingness to participate in the study, corresponding to a response rate of 16.42 per cent. Together with these veterinarians, 52 pig farms were visited. All of them agreed to collaborate in the study.

General farm information
The number of animals per farm type and per age category present is represented in table 1. In total, the farms housed 106,666 pigs, which corresponds to 1.73 per cent of the number of pigs in Belgium.23

Construction of feeding/drinking water system
Source/type of water/feed used per production category
The type of feed and drinking water that was used per production stage is shown in table 2. Feed types used on the pig farms were pellets, mash feed, wet/dry feed where the pigs mix their mash with drinking water, and crumbs. Well water, the most often used source of drinking water in all three production categories, originated from a well with a borehole between 13 metres and 245 metres deep, depending on the geographical location (data not shown).

Age of the oldest part of the feed and water supply
The oldest part of the feed supply system (eg, silo, piping, feeding troughs) and drinking water supply system (eg, water source, water reservoir, piping, nipples and drinking troughs) is presented in figure 1. If the age was more than 30 years, a specific number of years could often not be given by the farmer. Also, one farmer had no idea about the age of his farm. Consequently, the age is presented with the use of age categories.

Presence of a water consumption metre and composition of feed/water pipelines
Pipelines were often composed of different materials, as seen in table 3. Pipelines for transporting feed consisted of a combination of two materials on 30 farms. The majority of feed pipelines were made of PVC or polyvinyl chloride (n=46), followed by stainless steel (n=19), galvanised iron (n=11), iron (n=5) and tylene (n=1). Drinking water pipelines were made of more than one material on 21 farms. PVC (n=44) and stainless steel (n=17) were the most commonly used materials, while iron (n=6), galvanised iron (n=4) and tylene (n=1) were less common.

Drinking water purification, quality control and acidification
In 26 farms, no purification of the drinking water was performed. Six farms used a combination of measures. The data regarding the purification, acidification and quality control of drinking water are presented in table 4. Both the frequency and location of water sampling were surveyed.
Cleaning and disinfection when no treatment is given
The data concerning cleaning and disinfection protocol (ie, frequency and products used), when no medicated feed or medicated drinking water are used, are presented in table 5. Different products were used on the 43 farms that did perform cleaning and disinfection of (different components of) the feeding system. On eight farms, more than one product was used. In most of the cases, the products used were unknown to the farmer (n=32). If the silo was cleaned (n=18), an antifungal agent was used. The feed pipelines were never cleaned or disinfected. On farms that did perform cleaning and disinfection of the drinking water system (n=32), more than one product was used in four cases.

Group treatment via feed/drinking water
Production categories that receive medicated feed/medicated drinking water
Medicated feed was used on 69.2 per cent of the farms (n=36). It was most often used for piglets (75.0 per cent, n=12), followed by sow (65.0 per cent, n=13) and fattening pigs (59.1 per cent, n=26). Medications were administered to pigs via water in 90.4 per cent of the farms (n=47). This method was often used for fattening pigs (90.9 per cent, n=40) and piglets (87.5 per cent, n=14), and less in sows (40.0 per cent, n=8). In this data set, 32 farms used both medicated feed and medicated drinking water (61.5 per cent).

Table 3 Composition of feed and water pipelines on the visited farms (n=52), per production category, expressed as percentage

<table>
<thead>
<tr>
<th>Pipeline materials</th>
<th>Feed Sows</th>
<th>Feed Piglets</th>
<th>Feed Fattening pigs</th>
<th>Water Sows</th>
<th>Water Piglets</th>
<th>Water Fattening pigs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td>7.4</td>
<td>4.8</td>
<td>6.6</td>
<td>7.1</td>
<td>4.8</td>
<td>7.3</td>
</tr>
<tr>
<td>Galvanised iron</td>
<td>25.9</td>
<td>28.6</td>
<td>14.8</td>
<td>14.3</td>
<td>9.5</td>
<td>5.5</td>
</tr>
<tr>
<td>Polyvinyl chloride</td>
<td>51.9</td>
<td>47.6</td>
<td>63.9</td>
<td>53.6</td>
<td>61.9</td>
<td>58.2</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>14.8</td>
<td>14.3</td>
<td>13.1</td>
<td>21.4</td>
<td>19.0</td>
<td>25.5</td>
</tr>
<tr>
<td>Steel with enamel coating</td>
<td>0.0</td>
<td>4.8</td>
<td>1.5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Other</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>3.6</td>
<td>4.8</td>
<td>3.6</td>
</tr>
</tbody>
</table>

