Evaluation of biosecurity practices in smallholder pig production systems in Midvaal Local Municipality, Gauteng Province

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Abstract
Prevention and control of diseases should be prioritized to boost production efficiency and avert the collapse of pig enterprises. The application of biosecurity measures encompasses all aspects of preventing pathogens from entering and spreading within a population of animals. The objectives of the study were to appraise the adoption level of biosecurity practices in a smallholder pig production system and determine the variables associated with them. A sample of 57 pig enterprises was randomly selected and a pre-tested structured questionnaire was deployed to gather data. The adoption level (AL) of biosecurity measures was used to quantify the extent of biosecurity practices. An AL <50% was defined as a low level of biosecurity practices, whereas AL ≥50% was a high level. Descriptive statistics, nonparametric test and a classification tree model were used to analyze the data. The results revealed that 59.6% of pig enterprises had a low level, while 40.4% had a high level of adoption of biosecurity practices. There was a significant association between gender, age, and pig production training with biosecurity levels. The predictive tree model identified age, pig management training, farming status and age as the best predictors of response variables. There was also a significant association between some biosecurity measures and the level of biosecurity. The predictive tree model further singled out the isolation area, production and health records, and footbath as the best predictors of response variables. An inference based on the results was that the risks of disease outbreaks were high in the study area.

Keywords: Adoption level, Biosecurity score, Disease prevention, Odds ratio, Predictive tree
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Introduction
Pig production is an important component of the livestock sector contributing significantly to food security and economic development, particularly in communities where pig meat is not associated with religious taboos. Its meat offers a good source of animal-based protein and revenue (Majunder *et al.,* 2020), primarily in rural regions of developing countries. Furthermore, pigs have high fertility and prolificacy, good mothering ability, improved feed conversion efficiency, rapid growth rate, early sexual maturity, a short generation interval and a high dressing percentage (Rajesh *et al.*, 2019; Majunder *et al.*, 2020). However, poor production management and inadequate control of diseases are some of the limiting factors compromising their production potential in a smallholder system.

As a result, achieving efficient production, high-quality products and optimizing economic returns is critical while not compromising animal welfare or environmental concerns (Solà-Oriol & Gasa 2017). Pigs on the other hand, are vulnerable to a wide range of endemic and epidemic diseases, including zoonotic infections, which can have a negative impact on health, welfare, and productivity, as well as have a direct economic impact (Dewulf *et al.*, 2019). They become infected through direct contact with infected animals, eating virus-contaminated meat, or physical contact with people and vehicles (Mutua *et al.*, 2020).

Disease outbreaks not only have a negative impact on animal health, but they also put a strain on the profitability and sustainability of pig enterprises. The prevention and control of diseases should be prioritized to boost production efficiency and avert the collapse of pig enterprises. Thus, implementation of biosecurity measures is critical in pig production to help reduce the transmission of diseases (Dewulf *et al.*, 2019; Ojabo & Enya 2020; Alarcón *et al*., 2021).

Biosecurity was defined as a set of practices or measures applied to reduce the introduction and further spread of infectious agents in a pig farm (Silva *et al.*, 2018; Alarcón *et al.*, 2021). Biosecurity measures are further classified as external or internal measures.

External biosecurity measures are actions taken to prevent disease introduction or entry into the pig farm, whereas internal biosecurity measures are control measures implemented to prevent disease transmission within the herds (Niemi *et al.*, 2016; Dewulf *et al.*, 2019).

According to Postma *et al*. (2016), the biosecurity level of a herd can be assessed by cross-examining the farmer about biosecurity activities and visual inspection. There is therefore a scarcity of data on the level of biosecurity practices in a smallholder pig production system in the study area. Therefore, without baseline data, it is impossible to develop biosecurity plans and minimize the risk of disease outbreaks. Disease prevention is essential for the wellbeing of animals, food safety, public health, and economic productivity (Alarcón *et al*., 2021). Thus, the current study endeavored to quantify and qualify the adoption level of biosecurity measures and identify the variables associated with the level of biosecurity. It was hypothesised that biosecurity measures were widely adopted among smallholder pig producers in the study area.

Materials and methods

The study was conducted in the Midvaal Local Municipality (26.5837° S, 28.0654° E) within the Sedibeng District Municipality of Gauteng Province in the Republic of South Africa. Selection of the study area was based on the willingness of the smallholder pig farmers to participate, access to the smallholder pig farmer's database and the population density of pigs in the area.

