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NARRATIVE STUDENT REVIEW

Pig Diseases in Papua Province, Indonesia: Aetiology, Eco-epidemiology and Control Options

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Abstract Pigs are an important commodity for Papuans, culturally and economically, but diseases and high pig mortality hamper production. The purpose of this review is to describe the ecology and epidemiology of pig diseases prevalent in Papua and to propose control options that may be suitable for the Papuan situation. The review was conducted using published papers on pig production and diseases in Papua, government documentation and published papers on related diseases from other locations. We determined that the major pig pathogens in Papua are Classical Swine fever (CSF), porcine circovirus 2 (PCV2), *Trichuris suis*, strongyle parasites and *Streptococcus zooepidemicus*. Farmers' knowledge of pig diseases is low; hence the role of local government in control measures is pivotal. Control approaches should involve pig confinement as a prerequisite. Vaccination against CSF and parasite control, when indicated, should be part of routine control measures for confined pigs. Education of farmers is an important part of any control program and needs to focus on good farming practices such as the aforementioned confinement, appropriate feeds and feeding, sanitation, recognition of the clinical signs and major pathology of pig diseases, and the reporting of disease to local veterinary services. The ecology and epidemiology of pig diseases in Papua are still largely not understood. Future studies should be aimed at the evaluation of the proposed methods of disease control, an understanding of the impact of PCV2 infection on pig production in Papua and the role of the movement of pig products into and among regions in Papua in regard to CSF and PCV2 viral transmission as well as investigations of other underdiagnosed yet important pig diseases, such as PRRS, H1N1 influenza and toxoplasmosis.

Keywords Pig diseases · Ecology · Epidemiology · Control · Papua · Indonesia

Introduction

Pigs are a major livestock of social, cultural and economic importance in South-East Asia and Pacific areas [27, 69] including Papua province (referred to as Papua hereafter), Indonesia [98]. For centuries, Papuan pigs have been used as an economic commodity, as offerings in traditional events, as gifts for relatives and for family consumption [107, 119, 126]. Cash income generated from pigs in 2006 by traditional farmers in Jayawijaya region, Papua comprised 67–86 % of total family income, with actual figures of 14–16.5 million IDR (~1400 USD at an exchange rate of 1 USD equal to 10,000 IDR). Family in the study was defined as the traditional *sili*, which comprised, on average, 13 persons [98]. Apart from the high dependency of pig farmers on pigs as a source of cash, the number of pig farmers in Papua was also high; 196,724 households [24], or approximately 30 % of all total 658,794 household in Papua [23]. This highlights the importance of pig production for the Papuan economy. A recent survey

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suggested that pig consumption peaks during December and August, which may reflect the more intensive use of pigs and the pig trade on special occasions, such as Christmas and National Day celebrations [126].

The latest agricultural census in 2013 recorded the pig population in Papua as 1,346,800 heads [24]. Papua, the eastern most province of Indonesia has the fifth highest pig population in the country, after Nusa Tenggara Timur (NTT), Bali, North Sumatra and South Sulawesi [164]. Among 29 regions in the province, the Jayawijaya region has the highest pig population, comprising 24.1 % of the total pig population [23]. Pig density in Jayawijaya was estimated to be 23 heads per km^2 [126]. Pig density in Papua Province is illustrated in Fig. 1. It shows that besides that in Jayawijaya, high pig densities are also found in other regions, such as Pegunungan Bintang, Lanny Jaya, Paniai, Jayapura Kota, Yahukimo, Yalimo, Tolikara and Mamberamo Raya.

Domestic Papuan pig production has doubled in the period from 2001 to 2013 (Fig. 2), but the production has only been for local consumption, none of it for export. There are no specific data regarding pig/pork imports for Papua but imports of combined food stock and life animals was reported to have reached 39,000 metric tonnes in 2012, while no food stock/live animal was exported from Papua [23]. At the national level, the export of life pigs was recorded as reaching 32,000 metric tonnes, while import

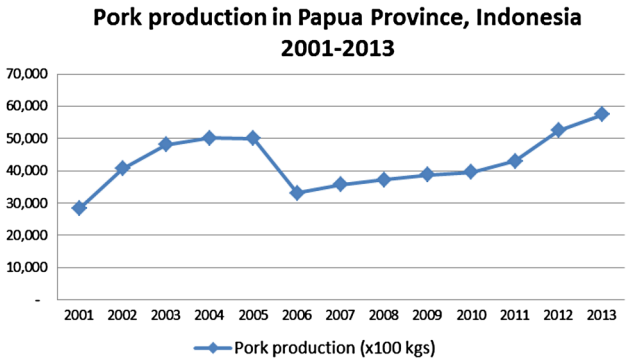

Fig. 2 Total pork production (kg) during 2001–2013 in Papua Province, Indonesia (adapted from [23])

was negligible. However, the import of pork was reported to be 765.5 metric tonnes, while the export was recorded far lower, at 68 metric tonnes [112]. Some of the imported pork can be seen in Papuan markets.

While Papuan pig production has been increasing, pig farm productivity in Papua has remained low [33, 126]. Studies in Jayawijaya revealed that pig disease and mortality have been major constraints to pig farming [98, 126]. Not only are these conditions economically devastating, a few identified pig diseases in Papua also have zoonotic potential. The potentially zoonotic pathogens *Streptococcus suis* and *S. zooepidemicus* were recently isolated from