Use of combination treatment
In three farms using medicated feed, combinations of medicinal products in feed (doxycycline-sodium salicylate and doxycycline-trimethoprim-sulphonamides) were used (8.3 per cent). In farms using medicated drinking water (n=47), combination treatment was used on 13 farms (27.7 per cent), in various combinations and often more than one combination was used per farm (n=24). The most common combination for drinking water medication was amoxicillin and sodium salicylate (21.3 per cent, n=10). Also, combinations of amoxicillin, trimethoprim and sulphonamides (4.3 per cent, n=2), amoxicillin and colistin (4.3 per cent, n=2), doxycycline and sodium salicylate (2.1 per cent, n=1), doxycycline and tylosin (2.1 per cent, n=1), and amoxicillin and doxycycline (2.1 per cent, n=1) were used.

Group size treated when receiving medicated feed/medicated drinking water
Treatment can be given per stable, per compartment, per pen or individually. The smallest group of animals, per production category, that could possibly receive medicated feed/medicated drinking water when a treatment is installed is presented in table 6. For example, in 46.2 per cent of the farms, it is possible to treat sows individually, whereas on other farms keeping sows they can be treated per pen (23.1 per cent), per compartment (7.7 per cent) or per stable (23.1 per cent).
Table 5  Frequency and products used for cleaning and disinfection, in case no medication is added to feed/drinking water, expressed as percentage

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Silo</th>
<th>Feeding pipelines</th>
<th>Feeding troughs</th>
<th>Water tank</th>
<th>Water pipelines</th>
<th>Drinking troughs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Never</td>
<td>65.4</td>
<td>100.0</td>
<td>26.9</td>
<td>66.7</td>
<td>44.2</td>
<td>42.3</td>
</tr>
<tr>
<td>At end of production cycle</td>
<td>0.0</td>
<td>0.0</td>
<td>51.8</td>
<td>0.0</td>
<td>17.3</td>
<td>46.2</td>
</tr>
<tr>
<td>After weaning</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Once every two years or</td>
<td>19.2</td>
<td>0.0</td>
<td>3.8</td>
<td>0.0</td>
<td>5.8</td>
<td>3.8</td>
</tr>
<tr>
<td>once per year</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Twice a year</td>
<td>13.5</td>
<td>0.0</td>
<td>0.0</td>
<td>16.7</td>
<td>3.8</td>
<td>5.8</td>
</tr>
<tr>
<td>3–6 times a year</td>
<td>1.9</td>
<td>0.0</td>
<td>1.9</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>6–12 times a year</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>3.8</td>
<td>1.9</td>
</tr>
<tr>
<td>Permanently</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>8.3</td>
<td>23.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Only when problems occur</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>8.3</td>
<td>1.9</td>
<td>0.0</td>
</tr>
<tr>
<td>Frequency unknown</td>
<td>0.0</td>
<td>0.0</td>
<td>3.8</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Products used</th>
<th>Feed</th>
<th>Drinking water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unknown</td>
<td>62.7</td>
<td>25.0</td>
</tr>
<tr>
<td>Antifungal</td>
<td>17.6</td>
<td>0.0</td>
</tr>
<tr>
<td>Quaternary ammonium</td>
<td>9.8</td>
<td>0.0</td>
</tr>
<tr>
<td>derivatives</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organic acids</td>
<td>5.9</td>
<td>0.0</td>
</tr>
<tr>
<td>Hydrogen peroxide</td>
<td>3.9</td>
<td>44.4</td>
</tr>
<tr>
<td>Sodium chloride and</td>
<td>0.0</td>
<td>16.7</td>
</tr>
<tr>
<td>sodium bisulphate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorine dioxide</td>
<td>0.0</td>
<td>11.1</td>
</tr>
<tr>
<td>Glutaraldehyde</td>
<td>0.0</td>
<td>2.8</td>
</tr>
</tbody>
</table>

Presence of separate pipelines for medicated and non-medicated feed and water
None of the farms administering medication via feed (n=36) had a separate pipeline for medicated and non-medicated feed. In farms using water medication, 27.7 per cent (n=13) of the farms did have separate pipelines.

Preparation of feed and water medication
Protocol for mixing the formulation in feed/drinking water
The method of preparation of medicated feed/medicated drinking water is shown in figure 2. Medicated feed, which was used on 36 farms, was purchased from the feed manufacturer in 68.2 per cent of the cases (n=30) and was prepared at the farm on 14 farms. On the latter farms, this was mostly done by top dressing (25.0 per cent; n=11, of which 10 farms use this for sows). On these 11 farms, the desired amount of the formulation was taken with a measuring scale (n=6) or a measuring cup (n=5). A dosing device on the feed line was used on three farms (6.8 per cent), where a measuring scale (n=2) or a measuring cup (n=1) was used to add the formulation into the dosing device.