To minimize the sample error, a database of smallholder pig producers was obtained from the Gauteng Department of Agriculture and Rural Development (GDARD) and was adopted as a population unit of the study. A total of 57 pig enterprises were randomly selected and inactive registered pig enterprises in the database were excluded from being chosen. A structured questionnaire was developed to gather information in accordance with the objectives of this investigation. Prior to data collection, the questionnaire was pre-tested on seven smallholder pig farmers who were not part of the study, which constituted 12.3% of the sample size of the current study to improve the quality of the questionnaire.

To assess the level of biosecurity, fifteen (15) biosecurity measures were used: biosecurity plan, record keeping, availability of an isolation area, washing and disinfecting of equipment and pig units, farm fence, pig unit fence, presence of a foot bath, visiting pig farms, mixing of different age groups, application of a vaccination program, regular removal of manure and litter, access of birds and rats in a feed store room and pig unit, swill feeding, and sharing of a boar.

The adoption level (AL) of biosecurity measures for each pig enterprise was used to determine the biosecurity levels. Pig enterprises with an AL <50% were classified as having low biosecurity practices (LB), while those with an AL ≥50% were recorded as having high biosecurity practices (HB). The biosecurity level was adopted as a binary response variable, denoted as LB (0) and HB (1). The responses to biosecurity measures were coded as Yes (1) and No (0).

The adoption level of biosecurity measures was computed as follows:

$$\text{Adoption level} = \frac{\text{Number of biosecurity measures implemented}}{\text{Total number of biosecurity measures observed}} \text{ x } 100$$

Data collected were analyzed using descriptive statistics, nonparametric test and predictive or classification tree model. Descriptive techniques were used to condense the data, so it was manageable and present the results clearly through tables and numerical descriptors. A nonparametric test known as Pearson's Chi-square test (χ^2) was deployed to determine the association between socioeconomic characteristics, biosecurity measures and biosecurity levels. The odds ratio (OR) was applied to measure the likelihood of pig farmers to adopt biosecurity practices within the 95% confidence interval (CI).

The Chi-square Automatic Interaction Detector (CHAID) algorithm was employed to construct a predictive or classification tree model, to establish how socioeconomic characteristics and biosecurity measures link to the outcome (biosecurity levels). The socio-economic characteristics were classified as described in Table 1.

Table 1 Description of socioeconomic characteristics

Variable	Categories	Coding
Gender	Female	0
	Male	1
Age	<40	0
	>40	1
Education	Secondary	0
	Tertiary	1
Farming experience	<10	0
	>10	1
Pig production training	No	0
	Yes	1
Farming status	Part-time farmer	0
	Full-time farmer	1

Results and discussion

The impact of socio-economic status on the likelihood of adopting biosecurity practices is presented in Table 2. The results showed that 42.1% of the participants were female and their male counterparts accounted for 57.9%. There was an association (*P* <0.05) between gender and biosecurity level. Female pig producers were found to be more likely (OR = 0.3; $CI_{95\%}$ = 0.088 - 0.818) to implement biosecurity measures. The likelihood of male pig producers not observing biosecurity measures was 3.7 times higher. In addition, an association (*P* <0.001) between age and biosecurity level was observed. Therefore, the odds of pig producers <40 years old not adhering to biosecurity measures were 0.09 times lower in comparison to those who were >40 years old. In view of that, pig producers >40 years of age were 11.6 times more likely to not implement biosecurity measures.

No association (*P* >0.05) was detected between education and biosecurity levels. The odds of not complying with biosecurity practices when holding secondary education were 2.2 times higher. Postulating that those with tertiary education were less likely (0.447) to not conform to biosecurity protocols. Similarly, no association (*P* >0.05) was noticed between farming experience and the level of biosecurity. Pig producers having <10 years of pig farming experience had a better chance (OR = 0.7; $CI_{95\%}$ = 0.20 - 2.08) of following biosecurity procedures. Smallholder pig farmers with more than 10 years of experience were 1.5 times more likely to not fully implement biosecurity measures.