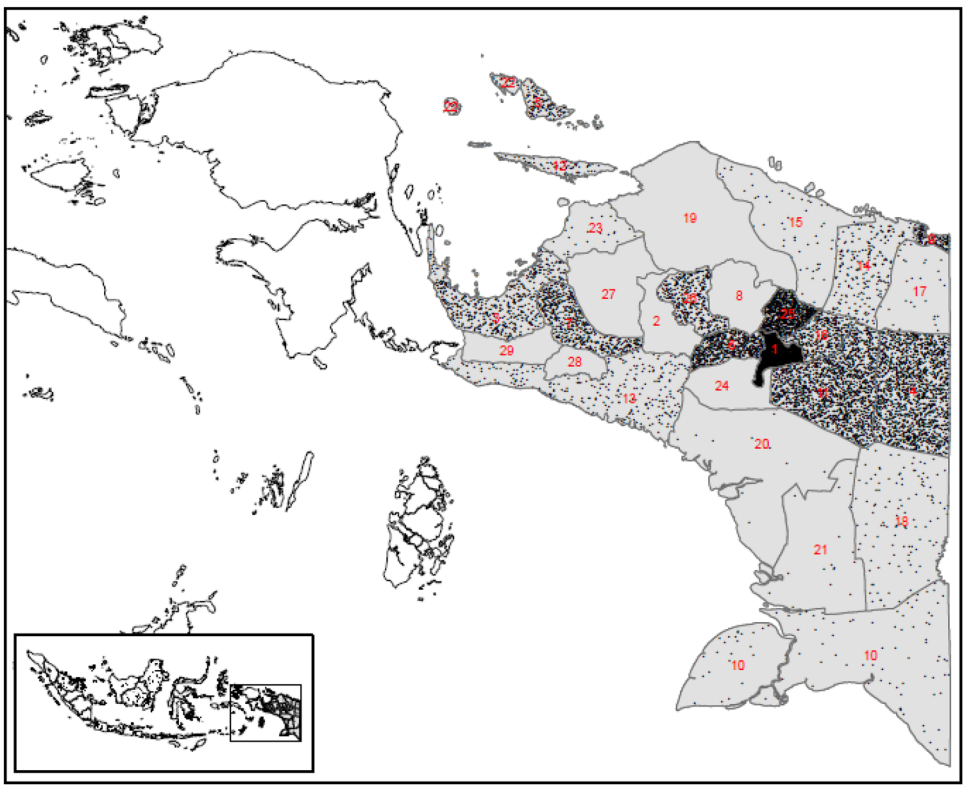

Fig. 1 Density of pig populations in regions of Papua Province, Indonesia (*one dot* represents 50 pigs). Names of regions: 1. Jayawijaya, 2. Puncak, 3. Nabire, 4. Pegunungan Bintang, 5. Biak Numfor, 6. Lanny Jaya, 7. Paniai, 8. Mamberamo Tengah, 9. Kota Jayapura, 10. Merauke, 11. Yahukimo, 12. Kepulauan Yapen, 13. Mimika, 14. Jayapura, 15. Sarmi, 16. Yalimo, 17. Keerom, 18. Boven Digoel, 19. Mamberamo Raya, 20. Asmat, 21. Mappi, 22. Supiori, 23. Waropen, 24. Nduga, 25. Tolikara, 26. Puncak Jaya, 27. Intan Jaya, 28. Deiyai, 29. Dogiyai (adapted from [23])

cases of mortality in Papuan pigs and their involvement in human diseases needs further studies [127]. Cysticercosis due to *T. solium* is known as an important pig-associated zoonosis in Papua. Wandra et al. [186] indicated that cysticercosis was associated with incidences of epileptic seizure in humans in Jayawijaya. Further studies reported human taeniasis from *T. solium* in regions of the Jayawijaya, Paniai, Nabire, Pegunungan Bintang, Puncak Jaya and Manokwari [102, 152, 188]. A further recent study reported the seroprevalence of pig cysticercosis (PCC) in Jayawijaya as high, at 40.5 % [9].

The purpose of this review is to describe the ecology and epidemiology of pig diseases in Papua and to propose an approach that could be applicable for and transferable to Papua, based on existing scientific information, in order to alleviate the problems of pig diseases and zoonoses in the province. To this effect, we reviewed papers on pig production and diseases in Papua from peer-reviewed journal articles, government documents, conference papers, books, theses and unpublished works. Some pictures from our experience during the conduct of studies in the Jayawijaya Region are also presented to assist with an understanding of pig farming and some pig diseases in Papua. With the relatively small number of relevant references related to the topic from Papuan studies, the review was expanded to include publications from other locations studying these diseases of interest.

We organised this review by firstly describing the traditional pig production system, followed by a description of the diseases affecting pigs in Papua, and then discussing the ecology, epidemiology and control of each selected disease under the subheadings of: prevalence, impact on pig performance, co-infection, pathology, risk factors and available control measures. Finally, we propose steps to be taken in disease control, appropriate in the context of Papuan pig farming.

A Concise Overview of Pig Production in Papua, Indonesia

Pig farms in Papua are relatively small. Using either household or the *sili* (defined as several closely related family groups living in one enclosure) as the unit of observation, the average pig farm in Jayawijaya comprises 8–13 head of pigs, with the ratio of humans to pigs being one [98, 126]. The average numbers of boars, sows, growers and sucker piglets in household farms are 1.3, 1.7, 2.2 and 3.6, respectively [126].

Pig movements onto a farm as a gift or by purchase are common, while hunting for pigs in the bush is rarely carried out. Pig housing is largely traditional; most pig housing is without ventilation, uses bare earth as the floor, has thatched roofs, and commonly uses grass bedding [126]. Thatched roofs were reported to provide for lower temperature fluctuations compared to tin-roofed pig housing or direct exposure to ambient temperature, therefore facilitating a better environment for pig production [33]. Despite the provision of pig housing, most farmers allow pigs to scavenge outside during the day and only 16 % of farms fully confine their pigs. The vast majority of farmers weaned pigs at 2 months of age and more than half of them mixed weaners from different litters [126]. Figure 3 depicts the local pig breed, daily scavenging, and traditional pig housing in Jayawijaya.

Farrowing rates and the litter size of Papuan pigs are low; Cargill et al. [33] reported that sows produced just 0.7 litter/year. The size of the litter ranged from 4.4 to 6 piglets per litter [33, 98, 126]. Traditional pig feeds are sweet potato tuber and vine, and domestic swill. Half of the farmers fed their pigs twice a day, or more frequently. Water provision for pigs in the pen was uncommon [126]. One study reported low bodyweight gains of just 18 g/day in Papuan pigs that were fed with uncooked sweet potato tuber and vines. However, when fed with boiled sweet potato tuber and vines, healthy pigs grew at 160–220 g/day, while the same breed fed with cooked feed with a higher level of protein could grow as fast as 300 g/day [33]. Heat treatment of sweet potato reduces the toxic HCN content, increases ileal digestibility [124] by reducing trypsin inhibitors and improving starch digestibility [50]. Many farmers with full confinement systems reported cooking the feed daily for their pigs [127], although many other farmers also fed pigs uncooked feeds [33].

Furthermore, total pig mortality rate is high in Papua. Pig mortality rates on traditional piggeries may be as high as 40–50 % [33, 126]. Farmers do realise that pig disease and mortality act as a major constraint to production in Papua [98]. However, extensive use of veterinary services is rare and many farmers leave diseased pigs without any attempts to treat them. On the other hand, two-third of farmers reported that they consumed sick pigs or those that had died from natural causes [126], rather major concerns about foodborne infections and intoxications.

Infrastructure to support pig production is available in Papua. Local livestock offices are available in all 29 regional governments in Papua to assist with local livestock production. However, only six regions; Merauke, Puncak Jaya, Nabire, Paniai, Timika and Supiori have specialised offices for livestock, while other regions mix the livestock offices with fisheries, horticulture or field crops [112]. Some of them; Timika, Nabire, Jayapura, Sentani and Jayawijaya employ veterinarians but other regional offices have not hired veterinary staff. A few regional livestock bureaus have simple laboratories,

Fig. 3 Traditional pig farming system in Papua Province, Indonesia. Pigs are confined in a fenced yard called "laleken/lakenma/enggenma" and allowed to scavenge freely during the day. During the night, pigs are confined to the traditional pig house constructed with wood partitions and thatched roof and a floor consisting generally of bare earth

capable of examining faeces microscopically, and able to store vaccines and tissue samples. This situation may be a reflection of different priorities for the livestock sector in the regions.

To cope with animal diseases, the central government has developed a diagnostic laboratory in Maros, South Sulawesi province and conducts annual animal disease surveillance in 10 provinces in eastern Indonesia, including Papua. Four quarantine offices have operated in Papua aimed at protecting Papua from exotic disease [109]. In the legislation aspect, the Ministry of Agriculture has declared 22 animal diseases of national priority, which for pigs have included Brucellosis (*Brucella suis*), CSF, cysticercosis, helminthiasis, H1N1 influenza, PRRS and toxoplasmosis [110].

Aetiology of Pig Diseases in Papua

Pig diseases can impact the performance of Papuan pigs in a number of ways, such as by causing low daily weight gain, low annual farrowing rate, low litter size and high mortality. Several pathogens have been identified as major causes of disease in Papuan pigs. Details of studies on the investigation of pig pathogens and zoonoses is presented in Tables 1, 2. It shows that pathogens such as Classical swine fever (CSF) virus, porcine circovirus type 2 (PCV2) virus, *S. zooepidemicus*, *S. suis*, *Taenia solium* and endoparasites, especially *Trichuris suis* and strongyle parasites have been the major pathogens of pigs in Papua.