Concerning the device for preparation and distribution of medicated drinking water, 52 answers were received for the 47 farms using water medication, as some farms used more than one device. A mechanical dosing pump was most often used (51.9 per cent, n=27), followed by an electric dosing pump (30.8 per cent, n=16). Alternatively, a drinking water reservoir, located at the compartment (11.5 per cent, n=6) or at the water source (5.8 per cent, n=3), was used. To prepare medicated drinking water, a presolution was made on 46 of the 47 farms. In most farms, the presolution was mixed in cold water (55.3 per cent, n=26), while in others the presolution was mixed in (luke)warm water (36.2 per cent, n=17). In fewer farms (6.4 per cent, n=3), the presolution was mixed in water with a temperature according to the leaflet’s instructions. One farm reported not to make a presolution, adding the formulation directly into the drinking water tank (2.1 per cent). A measuring scale was most often used (75.0 per cent, n=39) to take the required amount of the formulation, 10 farmers used a measuring cup (21.3 per cent), and three of them estimated on sight (6.4 per cent).

Use of additives to enhance the solubility
When drinking water was prepared, 53.2 per cent of the farmers reported using a solubility enhancer when using certain formulations. In most cases it was sodium carbonate combined with amoxicillin (42.9 per cent, n=21), and in a few cases it was Huvesol (maltodextrin, sodium carbonate, lactose and vitamin
Frequency of using certain methods to prepare medicated feed/medicated drinking water, expressed as percentage and number of farmers (n).

C) with florfenicol (6.1 per cent, n=3). In two cases (4.1 per cent), sodium carbonate was used together with an unknown antibiotic, and in one case (2.0 per cent) an unknown product with unknown medication was used as solubility enhancer. All farms using water medication (n=47) reported that they stirred or mixed as long as the manufacturer indicated on the leaflet.

Frequency of preparing and administering medicated feed/medicated drinking water

When medicated feed was prepared at the farm (n=14), it was prepared once or twice a day in most of these farms (92.9 per cent, n=13) or when the formulation in the dosing device was finished (7.1 per cent, n=1). Medicated feed was mainly administered throughout the day (77.8 per cent, n=28). In fewer cases (22.2 per cent, n=8), it was administered for a few hours a day.

Water medication was mostly prepared once a day (63.8 per cent, n=30). In other farms, it was prepared once a day for every active compound, except for amoxicillin which was prepared twice a day (19.1 per cent, n=9), when the presolution was finished (8.5 per cent, n=4), twice a day for every compound including amoxicillin (6.4 per cent, n=3), or every four to six hours, depending on the need (2.1 per cent, n=1). In the majority of cases (70.8 per cent, n=34), water medication was administered throughout the day, while in some cases (27.1 per cent, n=13) it was used for several hours during the day.

Maintenance and calibration of the dosing device

Dosing devices on the feed line (n=3) were not calibrated or maintained by the manufacturer. The majority of the farms using water medication did not generally perform pump maintenance or calibration, unless a problem arose (78.7 per cent, n=37). On the contrary, some farms performed pump maintenance and calibration once a year (14.9 per cent, n=7), twice a year (2.1 per cent, n=1) or three times a year (2.1 per cent, n=1). One farm maintained and calibrated the electric pump, but never the mechanical one (2.1 per cent).

Use of gloves and/or mask when preparing medicated feed/medicated drinking water

When medicated feed was prepared at the farm (n=14), gloves were used by three farmers (21.4 per cent) and masks by five farmers (35.7 per cent). When preparing medicated drinking water (n=47), gloves were used by 29.8 per cent (n=14) of the farmers and masks were used by 31.9 per cent (n=15).

Cleaning and disinfection before and after medication

Frequency of cleaning and disinfection of the pipelines before and after treatment

The vast majority of farms using medicated feed did not clean the pipelines before (91.7 per cent, n=33) or after (94.4 per cent, n=34) the use of this feed. For water medication this was 70.2 per cent (n=33) and 48.9 per cent (n=23), respectively.