There was an association (*P* <0.05) between pig management training and biosecurity level. Pig producers who did not attend training were 3.0 times more likely to not observe biosecurity measures. The prospects of not complying were lower (0.03) for those who attended training. The study found that 15.8% of pig producers were part-time pig farmers. However, no association (*P* >0.05) was detected between farming status and biosecurity level. Part-time pig producers were 1.4 times more likely to not implement biosecurity practices. That meant the likelihood of full-time pig producers not observing the biosecurity protocols was low (0.7).

Table 2 The impact of socio-economic status on the likelihood of adopting biosecurity practices (N = 57)

Variables	**Categories**	**Proportion (%)**		χ^2	**Odds Ratio**	**95% Confidence interval**	**P-Value**
		Low	High				
Gender	Female	17.5	24.6	5.569	0.3	0.088 - 0.818	0.018
	Male	42.1	15.8				
Age	<40	7.0	24.6	15.311	0.1	0.022 - 0.327	0.000
	>40	52.6	15.8				
Education	Secondary	26.3	10.5	1.917	2.2	0.708 - 7.070	0.166
	Tertiary	33.3	29.8				
Farming experience	<10	38.6	29.8	0.538	0.7	0.202 - 2.078	0.463
	>10	21.1	10.5				
Pig production training	No	43.9	19.3	3.895	3.0	0.991 - 9.269	0.048
	Yes	15.8	21.1				
Farming status	Part time	10.5	5.3	0.219	1.4	0.319 - 6.402	0.640
	Full time	49.1	35.1				

The classification tree model (Figure 1) likewise demonstrated that there was an association between socio-economic characteristics and biosecurity level. The root of the tree (Node 0) showed that 59.6% of the pig producers observed had a low adoption of biosecurity measures, while 40.4% of them showed a high adoption. The model identified age (χ^2 = 15.311; P <0.001) as the first best predictor of biosecurity level. As a result, 68.4% of pig producers were found to be older than 40 years, of which 76.9% had low adoption of biosecurity measures, while 21% showed high adoption (Node 1). Those younger than 40 years old constituted 31.6%. Therefore, 22.2 and 77.8% demonstrated low and high adoption of biosecurity measures, respectively (Node 2).

Furthermore, pig management training (χ^2 = 3.933; P <0.05) was the second-best predictor for farmers older than 40 years. Therefore, 23.3% of those older than 40 years of age attended training. Consequently, 40% of them displayed high adoption even though 60% exhibited low adoption of biosecurity measures (Node 3). On the other hand, 42.1% of pig producers older than 40 years did not attend pig management training. Thus, 87.5% demonstrated low adoption compared to 12.5% that demonstrated high adoption of biosecurity measures (Node 4).

Farming status (χ^2 = 8.288; P <0.05) was the second-best predictor of biosecurity level for pig producers younger than 40 years old. Therefore, 24.6% of pig producers younger than 40 years old were full-time farmers. In that group, 92.9% maintained a high level of adoption, while 7.1% continued to take low-level biosecurity measures (Node 5). Moreover, 7% of pig producers younger than 40 years old were part-time farmers. Subsequently, 75% of them retained low adoption levels and 25% achieved high adoption of biosecurity measures (Node 6).

Ultimately, gender (χ^2 = 10.286; P <0.001) was recognized as the third best predictor of biosecurity level for pig producers who did not attend pig management training. There were 36.1% of male pig producers who did not attend pig management training, and 100% of them displayed low adoption of biosecurity measures (Node 7). Contrary to the 10.5% of female pig producers who did not attend pig management training, 50% of them sustained either low or high adoption of biosecurity practices (Node 8).