Among the zoonotic diseases, cysticercosis is a well-known endemic in Papuan pigs [171]. Cargill et al. [33] demonstrated the presence of two other potential zoonotic diseases serologically from pigs in Jayawijaya; Trichinosis and Toxoplasmosis. Further studies are required to confirm the presence of these diseases in Papuan pigs. Clinical Japanese encephalitis (JE) was reported in humans in Timika and Jayapura regions of Papua by serology [140, 167, 168]. Pigs are known to be capable of acting as amplifier hosts for JE virus and transmission to humans from pigs may occur via *Culex* mosquitoes acting as vectors [40]. While the pig population in Papua is high, the role of pigs in the transmission of JE to humans in Papua has never been investigated.

A pig disease serological survey was performed in Jayawijaya region, Papua in 2002 looking at the presence of porcine brucellosis (*B. suis*), leptospirosis (*Leptospira pomona* and *L. tarossovi*), porcine parvovirus (PPV) and Mycoplasmosis (*Mycoplasma hyopneumoniae*). Thirty-nine sera taken from 10 villages failed to demonstrate indications of the presence of these diseases in Papuan pigs [33]. Other important pig diseases, such as colibacillosis and porcine reproductive and respiratory syndrome (PRRS) have been reported from pigs in Bali Island [18, 170] but have as yet not been identified in Papua. The following sections will review the ecology, epidemiology and control of the abovementioned major pig pathogens identified in Papua.

Porcine Circovirus Type 2 Disease (PCVD)

PCV2 is one of the smallest known viruses, with a non-enveloped virion particle of 12–23 nm in diameter. PCV2 has a circular, covalently closed, single-stranded DNA that contains 1767–1768 nucleotides. It belongs to the family Circoviridae, genus *Circovirus* [160]. Four major genotypes of PCV2 have been established based on ORF2 region or full genome sequencing, namely PCV2a, PCV2b, PCV2c and PCV2d. Later on, four different intermediate (IM) clades have also been proposed [194]. PCV2a, PCV2b and PCV2d have been reported to be equally pathogenic. PCV2b is the most prevalent genotype in farmed pigs, followed by PCV2a and PCV2d [158, 194]. By far, the virulence of PCV2c and intermediate clades are unknown.

Table 1 Pathogens of pigs and zoonoses of viral and bacterial origin studied in Papua, Indonesia

Organism	Methods	Prevalence in pigs, % (*n*)	Prevalence in humans, % (*n*)	Regions of the study	References
Viruses					
Classical swine fever	ELISA antigen	1 (103)	–	Jayawijaya	[127]
	ELISA antibody	33 (103)	–	Jayawijaya	[127]
Porcine circovirus type 2 (PCV2)	ELISA antibody	28 (103)	–	Jayawijaya	[127]
	PCR	41 (32)*	–	Jayawijaya	[125]
Transmissible gastroenteritis (TGE)	Serology	Nil (39)	–	Jayawijaya	[33]
Porcine parvovirus (PPV)	Serology	Nil (39)	–	Jayawijaya	[33]
Japanese encephalitis (JE)	ELISA	ND	1 (226)**	Jayapura	[140]
	ELISA	ND	9 (96)	Timika	[168]
Pseudorabies virus (Aujeszkey's disease)	Serology	13 (39)	ND	Jayawijaya	[33]
Bacteria					
Streptococcus suis	Isolation-PCR	9 (103)	ND	Jayawijaya	[127]
	Dot-Blot	11(67)	ND	Timika	[151]
Streptococcus zooepidemicus	Isolation-API 20 Strep	Nil***	ND	Jayawijaya	[127]
Leptopsira pomona	Serology	Nil (39)	ND	Jayawijaya	[33]
Leptospira tarossovi	Serology	Nil (39)	ND	Jayawijaya	[33]
Brucella suis	Serology	Nil (39)	ND	Jayawijaya	[33]
Mycoplasma hyopneumoniae	Serology	Nil (39)	–	Jayawijaya	[33]

* From PCV2 seropositive samples

** Samples were non-malaria febril patients

*** 15 % ($n = 92$) prevalence was reported using isolation in pig mortality cases [126]

A study has identified genotype PCV2b and PCV2-IM3 in Jayawijaya with PCV2-IM3 having a higher prevalence [125].

Prevalence

PCV2 is a ubiquitous virus present in domestic as well as in feral pigs worldwide [12, 55]. In Jayawijaya Region, Papua, PCV2 was detected in 59 % ($n = 71$) of dead pigs and in 28.2 % ($n = 103$) of healthy pigs [126]). For comparison, in Chinese farms the reported prevalence ranged from 36.3 to 64.2 % [83, 199], was 22 % in Brazilian pig herds [45], and 63 % in Hawaiian feral pigs [169].

Impact on Pig Performance

PCV2 is known to contribute to various pathologic conditions, collectively called Porcine Circovirus Diseases (PCVD) [12]. The most well-known clinical feature of PCVD is post-weaning multi-systemic wasting syndrome (PMWS), which causes significant pig mortality [80, 190]. More chronic PCV2 infections have been known to result in stunting, reduced weight gain and reproductive failure including return-to-oestrus, late abortion, mummified fetuses, stillbirths and non-viable live-born piglets [158]. There has been a shift in PMWS manifestation in Europe and North America from a fatal to a more chronic and subclinical outcome [12] but mortality is still reported from China [196]. There is currently no indication or knowledge of impact of PCV2 infection on pig performance in Papua.

Co-infections

In Papua, co-infection of pigs with PCV2, CSF virus and endoparasites is common. Specifically, infection with both, PCV2 and CSF virus was more common in dead pigs when compared to healthy pigs [127]. Co-infection of pigs with PCV2 and various pathogens has been reported to increase the severity of PMWS. Pathogens reported to co-infect with PCV2 include PRRS, PPV, Swine Hepatitis E virus (HEV), *M. hyopneumoniae*, *Salmonella* spp., or *Metastrongylus elongatus* [4, 5, 64, 76, 129, 196]. Recently, a simple temperature fluctuation and high stocking density without involvement of any other pathogen was shown to be capable of triggering clinical manifestations of PMWS [132].

Table 2 Internal parasitic pig pathogens and zoonoses studied in Papua, Indonesia

Organism	Methods	Prevalence in pigs, % (*n*)	Prevalence in humans, % (*n*)	Regions of the study	References
Internal parasites					
Cysticercus cellulosae	ELISA, Serology[1]	41 (111)	8 (109)[1]	Jayawijaya	[9], Swastika in [188] [1]
	Immunoblotting	ND	29 (633)	Paniai	[152]
	Serology	ND	9 (105)	Nabire	[187]
	Immunoblotting	ND	2 (654)	Puncak Jaya	[152]
	Immunoblotting	ND	3 (391)	Pegunungan Bintang	[152]
Toxoplasma gondii	Serology	18 (39)	ND	Jayawijaya	[33]
Trichinella spiralis	Serology	13 (39)****	ND	Jayawijaya	[33]
Trichuris suis	Faecal examination	8 (102)	–	Jayawijaya	[127]
Strongyloides ransomi	Faecal examination	16 (102)	–	Jayawijaya	[127]
Ascaris suum	Faecal examination	12 (102)	–	Jayawijaya	[127]
Hyostrongylus rubidus	Faecal examination	10 (10)	–	Jayawijaya	[135]
Globocephalus urosubulatus	Faecal examination	80 (10)	–	Jayawijaya	[63]
Macracanthorhyncus hirudinaceus	Faecal examination	50 (10)	–	Jayawijaya	[63]
Ascarop strongylina	Faecal examination	ND	–	Jayawijaya	[33]
Physocephalus sexalatus	Faecal examination	ND	–	Jayawijaya	[33]
Metastrongylus spp.	Faecal examination	ND	–	Jayawijaya	[33]
Oesophagostomum spp.	Faecal examination	ND	–	Jayawijaya	[33]
Gnathostoma hispidum	Faecal examination	ND	–	Jayawijaya	[135]
Eimeria debliecki	Faecal examination	ND	–	Jayawijaya	[33]
Eimeria scabra	Faecal examination	ND	–	Jayawijaya	[33]
Eimeria suis	Faecal examination	ND	–	Jayawijaya	[33]
Balatidium coli	Faecal examination	ND	–	Jayawijaya	[33]
Entamoeba sp.	Faecal examination	ND	–	Jayawijaya	[33]
Jodamoeba sp.	Faecal examination	ND	–	Jayawijaya	[33]