Cleaning of the tools used to prepare medicated feed/medicated drinking water

In 71.4 per cent (n=10) of farms preparing medicated feed at the farm, the tools used to make this feed were never cleaned afterwards. Only two farms always cleaned them and two farms sometimes did. On the contrary, at the farms where water medication was used, the used tools were always cleaned in 70.2 per cent of cases (n=33), while these tools were sometimes cleaned in 19.1 per cent (n=9) and never cleaned in 10.6 per cent (n=5) of them.

Cease of drinking water disinfection when medicated drinking water is used

At the farms where water medication was used, in the majority of cases (53.2 per cent, n=25) no water disinfection was performed. In the farms that did so (n=22), 16 of them stopped the water disinfection when water medication was used (72.7 per cent), while six farms (27.3 per cent) did not stop water disinfection.

Farmers’ experience with feed/drinking water medication

Ease of use and practical problems

The majority of the farmers reported no problems regarding the ease of use of medicated feed (89.2 per cent, n=25) and medicated drinking water (80.0 per cent, n=36). Six farmers preferred medicated feed over medicated drinking water because of a lesser workload and medicated feed being more easy to use.

Figures 3 and 4 show the main practical problems farmers encountered when using medicated feed and medicated drinking water. Twenty-two out of the 30 farmers (73.3 per cent) who used medicated feed reported to encounter no practical problems during the therapy with medicated feed. No practical problems
were reported by 19 farmers (36.5 per cent) regarding the therapy with medicated drinking water.

Further issues involved the responsible person forgetting to switch off the water disinfection before administration of water medication (3.8 per cent, n=2), forgetting to switch off the faucets from normal to medicated water (1.9 per cent, n=1) or accidentally adding feed medication in water (1.9 per cent, n=1). The necessary rinsing of the pump (3.8 per cent, n=2), difficulty of cleaning a large reservoir (1.9 per cent, n=1) and lack of infrastructure allowing the treatment of more than one stable at once (1.9 per cent, n=1) were also reported as practical issues during therapy with medicated drinking water.

Efficacy of treatment

Most farmers who have been using feed medicated with antimicrobials found the treatment to be very effective (55.0 per cent, n=11) or reasonably effective (25.0 per cent, n=5), in contrast to few of them who reported regular relapse (5.0 per cent, n=1) or no improvement at all (5.0 per cent, n=1). When using drinking water with antimicrobials, most farmers reported that the treatment administered via this route was very effective (50.0 per cent, n=23) or reasonably effective (28.3 per cent, n=13). Regular relapse (10.9 per cent) was seen on five farms. The mean ranks of farmers’ perceptions about the efficacy of treatment with medicated feed and medicated drinking water were equal (P=0.657 and z=−0.445).

Preference of a certain type of medication

An equal number of farmers had a preference for feed and water medication (15.4 per cent, n=8). Feed medication was preferred because of the low workload and water medication because ill pigs tend to drink longer than they eat, according to the farmers. Five farmers (9.6 per cent) preferred injectables over oral medication because the dose is delivered even when the pigs are too sick to eat or drink. Fourteen farmers stated not to have a preference (26.9 per cent), and there were three farmers who mentioned they leave the decision to the veterinarian (5.8 per cent). Three farmers stated they would prefer medicated feed, but that it is prohibited by the quality label they adhere to (5.8 per cent).

Discussion

Limiting the use of antimicrobial drugs, by reducing the number of treatments and the number of animals treated, is key to preserve the efficacy of antibiotics. If antimicrobial use is necessary, a targeted pharmacological treatment that follows the best clinical practice methods should be provided. If an oral group treatment is applied, then keeping medicated feed and medicated drinking water homogeneously mixed and stable, while limiting residue formation, is crucial. The homogeneity, stability and residue formation are suspected to be largely influenced by the protocols used to prepare, store and administer at the farm level. To evaluate these protocols, 52 Belgian pig farms were visited. These pig farms did not cover the entire pig farming industry; however, they are considered a good representation of industrial pig farming.

The results showed that the composition of the feeding and drinking water system varied widely, with the oldest parts of the feed and drinking water system being more than 30 years old in almost half of the farms. Water purification was only performed on half of the farms. However, because the drinking water quality at the visited farms was unknown, it was not clear if additional water purification would be recommended. A yearly evaluation of the drinking water quality should be advocated, but this was only the case in 31 per cent of the farms. This was also reported by Backhans et al., where only 30 out of 60 farms in Sweden performed a yearly drinking water control.