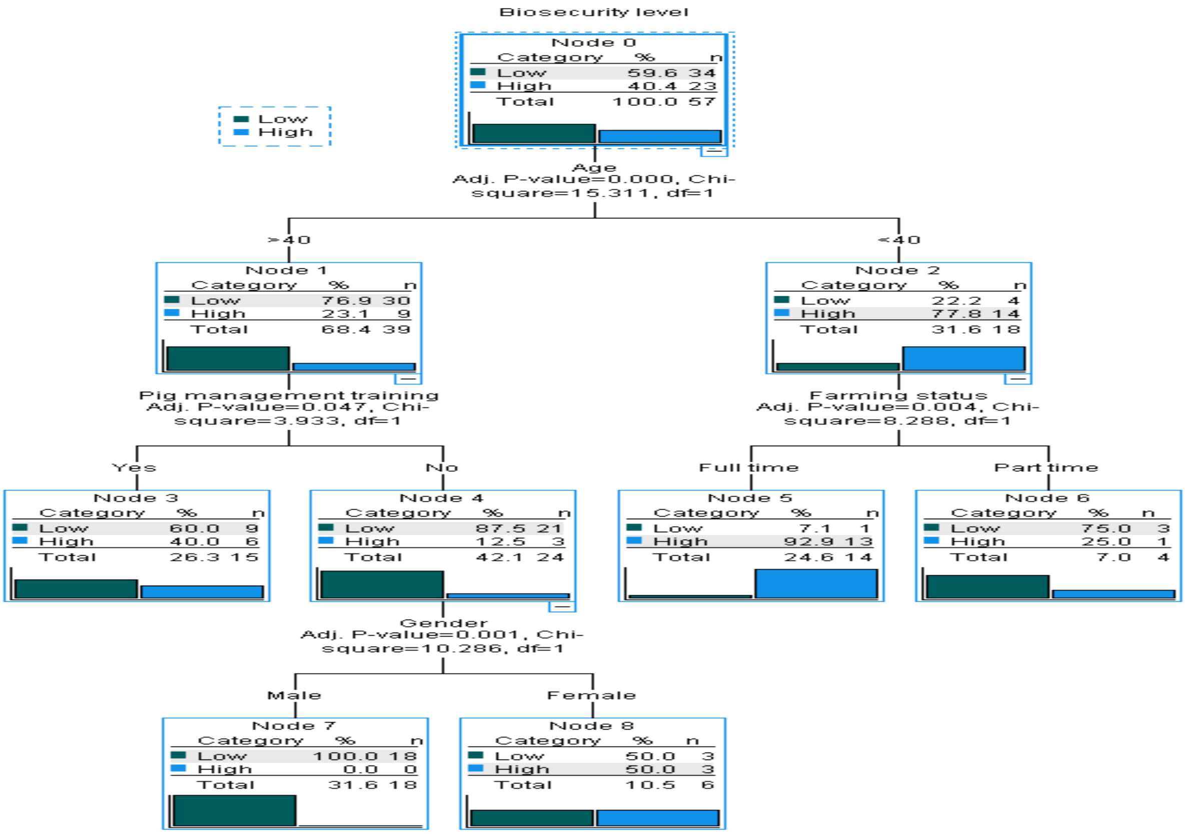

Figure 1 Classification tree of biosecurity level and socio-economic status of smallholder pig producers

Biosecurity encompasses all aspects of preventing pathogens from entering and spreading within a population of animals (Alarcón *et al.*, 2021). A total of 15 biosecurity variables (Table 3) were used to appraise the application of biosecurity practices in smallholder pig enterprises in the study area. The results revealed that only 14% of the observed pig enterprises had a biosecurity management plan. There was an association (P <0.05) between the biosecurity plan and the biosecurity level. Pig enterprises without a biosecurity plan were 5.6 times more likely to experience biosecurity risks. Indicating that those who had a biosecurity plan had a lower probability (0.2) of facing a biosecurity threat. In addition, most pig producers (54.4%) did not maintain production and health records, and a high association (P <0.001) with biosecurity level was observed. The pig enterprises that were not keeping records were 31.1 times more exposed to biosecurity threats. Postulating that those that kept production and health records were less (0.03) likely to experience biosecurity risk.

The study found that the bulk of pig enterprises (54.4%) did not have isolation areas for sick and purchased pigs. The association (P <0.001) between the isolation area and the biosecurity level was high. Therefore, the odds of pig enterprises not having an isolated area to experience biosecurity challenges were 49.0 times greater. Suggesting that the likelihood of pig enterprises having isolated areas being exposed to biosecurity peril was less (0.02). Moreover, 7.1% of pig producers were not regularly washing and disinfecting the equipment utilized in their operations. Even though no association (P >0.05) was detected, the pig enterprises where regular washing and disinfecting were not standardized were 2.1 times more prone to biosecurity challenges. This indicates that regular washing and disinfecting of equipment remains critical since pig enterprises practicing that had a 0.5 chance of experiencing biosecurity problems.