[1] Indicating a corresponding data

**** The cyst has never been described

The odds of PMWS decrease when vaccination against atrophic rhinitis [91] or *Escherichia coli* is administered [148]. In contrast, PMWS has been reported to emerge after vaccination against PRRS [51, 91, 148, 190]. Emergence of PMWS was also reported when PCV2 infected animals were vaccinated against CSF virus [65]. These findings suggest that vaccination could otherwise risk the PMWS, therefore the implementation of vaccination to prevent PMWS needs to consider the health and likely infection status of an animal.

Transmission

International transmission, transmission among local herds and rapid viral evolution were thought to contribute to the spread of PCV2 [56]. The role of pork imports on the course of PCV2 infection in Papua is unknown, but imported pork products from several countries have been available in Papua.

Transmission among pig herds in Papua may be facilitated by direct contact between pigs as most farms leave their pigs scavenging during daylight [126]. Other potential modes of transmissions for PCV2 have never been studied in Papua, but have been identified in other countries. Semen from infected boars was reported as a source of infection [115, 148]. Transmission by humans as a mechanical vector has been suspected and one study has suggested that humans should have no pig contact for at least 2 days prior to visiting a farm [4]. *Culex* mosquitoes and *Musca* flies living on pig farms may carry PCV2 [19, 195]. Other insects or external parasites that live on pig body surfaces may act as mechanical vectors for the virus and could partly explain why regular treatment against external parasites was found to reduce the risk of PMWS

[148]. Potential airborne transmission has been suggested and interestingly the level of air contamination was indicated to be independent of stocking density [181]. In the external environment, viable PCV2 was isolated from pig manure [182] leading to speculation that contaminated water might be another vector for PCV2 transmission. In addition, the role of other species such as calves and rodents as biological vectors have been demonstrated [66, 82, 88, 92].

Pathology

PCV2 infections manifest in various forms, either as systemic disease, respiratory, enteric disease, dermatitis and nephropathy syndrome or reproductive diseases. Enlarged superficial inguinal lymph nodes are a common *ante-mortem* sign of PCV2 systemic disease. Other signs may include rough hair coat, emaciation, irregular red-to-purple skin macules and papules, locally subcutaneous haemorrhages and oedema, and cutaneous scars in cases that have recovered from the acute phase [159].

During *post-mortems*, lungs may show a tan-mottled surface and a lack of collapse [159]. This pathology occurred in approximately 65 % of diseases associated with PCV2 infection [161]. Lesions in the alimentary tract show catarrhal enteritis with or without mesenteric oedema, thickened mucosa and enlargement of mesenteric lymph nodes. Moreover, bilateral renal enlargement with small cortical petechiae or whitish spots, and oedema of the renal pelvis may be observed. Lesions in other organs include occasional splenic infarcts, atrophic-discoloured liver and slightly rough hepatic surface [159].

As a reproductive disease, PCV2 infections were reported to cause mummification or oedema of aborted fetuses. Fetal livers were enlarged and congested and fetal hearts showed hypertrophy with multifocal discoloured areas of myocardium. Additionally, ascites, hydrothorax and hydropericardium of the fetuses were detected [159]. There is no detailed study of PCV2 pathology in Papua, but gross lesions of non-collapsed tan-mottled lungs were found in a dead pig in which PCV2 genetic material was detected (Fig. 4). It indicated that in Papua PCV2 might associate with respiratory disease.

Risk Factors

In healthy Jayawijayan pigs, where the prevalence of PCV2-CSF co-infection is lower than in dead pigs, farms were characterised as fully confined, used cooked feeds, had floors made of concrete or wood and were relatively isolated from contact with other pigs [127]. In contrast, on the majority of Papuan pig farms where dead pigs originated from, pigs were raised on bare-earth floors and were scavenging during the daylight [126]. It seemed that the locally adopted confinement system was beneficial in reducing the risk of PCV2 infection in Papua compared to a scavenging system.

Studies on the role of confinement in PCV2 infection have produced conflicting results. A European study on wild boar suggested that intensively managed wild boar had a higher prevalence of PCV2 [183]. However, studies in Hawaii and Brazil reported that the prevalence of PCV2 in wild boar can be higher than in domesticated pigs [45, 169]. This suggests that housing and stocking density may be only among other factors sufficient to induce the infection with PCV2. In Papua, while confinement seemed to reduce the risk of PCV2 infection, the level of subclinical PCV2 infection in healthy confined pigs in Jayawijaya was still high, approaching 30 % of the animals studied [127]. The significance of subclinical PCV2 infection for performance parameters of Papuan confined pigs, such as a possible reduced daily weight gain and reproductive failure, remains open for investigation.

In intensive piggeries, management factors may be important for reducing clinical manifestation of PMWS. A European case study of a PMWS outbreak indicated that after a reduction in stocking density, segregation of batches of pigs, cleaning and disinfection of the housing and a strict application of an all-in/all-out pig flow, mortality dropped from 12 % to 6 % [95]. Leaving farrowing and weaning pens empty for 5 days could reduce the risk of PMWS [148]. In contrast, an increased severity of PMWS was reported to be associated with rearing growers indoors with a density of more than 1 pig per m^2 [4] and with having poorly isolated hospital pens, indicating a role for higher density as a risk factor and the hospital pen as a source of infection for other pens [148].

Age at infection with PCV2 may be important in the development of PMWS. Suckling piglets were more likely to exhibit PMWS if they were weaned before 21 days and infected with PCV2 before 7 weeks of age [91, 147]. An increased severity of PMWS was associated with a high level of cross-fostering during the first 24 h of life, which might be due to increased risk of early PCV2 transmission from different sows to newborn piglets [148]. In Papua, the average farmer weaned their piglets at 2 months of age and cross fostering was not common [126]. Therefore, infection resulting from such intensive newborn rearing strategies is unlikely in Papua.