The present study revealed that all the farms used medicated feed and/or medicated drinking water, and
62 per cent of the farmers even used both. Medicated feed was most often used in piglets, followed by sows and fattening pigs. In previous studies, it was found that antimicrobials are mainly consumed by pigs from weaning (at four weeks old) to the start of finishing (at nine weeks old),\(^{27,28}\) and that resistance was less common in finisher pigs compared with piglets.\(^{29}\) It is therefore important to focus on good practices concerning the antimicrobial use in the weaners, for example, to make further efforts to ban prophylactic use for this age category. Medicated feed was most frequently bought from the feed manufacturer. A dosing device on the feed line was rarely used in this study, probably because it is prohibited for some quality labels. Most of the time, the formulation was already mixed in the feed when it was stored at the silo. Because the silo was often used to feed an entire pig stable, the whole stable was indeed often treated at the same time, thus exposing large groups of pigs to antimicrobial drugs at once. In contrast, medicated feed was sometimes used to treat individual sows via top dressing, in spite of the fact that this was off-label use, since there are no antimicrobial formulations registered for this administration route in Belgium.\(^{30}\)

On the other hand, medicated drinking water was most often used in fattening pigs. When treated with medicated drinking water, generally a smaller group of animals (at compartment level) were treated compared with medicated feed. Hence, the exposure to antimicrobial drugs and consequently the risk of resistance development after using medicated drinking water would be smaller than after using medicated feed.

Separate pipelines for medicated feed and non-medicated feed are recommended; however, this was not seen on farms using medicated feed and in less than a third of the farms using medicated drinking water. Cleaning and disinfecting before and after treatment were not done by the vast majority using medicated feed and/or by the majority using medicated drinking water, enhancing the risk of spreading drug residues downstream the pipelines. When the silo was cleaned, this was performed with an antifungal agent to prevent contamination with mycotoxins, and consequently not with the purpose of removing drug residues. Residues of antimicrobial drugs can be distributed from the silo to the feed pipelines and the troughs, potentially leading to antimicrobial drug resistance selection.\(^{31}\)

Medicated drinking water was prepared at least daily, in contrast to feed medication that has been stored in the silo for several days. Remarkably, dosing devices/pumps were rarely calibrated or given maintenance as long as they seemed to work properly. Personal safety measures such as mask and gloves were worn by less than a third of the farmers, thus increasing the exposure of most farmers to antimicrobial drugs. When medicated drinking water was used, the water disinfection was not stopped in about a quarter of the farms using water disinfection. This could possibly lead to interactions between the disinfectant and medicated drinking water.\(^{18}\) Medicated feed and medicated drinking water were both regarded as easy to use, although for medicated drinking water more remarks were made with respect to an increased workload when using it. This is most likely due to the fact that medicated feed is mostly bought ready-to-use. A possible consequence is that veterinarians might prescribe medicated feed over medicated drinking water, to have a greater chance at therapy compliance. Also, most farmers did mention more practical problems when executing the therapy with medicated drinking water than with medicated feed, often related to solubility problems and precipitation, resulting in clogging of different parts of the drinking water system. This was also reported by Hémonic et al,\(^{32}\) where the homogeneity of oxytetracycline in a drinking water tank with and without stirring device was compared. In the present study, 53 per cent of the farmers make use of solubility enhancers when preparing medicated drinking water. This could indicate that extra efforts are required by the pharmaceutical industry to develop appropriate formulations for administration with dosing pumps on the water pipelines, especially since dosing pumps are generally set at 0.5–2 per cent. Hence, a presolution is often 100 times more concentrated than the therapeutic dose, posing a real challenge for formulations to be sufficiently water-soluble.\(^{36}\) Also, a better training of the farmers in using medicated drinking water, and a more frequent monitoring and if needed improvement of the drinking water quality, could also result in a reduced need of solubility enhancers.

In conclusion, this study gives a first insight into the use of feed and water medication at the farm level. Although in-feed and drinking water medications are common practice, the protocols used and compositions of the feed and drinking water systems vary widely. The influence of these systems on homogeneity and stability of antimicrobials up to the moment of intake and residues thereof will be further investigated in follow-up studies. When antimicrobial use is necessary, it should be applied with the best clinical practices. These best practices should include the banning of prophylactic antimicrobial use (obligatory in Europe by 2022\(^{35}\)).
limiting the number of animals treated, developing suitable pharmaceutical formulations facing the challenges of use in dosing pumps for drinking water medication, controlling the drinking water quality, the use of separate pipelines for medicated and non-medicated feed and drinking water, and thorough cleaning and disinfecting protocols.

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Competing interests

None declared.

Data availability statement

Data are available upon request.

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