The study discovered that there were free movement of animals and people in most pig enterprises (82.4%). There was an association (*P* <0.01) between free movement and biosecurity level. Pig enterprises that restricted free movement were not at high risk of biosecurity complications (OR =0.1; $CI_{95\%}$ = 0.022 - 0.0620). Those enterprises authorizing free movement were 10 times more likely to suffer from biosecurity issues. On the other hand, it was found that 12.3% and 94.7% of the farms and pig production units were not fenced, respectively. However, no association (*P* >0.05) was realized between the fencing and the biosecurity level. Pig farms and pig production units that were not fenced were 4.7 and 3.1 times more vulnerable to biosecurity problems, respectively. Illustrating that fence is among the vital factors to combat the adversity of biosecurity encounters, pig farms and pig production units that were fenced had a 0.2 and 0.3 possibility of being exposed to biosecurity risk, respectively. Humans can act as mechanical vectors of disease to pigs and some animals can also transmit some diseases or pathogens to pigs (Kouam *et al*., 2020). The risk associated with free movement can be reduced by applying barricade measures and rules that restrict access to the farm (Alarcón *et al*., 2021).

According to the study, 70.1% of pig enterprises did not have footbaths at the entrances of their pig production units. A significant association between footbaths and biosecurity levels was discovered. Therefore, pig enterprises without a footbath were 30 times more exposed to biosecurity risk. That indicated those maintaining footbaths posed a lower (0.003) biosecurity hazard. Footbaths are necessary for footwear disinfection and should be replaced on a regular basis (Kouam *et al*., 2020). Most of the pig producers (87.7%) were found to be visiting other pig-producing farms. There was an association (*P* <0.01) observed between the farm visit and the biosecurity level. Pig producers who did not visit other pig enterprises were safe (OR = 0.1; $CI_{95\%}$ = 0.010 - 0.772) from biosecurity threats. Yet those who visited pig enterprises were 10 times more vulnerable to biosecurity risks. The study established that 81% of pig producers did not confine pigs of different age groups in the same pen. Nevertheless, no association (*P* >0.05) was observed between blending pigs of different age groups and the level of biosecurity. However, not blending pigs of different age groups curtailed (OR = 0.9; $CI_{95\%}$ = 0.186 - 4.060) biosecurity risk. However, noting that the odds ratio was closer to 1, that meant there were equal chances of either having or not having a biosecurity risk.

Pig producers adhering to the vaccination program constituted 57.9%. An association (*P* <0.01) was noticed between the vaccination programme and the level of biosecurity. Therefore, no application of the vaccination programme posed a high (OR = 5.2, $CI_{95\%}$ = 1.653 - 16.408) biosecurity risk. Yet, those implementing the vaccination program were 0.2 times less likely to experience biosecurity hazards. In addition, the study discovered that 26.4% of pig producers were not regularly removing manure and litter from their pig production units. However, there was no association (*P* >0.05) between manure and litter removals and biosecurity levels. Even so, pig enterprises that did not regularly remove manure and litter were 3.6 times more exposed to biosecurity threats. On the contrary, those who regularly removed manure and litter were 0.3 times less susceptible to biosecurity danger.

The birds and rats had access to the feed storage rooms of almost 91.2% of the pig enterprises in the present study. There was no association (*P* >0.05) detected between birds and rats' access and the level of biosecurity. However, pig enterprises where birds and rats had no access to the feed storage room had a lower (OR = 0.5; $CI_{95\%}$ = 0.064 - 2.715) biosecurity risk. On the other hand, where birds and rats accessed the feed storage room, those pig enterprises were 2 times more exposed to biosecurity threats. It was also established that 52.6% of pig producers were swill-feeding pigs. There was an association (*P* <0.05) between swill feeding and biosecurity level. Pig producers not swill feeding pigs reduced (OR = 0.3; $CI_{95\%}$ = 0.096 - 0.882) the biosecurity threat, whereas those swill feeding were 3.3 times more likely to experience biosecurity risk. Finally, the study revealed that 7.1% of pig producers were sharing a breeding boar with other pig producers. Nonetheless, no association (*P* >0.05) was noted between sharing a boar and the level of biosecurity. However, pig enterprises that did not share a boar were to a lesser extent exposed (OR = 0.5; $CI_{95\%}$ = 0.046 - 4.819) to biosecurity risk, whereas those sharing a boar were 2 times higher. Such conduct can increase the risk of disease transmission from one pig enterprise to another and lead to disease outbreaks.