Feeding regimes may be another important preventive factor of PMWS. A feeding frequency of more than twice daily for weaners until they reach 14 weeks of age reduced the risk of PMWS [4]. Feeding twice daily may reduce the risk of scavenging by pigs and may reduce the risk of disease transmission, including that of PCV2 infection. A feeding regimen of twice daily or more was practiced by

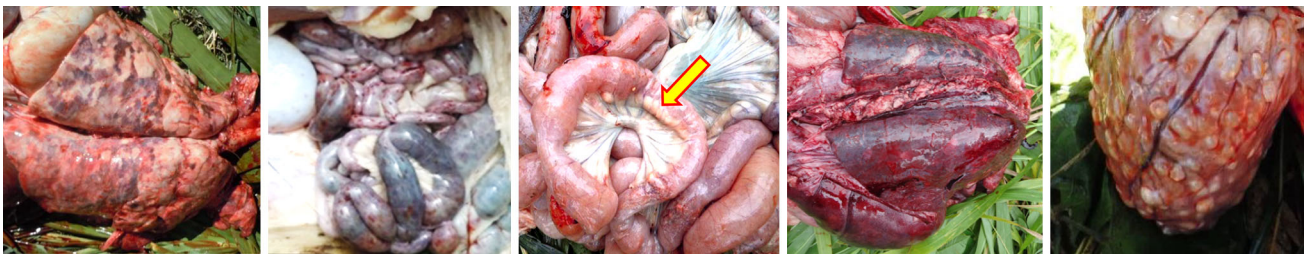

Fig. 4 Examples of the gross pathology of pig diseases in Papua: A non-collapsed tan-mottled lung due to severe PCV2 infection, ecchymotic haemorrhage of the intestine caused by classical swine fever (CSF) virus infection, nodules in the serous layer of the colon due to *Oesophagostomum* infestation (*arrow*), diffuse haemorrhagic pleuropneumonia from an acute *Streptococccus zooepidemicus* infection and heavy infestation with cysticeri of the heart (from *left to right*) [125]

almost half of farmers in the Jayawijaya region [126]. A study is warranted to understand whether feeding twice daily is beneficial in reducing the risk of PCV2 infection and its clinical manifestation under Papuan piggeries settings.

Control Measures

Vaccination has been widely used in many countries as an effective tool for the control of PCV2 disease [41]. Available commercial vaccines have been developed based on the PCV2a genotype. Such vaccines have been reported to be efficacious against PCV2a and PCV2b genotypes but the discussion is still open on their effectiveness against PCV2d genotypes [158]. Further, some of the Papuan PCV2 strains belong to the IM3 genotype, which was only recently recognised and there has not been study on the efficacy of commercial vaccines against this particular PCV2 genotype. The presence of PCV2b genotype in Papua has also been demonstrated [125]. However, as there is no information as to the prevalence of PCV2b and PCV2 IM3 genotypes in Papua, or any knowledge of heterologous protection of commercial vaccines for the IM3 genotype, the effectiveness of any vaccination program for Papuan farms using commercial vaccines cannot be predicted.

Classical Swine Fever (CSF)

The virus causing CSF (CSFv) belongs to the genus Pestivirus. It consists of a single-stranded, positive sense, 12.3 kb RNA genome, enclosed in a 45 nm in diameter hexagonally shaped envelope. Based on 190 nt of the E2 envelope glycoprotein gene, CSFv can be divided into three genotypes with three or four sub-genotypes: 1.1, 1.2, 1.3; 2.1, 2.2, 2.3; and 3.1, 3.2, 3.3, 3.4. Highly virulent CSFv strains and the vaccine strains belong to genotype 1. Genotypes 2 and 3 are moderately virulent. All of the genotypes have been found in Asia, but genotype 1 is mainly prevalent in South and Central America, genotype 2 in the European Union and genotype 3 in Asia [36]. Sub-genotype 2.2 has been reported in Java, Indonesia [138], but the genotypes circulating in Papua have not yet to be determined.

Prevalence

Recently in Jayawijaya, CSF viral antigen was detected in 31 % ($n = 71$) of dead pigs. In addition, antibody testing demonstrated that 55 % ($n = 71$) of dead pigs were seropositive. In healthy animals, the seroprevalence was just 33 % ($n = 103$) [127]. CSF is absent from North America, Australia, New Zealand, and most of Western Europe but remains a challenge in Asia, South America, Eastern Europe and parts of the former Soviet Union [72]. In a few endemic areas in Asia the seroprevalence of CSF in nonvaccinated pigs are varied. In Nusa Tenggara Timur, Eastern Indonesia, CSF seroprevalence in unvaccinated domesticated pigs was estimated at 13 % ($n = 883$) [156]. In Timor Leste, the seroprevalence in non-vaccinated pigs is 25 % ($n = 468$) [155]. Prevalence of CSF infection has been reported to be <1 % in non-vaccinated domestic pigs on Jeju Island, South Korea ($n = 22\,601$) [166]. A study in Karnataka, a state in the South western region of India, demonstrated a range in seroprevalence from 61 to 21 % in regions with intensive to primitive pig farming without vaccination ($n = 218$) [38].

Impact on Pig Performance

After its first report in Timika Papua in 2004, outbreaks of CSF causing pig mortality have rapidly spread to four other regions, namely Jayapura, Puncak Jaya and Jayawijaya [108]. CSF causes economic loss on pig farms due to high mortality associated with highly virulent strains. Lower virulence strains cause milder clinical signs and less mortality, while avirulent strains may only produce fever without further consequence [16]. Infection occurring during gestation can result in abortion, mummification, stillbirths, or persistently infected (PI) piglets [49, 179].

Co-infection

An infection with high or moderately pathogenic strains of CSFv is capable of producing severe clinical disease [89]. However, co-infection with pathogens may be important for lesser pathogenic strains to be able to produce clinical signs. Failure of CSF vaccination in PCV2 infected animals may be an example of how, with a co-factor, a non-pathogenic CSF could become pathogenic [65].

Co-occurrence of CSF and endoparasitic helminths was observed in 41 % of dead pigs [127]. The same study reported that mixed infection of CSF and PCV2 occurred in 11 % of cases of dead pigs, which was more than five times higher than that of healthy pigs. These data indicate that co-infection of CSF and endoparasitic helminths or PCV2 could play a significant role in cases of pig mortality in Jayawijaya. In contrast, a survey in Guangxi China reported co-infection of CSFv with swine influenza virus (SIV), PRRSV and PCV2 in less than 6 % of animals [141, 193].

Pathology

Pathological changes in Classical Swine Fever include conjunctivitis, petechiation of skin and ear necrosis, while, during *post-mortem* examination, petechial to ecchymotic haemorrhages of various organs have been the most common findings [52, 114]. Petechiae were observed during *post-mortem* examination of dead pigs in Papua and they might be the simplest gross pathology that farmers can recognise and report to local veterinarians (Fig. 4). Diagnosis of CSF using gross pathology of petechial or ecchymotic haemorrhages of bladder, kidney, stomach, lung or skin will result in 86.3–97.9 % specificity but a sensitivity of only 14.4–40.4 % [52]. However, gross lesions may be useful in locating hot spots in outbreaks involving large numbers of pigs.

Within the thoracic cavity, various pathological conditions may be observable including pulmonary oedema, pneumonia, pleuritis and chronic bronchitis, as well as chronic pericarditis, hydropericardium and hydrothorax. The pathology of the alimentary tract involves fibrin formation, chronic gastric ulceration, a hyperaemic intestinal tract, watery contents of jejunum and colon, oedema of the mesocolon and dry faecal contents in the colon. Renal cysts, renal enlargement and degeneration, liver and splenic enlargement have been reported in a few cases [52].

Transmission

Direct contact, horizontally and vertically, is the most efficient way to transmit CSFv [144] and may be the most effective transmission route in Papua. Various indirect transmission routes through a vector have also been proposed from a number of studies elsewhere. Wild boars are known to be an important biological vector [134, 144]. Mechanical vectors include contaminated feeds, vehicles, personnel, and infected semen used for artificial insemination. Additionally, airborne spread over short distances may be possible [144].

Risk Factors

Some risk factors for CSF infection have been identified. In a central market in Jayawijaya, CSFv was identified among pigs being traded, making this market a potential reservoir for CSFv and other pathogens for connected areas [127]. Pigs or pig feeds originating from, or people recently visiting, this market, may act as vectors of CSFv onto a farm.

Feeding vegetables harvested from areas with infected pigs, feeding offal from wild boar or feeding, swill feeding, contact with a neighbour's pigs, and artificial insemination have all been reported to increase the risk of CSFv transmission [115, 144]. Frequent shipments of pigs were also anticipated to increase the risk of CSFv transmission through contact with contaminated trucks [47, 104].

A study in the Eastern Cape Province of South Africa indicated that the risk of contracting CSF was lower if pigs were kept indoors but the risk was increased when farmers lived away from their farms or were uneducated [96]. Another study in Bulgaria suggested that areas, which were economically deprived were more likely to have a higher number of CSF [104]. These studies indicated that the risk of contracting CSF maybe linked to poverty in pig farmer communities. Inadequate knowledge or resources and thus not practicing general hygiene in underdeveloped regions may attribute to disease spread. The level of poverty in Papua is the highest among Indonesian provinces [11] and it may make the control of CSF in Papua more challenging.

Control Measures

Control efforts against CSF in Papua have not been successful to date. Vaccination against CSF was conducted by regional governments in Jayawijaya, Timika and Jayapura using injectable C-strain vaccine preparations, but the effectiveness remains unknown. Attempts to control CSF in other parts of Indonesia and in other countries will be discussed below to become a reference point for the design of comprehensive CSF control efforts in Papua in the future.

On Alor Island, NTT Province, a project to control CSF was conducted by the Australian Centre for International Agricultural Research. The activities included surveillance for the disease, education of students and farmers, vaccinations and the regulation of pig transports. Vaccination of 43 % of the pig population along with these other efforts was said to be sufficient to reduce the incidence of CSF

infection. However, eradication of CSF in Alor may not be feasible because a large population of wild boar makes vaccination of all pigs essentially impossible [145]. In contrast, West Sumatra Province was declared free of CSF in 2014, after previously being infected [111]. Control of CSF in West Sumatra had relied upon surveillance and elimination of serological reactors without vaccination.

In the Netherlands, where a policy of "no vaccination" was chosen after CSF had been eradicated from the country, separation of trucks used for national and international transport of pigs was thought to be the most cost-effective approach to prevent the risk of reintroduction of CSF into the country [47]. Information concerning the frequency of the importation of pigs or pork into Papua is unavailable publicly, but imported pig products have found their way into Papuan markets. The risk of CSF transmission in Papua from imported pork is unknown.

Vaccination has been used as the main strategy to control CSF in many endemic countries where a test and cull approach was not possible. The injectable C-strain vaccine was capable of producing complete protection in just 7 days after a single vaccination and protected pigs from horizontal infection [178]. Vertical transmission of CSFv from carrier sows can produce immunotolerance and persistently infected piglets [179], but oral vaccination of pregnant sow at 5 weeks after insemination was reported to be capable of protecting piglets from vertical transmission [73]. After vaccination, piglets older than 5 weeks developed a higher immune response than 3 week old pigs, indicating that a booster may be needed when young piglets are given a vaccine [172]. The health status of an animal may also be important for successful vaccination; CSF immunisation during an acute phase of PRRSv infection resulted in vaccination failure [173]. Further, vaccination against CSFv in PCV2 infected pigs resulted in the development of PMWS [65].

Infected boars were able to transmit virus to a sow through insemination and produce embryonic loss [97]. In Papua, where the CSF status of boars used for insemination is difficult to determine due to lack of diagnostic tools, it may be appropriate to vaccinate females against CSF 7 days before insemination to protect the sows and stop vertical transmission to the developing litter. However, further study is needed to confirm this option.

Early post-natal infection of piglets born from naïve sows also produces PI piglets. Such piglets neither produce neutralising antibody nor respond to vaccination [120, 121]. However, this scenario may be prevented by vaccinating pregnant sows.

Apart from the use of injectable vaccines, the efficacy of oral vaccination has been evaluated. In Serbia, a commercial oral vaccine (RIEMSER®) resulted in 73 % ($n = 41$) of pigs older than 12 weeks age being immune and 64 % ($n = 44$) of pigs being immune at 28 days post-vaccination [106]. In Bhutan, the same vaccine resulted in a mean of 60 % ($n = 193$) pigs of all ages and breeds being immune, and local farmers welcomed such an approach because of the ease of administration [116]. In light of the unsuccessful attempts to deliver an injectable vaccine across Papua, the efficacy and practicability of the use of an oral vaccine warrants a field trial.

When a CSF outbreak occurs, vaccination around the focus of the outbreak (ring vaccination) can limit the size and spread of the epidemic and thus reduce mortality [134]. C-vaccine is the vaccine of choice for this purpose rather than the oral vaccine, as it induces complete immunity after 7 days [178]. Theoretically, with ring vaccination the success in controlling the spread of CSFv is determined by whether viral transmission is able to reach the edge of the 'ring' pig population after the ring has been formed. Currently, there is no local strategy proposed for emergency vaccination in Papua.

When an outbreak of CSF occurs in a region, the consequences may be reduced if the disease can be recognised early [79]. In the Netherlands, farmers were encouraged to call a veterinarian when they observed mortality on their farms, after which further diagnostics were performed and the CSF status of the herd established [79]. Syndromic reporting to local government veterinary clinics was encouraged in NTT [145] and has actually been practiced by farmers in some regions in Papua. Education of farmers concerning clinical signs of diseases has been initiated in Jayawijaya but the results have not been evaluated [33]. Continuation and improvement of this initiative could assist with better records of CSF and other diseases in the future and support a better design of outbreak preparedness and surveillance programs.

The successful prevention of spread of CSFv in an epidemic area, through the isolation of affected herds, destruction of pigs and disinfections has been reported [79]. In Jayawijaya, pig movement onto farms through purchasing and as gifts was found to be very common and closely related to the local culture [126]. Therefore, prohibition of pig transport from and to an outbreak area seems currently not feasible.

The feasibility of eradication of infected pigs from an endemic area through a test and cull program in Papua is unknown, because there is no information on important aspects such as the availability of sufficient resources for compensation, the availability of rapid testing and preparedness of trained personnel. The lack of an adequate compensation scheme is known to have caused reluctance in farmers in Africa to follow such an approach though they realised CSF was a devastating disease [96]. Farmers hid piglets indoors or away in the bush when the government officers came to cull infected pigs [96, 134].

Wild boar may act as an important reservoir of the CSF virus [134, 144]. Control of CSFv infection in wild boar has been achieved through vaccination and a reduction of the population by various means such as shooting, trapping, fertility control or poisoning [31]. The status of CSFv in the Papuan wild boar population and its role in CSF transmission to farmed pigs is unknown and should be the subject of future study since many domesticated pigs are scavenging freely during the day and may come in contact with wild pigs.