Table 3 Biosecurity measures observed in smallholder pig production system

Biosecurity measures	Response	Proportion (%)		χ^2	Odds ratio	95% Confidence interval	P-value
		Low	High				
Biosecurity plan	No	56.1	29.8	4.642	5.6	1.026 - 31.066	0.031
	Yes	3.5	10.5				
Records	No	49.1	5.3	26.566	31.1	6.942 - 139.430	0.000
	Yes	10.5	35.1				
Isolation area	No	49.1	3.5	29.856	49.0	8.975 - 267.521	0.000
	Yes	10.5	36.8				
Wash and disinfect	No	5.3	1.8	0.421	2.1	0.208 - 21.843	0.516
	Yes	54.4	38.6				
Free movement	No	3.5	14.0	7.921	0.1	0.022 - 0.620	0.005
	Yes	56.1	26.3				
Farm fenced	No	10.5	1.8	2.253	4.7	0.528 - 42.098	0.133
	Yes	49.1	38.6				
Pig unit fenced	No	57.9	36.8	0.911	3.1	0.268 - 36.861	0.340
	Yes	1.8	3.5				
Foot bath	No	56.1	14.0	23.078	30.0	5.667 - 158.800	0.000
	Yes	3.5	26.3				
Visit pig farms	No	1.8	10.5	6.823	0.1	0.010 - 0.772	0.009
	Yes	57.9	29.8				
Blend different age groups	No	50.9	35.1	0.031	0.9	0.186 - 4.060	0.859
	Yes	8.8	5.3				
Vaccination	No	43.9	14.0	8.449	5.2	1.653 - 16.408	0.004
	Yes	15.8	26.3				
Manure and litter removal	No	21.1	5.3	3.503	3.6	0.894 - 14.785	0.061
	Yes	38.6	35.1				
Birds and rats' access	No	3.5	5.3	0.879	0.4	0.064 - 2.715	0.348
	Yes	56.1	35.1				
Swill feeding	No	21.1	26.3	4.927	0.3	0.096 - 0.882	0.026
	Yes	38.6	14.0				
Share a boar	No	54.4	38.6	0.421	0.45	0.046 - 4.819	0.516
	Yes	5.3	1.8				

The association between biosecurity measures and the level of biosecurity using the predictive tree model (Figure 2) singled out the isolation area (χ^2 = 29.856; P <0.001) as the first best predictor of the response variable (Biosecurity Level-Node 0). The model showed that 47.4% of pig enterprises had isolation areas. Of those, 22.2% had low biosecurity levels while 77.8% displayed high biosecurity levels (Node 1). On the contrary, 52.6% did not have an isolation area, of which 93.3% resulted in a low biosecurity level and only 6.7% sustained a high biosecurity level (Node 2). In addition, the model identified production and health records (χ^2 = 15.429; P <0.001) as the second-best predictor of biosecurity levels for pig enterprises having isolation areas. The predictive tree model further revealed that 31.6% of pig producers kept production and health records and 100% of them sustained a high level of biosecurity (Node 3).

While pig enterprises without records made up 15.8%, of which 66.7% and 33.3% had low and high biosecurity levels, respectively (Node 4). Also, the model indicated that production and health records (χ^2 = 5.893, P <0.05) were still the second-best predictor of biosecurity levels for pig enterprises without isolation areas. There were 14% of pig enterprises that kept records even though they did not have isolation areas. However, 75% of them offered a low biosecurity level and 25% showed a high biosecurity level (Node 5). Furthermore, 38.6% did not keep records and had no isolation area. As a result, 100% of those enterprises had a low level of biosecurity (Node 6). Finally, the model predicted footbath (χ^2 = 5.625, P

0.05) as the third best predictor, mainly for enterprises not maintaining production and health records but having isolation areas.

The model demonstrated that 7% of pig enterprises with isolation areas and not keeping records had a footbath at the entrances of their pig production units. Therefore, 25% of them sustained low biosecurity levels, whereas 75% displayed high biosecurity levels (Node 7). On the contrary, pig enterprises with isolation areas but not keeping records and without footbaths constituted 8.8% of pig enterprises. Consequently, 100% of them had a low level of biosecurity (Node 8).