Taenia solium—Cysticercosis

Prevalence

A recent study reported the seroprevalence of pig cysticercosis (PCC) in Jayawijaya at 40.5 % [9]. In other regions in Papua, although reported to be endemic for taeniasis due to *T. solium*, there is no publicly available information as to the prevalence of pig cysticercoses. Paniai, Nabire, Pegunungan Bintang, Puncak Jaya and Manokwari regions have reported human taeniasis from *T. solium*. A human case was once reported in the Merauke region but thought to be an infection acquired from other region since there has been no evidence of *T. solium* contamination in the region [102, 188]. In other Indonesian provinces, *T. solium* was only reported in Balinese people and serologically in Balinese pigs in Karangasem, with the seroprevalence at 15.8 % [188]. Additionally, the prevalence in dogs, a natural intermediate host of *T. solium* in Jayawijaya, tested by an immunoblotting technique was 11 % ($n = 64$) [71].

Impact on Pig Performance

Carcass condemnation is the main impact of PCC on pig performance. Excessive salivation, excessive blinking and tearing with or without subconjunctival nodules was reported in all pig samples with neurocysticercosis ($n = 18$), but not in neurocyst-free pigs ($n = 12$), indicating the association of neurocysticercosis with the abovementioned clinical signs [139]. Restlessness, due to these clinical signs presumably also has contributed to the reduced growth rate. However, pigs can be infected with more than a hundred cysts in the brain without being clinically affected [149]. However, the highest concern of pig cysticercosis is its public health consequence.

Co-infection

No data is available on PCC and co-infection and its clinical consequences for pigs.

Pathology

In heavy infections, lesion can spread throughout the muscles of the body. However, kidney, spleen, liver and lung were likely unaffected even in heavy infections with 80,000 cysts, and oesophagus was least affected [20]. On the other hand, in very light infected 2-month-old pig, showing only a single cyst, the liver was reported to be the only organ affected [157]. In naturally infected pigs with relatively light number of cysts (less than 80 vesicles), cysts were absent from the tongue, which may compromise the accuracy of diagnosis based on tongue inspection [84, 157]. In an experimental infection with 100,000 viable eggs, vesicles in the tongue were palpable 30 days post-infection. In this experiment, cyst in the pigs' brains remained vesicular and infective 350 days post-infection, but in the muscle they degenerated into caseous forms over the same period of time [44]. Cysts began to be infective approximately 45 days post-infection [85].

Transmission

Pigs acquire cysticercosis after ingestion of *T. solium* eggs. In the pig's alimentary tract, the eggs hatch and develop into onchospheres, which subsequently migrate to the muscle and encyst. Dogs are reported to be a natural intermediate host in Jayawijaya and could act as a pathway to pig cysticercosis in this area [71]. The life cycle of the encysted larvae can be completed when humans eat raw or undercooked pork or dog meat contaminated with the cyst. Under natural condition, humans are by far the only definitive host of *T. solium* [57]. *Chinchilla laniger*, immunosuppressed with methyl prednisolone acetate (MPA), was experimentally the only rodent able to act as a definitive host [10, 53, 101]. Hamsters treated with MPA would allow cysts to develop into mature proglotids but the proglotid was incapable of producing eggs [53]. Rat infected with *T. solium* experimentally, activated oncospheres intracranially and immunosuppressed mice experimentally infected subcutaneously were shown to be capable of developing cysticercosis [70, 180]. However, the role of rodents in the transmission of *T. solium* in the field is not apparent.

The beetle *Ammophorus rubripes* may carry *T. solium* eggs in its alimentary tract and the 40 % of eggs may remain viable at 24 days [59]. The role of insects in *T. solium* transmission has, however not been established in Papua. Human cysticercosis and taeniasis remain an important parasitic zoonosis in Papua [188].

Risk Factor

A cross sectional survey in Jayawijaya reported that free roaming and feeding uncooked feed could be risk factors

for pig cysticercosis [9]. In other study, confinement was also shown to prevent new exposure to *T. solium* to pigs in Jayawijaya as shown by serologic testing [3].

Pig owners not using a latrine was shown to be risk for pig cysticercosis in Tanzania [26], but not detected as a risk factor in Jayawijaya [9]. As pigs may roam in a radius of 1 km^2 [176], and a square km of land may be occupied by four to five families in Jayawijaya (BPS [25], free scavenging pigs may access other human faeces although the owners use a latrine in their own home, thus explaining the non- significant role of a latrine in pig cysticercosis infections in Jayawijaya.

Poverty, with an unawareness of personal hygiene and the exposure to risky animals is thought to correlate with the high prevalence of human cysticercosis [62]. Poor personal hygiene might also be a risk for transmission of *T. solium* to pigs. Contaminated feedstuff, even when boiled was thought to contribute to pig cysticercosis in Tanzania [26].

Control Option

A few options for the control of cysticercosis/taeniasis have been described. These include anthelminthic mass medication, vaccination, public education or combinations of any two of those options [85]. If anthelminthic treatment for pigs is chosen, using Oxfendazole at the dose of 30 mg/kg is one choice. All cyst were destroyed from tissue 12 weeks post-treatment [175]. A coverage of 75 % of the population and several rounds of drug administration over a period of several years (e.g. twice a year for 5 years) is likely to be required to have a sustained effect on the prevalence of *T. solium* [175]. In Papua, while 86 % of pig farmers in Jayawijaya trust in the efficacy of modern (western) medicine, only 12 % of them use modern medicine consistently [126]. The reasons that only these 12 % of farmers use modern medicine are unknown but it may hamper achieving the 75 % coverage required if anthelminthic treatments are to be effectively performed. This gap in knowledge may require further study before effective anthelminthic treatment can be achieved.

Efficacious, double-dosing vaccines against *Cysticercus cellulosae* or its oncospheres have been available [60, 117]. A study proposed a combination of chemotherapy and vaccination twice, using the TSOL18 vaccine in 4-month intervals to effectively eradicate *T. solium* in pigs in a population. The scenario assumes that pigs will be slaughtered at 12 months of age [85]. While this could be an excellent scenario under suitable conditions, approximately 50 % of Papuan pigs died during the first 4 months of age and Papuans would have slaughtered and consumed the meat [33, 126] and thus pigs would not get the second vaccination needed for full protection. If the vaccine could be modified so that it can be protective in a single dose this might be an excellent tool to combat porcine cysticercosis and, in turn, human taeniasis.

A control effort based solely on public education in Peru has seen an increase in the use of confinement pig husbandry systems, from 7 to 96 % in 42 months after initiation [85, 154]. In Mexico, education, in combination with vaccination programs, was reported. A pamphlet was delivered to a third of the target population, while one tenth of the population attended 219 oral presentations. 250 video copies were also delivered. The campaign reported to have increased the level of pig confinement from 36 % ($n = 220$) to 63 % ($n = 213$) within a period of 3 years, as well as increased the use of latrines by and the provision of potable water to the community [43].

Only 16 % of farmers confine pigs in Jayawijaya Papua, an area with the highest prevalence of cysticercosis [126]. Another study reported that properly confining pigs was the concern of only 1.7–4.3 % ($n = 228$) of farmers in that region [98]. Problems that may hamper a campaign aimed at confining pigs in Papua may be lack of resources to build a pig house and, in the long term, the ability to provide feed. A study in Jayawijaya, however reported that 48 % of farmers planted sweet potato with the purpose of feeding pigs. Moreover, when a project conducted by ACIAR (Australian Centre for International Agricultural Research) introduced feed processing technology that included ensiling, feed enrichment using fish protein, and heat treatment, 29 % of farmers would have adopted at least one the feed technologies introduced to them [33, 98]. Only 14 % of farmers, however, perceived that quality feed was important for pigs [98].