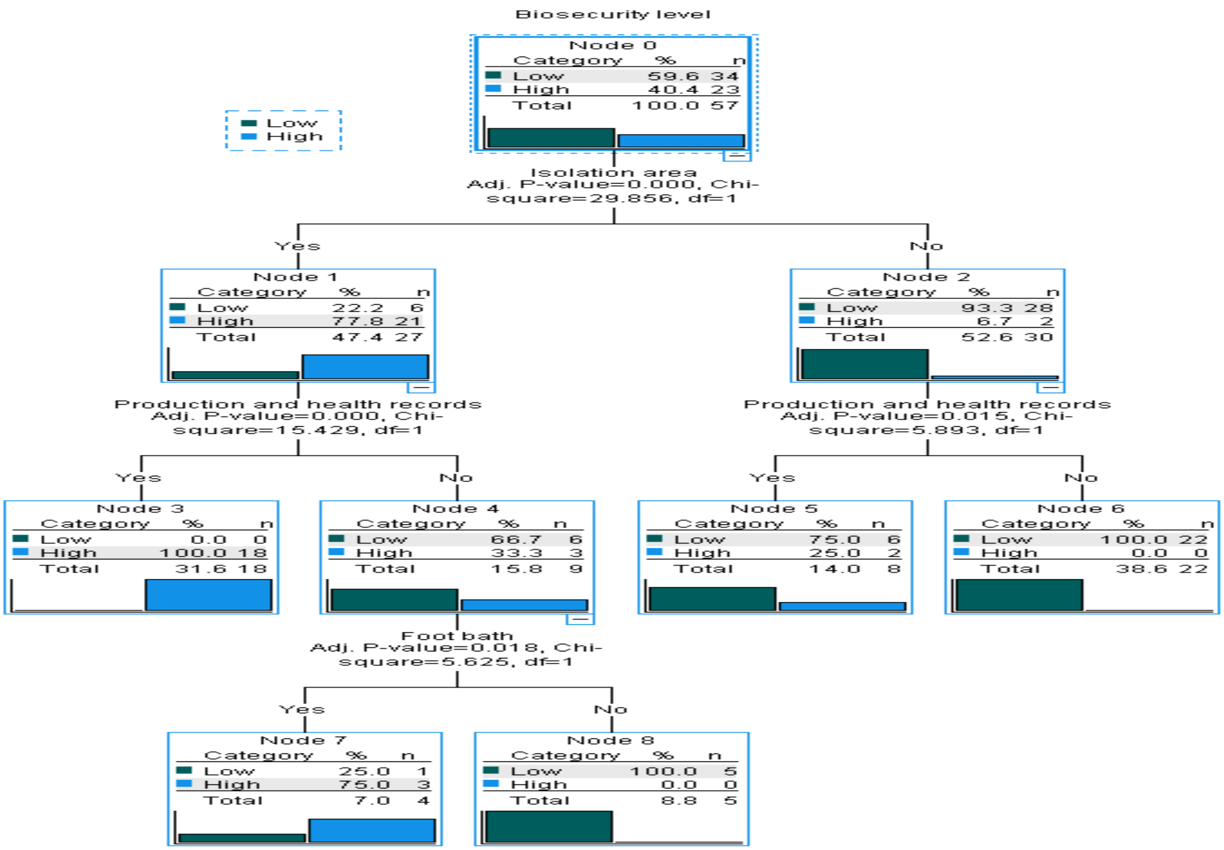

Figure 2 The predictive tree model of biosecurity measures and biosecurity level

Conclusion

There was a low adoption level of biosecurity practices and most of the pig enterprises had no biosecurity management plan. Therefore, the risks of disease outbreaks were high in the study area. Pig producers should be encouraged to constantly adhere to biosecurity measures and awareness campaigns should be conducted to empower pig producers. In addition, they must be assisted to develop biosecurity management plans. The findings of the current study can be used as a reference point to develop strategic interventions to combat and mitigate biosecurity threats in the study area. Application of biosecurity measures would enhance pig production efficiency, sustainability, and profitability of a smallholder pig production system. In return, a contribution towards food security, poverty alleviation and job creation will be realized.

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Authors' contributions

S. Maoba conceived the idea, B. Manyakanyaka and A.P. Mamaregane collected data. S. Maoba analyzed and interpreted the data. S. Maoba, B. Manyakanyaka & A.P. Mamaregane wrote the manuscript.

Conflict of interest

The authors wish to declare that there are no conflicts of interest

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