In Papua, where some tribes eat dog meat [71], eradicating human cysticercosis might be hampered in these communities. An assessment aimed at estimating the risk of acquiring pig and human cysticercosis and taeniasis, which is posed by consuming dogs is required.

Endoparasitosis

Prevalence

A study of endoparasite infections performed in the Jayawijaya Region of Papua, by faecal examination, found strongyles and *T. suis* were among important species detected. The prevalence of strongyle parasites in dead pigs was high at 70.5 % ($n = 44$), while in healthy, fully confined pigs it was much lower at 22.5 % ($n = 102$) [127]. Four strongyle parasites were identified in Papua; the stomach worm *Hyostrongylus rubidus* with a prevalence of 10 % ($n = 10$) [135], the small intestinal worm *Globocephalus urosubulatus* at 80 % ($n = 10$) [63], the colon worm *Oesophagostomum* spp. and the lung worm

Metastrongylus spp. [33]; the prevalence of the latter two is unknown. *T. suis* was present in 55 % ($n = 44$) of dead pigs in Jayawijaya, while in healthy pigs raised in concrete floored confinement the prevalence was low, at 8 % ($n = 102$) [127]. For comparison, in Denpasar, Bali, the overall prevalence of *T. suis* in confined pigs was 33 % ($n = 300$), with the prevalence in pigs confined on bare earthed floors at 52.7 % ($n = 74$), while the prevalence in pigs raised in concrete floored pig housing was 26.1 % ($n = 226$) [174]. Anthelminthic usage in the farms was not described in these two papers. However, it has been mentioned above that only 12 % ($n = 366$) of Papuan farmers use modern medicine [126]. In Bali, it was indicated that commercial anthelmintics were too expensive for local village farmers or they might just have been reluctant to purchase them [8].

Impact on Pig Performance

The most commonly expected outcome of endoparasite burden in pigs is reduced weight gain [78]. However, *T. suis* infection was reported to be associated with severe and persistent diarrhoea, growth retardation, emaciation and/or anaemia in a significant number of gilts and in fattening pigs [34]. Further, Cargill et al. [33] reported that parasitism was among the most important pathogens to cause pig mortality in Papua.

Co-infections

In cases of mortality studied in Jayawijaya recently, parasitism was found to be co-existing with either other parasites or with other pathogens, whereas in healthy pigs single infection of different endoparasites occurred at 1–4 % prevalence for each parasite investigated [127]. This indicated a possible need for concurrent infection with endoparasites and other pathogens to trigger clinical consequences. Experimentally, *T. suis* was reported to exacerbate the frequency and severity of diarrhoea and the severity of pathology of *Campylobacter jejuni*, while single infections of either pathogen caused only mild symptoms [100].

In Papua, concurrent burdens involving the gastric endoparasites *H. rubidus*, *Gnathostoma hispidum*, *Physocephalus sexalatus*, and *Ascarops strongylina* have been identified [33, 135]. Further, in the pig's small intestine a few parasites such as *Strongyloides ransomi*, *Ascaris suum*, *Macracanthorhyncus hirudinaceus* and *G. urosubulatus* were identified [63]. Additionally, the lung worm *Metastrongylus* spp. has also been identified [33]. These findings imply that a more complex mixed parasite burden may occur in Papuan pigs. However, competition among parasites could also occur in the alimentary tract of the host and at some levels of infestation. Stunted adult parasites were observed that could limit the overall endoparasitic load on the host [7]. An example of a negative interaction has been between *T. suis* and *O. dentatum* with *T. suis* domination [136].

Transmission

Transmission of *T. suis* and the four strongyle parasites is through the ingestion of eggs or larvae and the source of eggs and infective larvae may be contaminated soil or feed [123]. *T. suis* has a pre-patent period of 6 weeks, *O. dentatum* of approximate 5–6 weeks and *H. rubidus* of 3 weeks [54]. Temperatures of 6–26 °C and moisture in the soil are needed for the eggs to hatch and grow into infective larvae [7]. These suitable conditions occur in tropical Papua all year round [23] and may facilitate the continuous survival of parasite eggs and larvae in the ground. Indeed, parasite loads were found to remain relatively high throughout the seasons in free scavenging pigs in Jayawijaya [3].

Pathology

H. rubidus is a gastric parasite and, after ingestion, larvae penetrate the epithelial folds of the gastric mucosa, grow in the submucosal layer and result in the destruction of the epithelium and the formation of lentil-sized nodules and ulcers; adult worms produce a chronic catarrhal gastritis leading to the formation of a diphtheritic membrane as well as ulceration [7]. *G. urosubulatus* is not highly pathogenic, with young pigs more likely to become anaemic than older pigs [200].

T. suis and *Oesphagostomum* spp. are endoparasites of the caecum and colon of pigs. *T. suis* larvae penetrate the epithelial lining and the crypts of Lieberkühn and return to the lumen when mature. Lesions of *Oesphagostomum* spp. in pigs are most obvious in the caecum and are first observed 48 h post-infection. *T. suis* and strongyles may cause the formation of nodules and ulcers in the caecum and mid-colon within a few days post-infection [7]. Anaemia resulting from infections with *T. suis* was observed [34]. Nodules of *Oesphagostomum* spp. may be easily recognised by farmers as this lesion is quite visible (Fig. 4).

Risk Factors

Housing may be an important husbandry practice that could assist in reducing parasitism in Papua. A 15-month prospective observational study in Jayawijaya showed the effectiveness of confinement in reducing the prevalence of endoparasites in pigs [3]. In this study, sharp declines in the

prevalence of *T. suis*, strongyle parasites, *A. suum*, *Physocephalus* spp. and *Metastrongylus apri* occurred in confined pigs, whereas in the scavenging pigs the prevalence of all species increased. Another study supported this finding, showing that without anthelmintics, indoor housed pigs were likely to have lower burdens of *T. suis*, *A. suum* and *Oesophagostomum* spp. when compared to pigs with outdoor access [123]. Additionally, a lower burden of endoparasites in free range pigs was reported to be associated with the provision of night housing [75].

In pigs raised indoors with a higher level of hygiene, the level of infections of *T. suis* and *Oesophagostomum* spp. was negligible while *A. suum* remained but at a lower level compared to conventional indoor pigs [123]. A lack of bedding increased the risk of parasitism and the use of deep litter or slatted floors have been advised [35, 74].

The provision of low quality feeds was found to be significantly related to a high prevalence of *Oesophagostomum* spp. and *T. suis* [74]. In particular, feed rich in lignin and non-starch polysaccharides was shown to assist the establishment of *Oesophagostomum* spp. [137]. In this regard, cooking pig feeds as practiced by Papuan farmers [127] may be useful in increasing the digestibility of the feed and in reducing the chance of the establishment of parasite burdens. This could be incorporated into a program of parasite control in Papua.

Control Measures

It has been suggested that the overall pig mortality in Jayawijaya could be reduced from 48 to 10 %, by regularly treating with anthelminthic [33]. The effectiveness of the anthelmintic betel nut (*Areca catecu*) and papaw fruit (*Carica papaya*) has been examined. At a dose of 20 mg/50 kg body weight, a single dose of dried betel nut was capable of eradicating *T. suis*, *Strongyle* spp., *S. ransomi* and *A. suum* from the pig alimentary tract. With papaw, although it showed comparable efficacy, the high dose rate required of 1 kg/10 kg body weight makes this impractical for farmers [32]. However, another study reported that a single dose of 450 μmol cystein proteinase extracted from *C. papaya* provided good efficacy against *T. suis* infections in pigs [81].

Oxfendazole administered orally to naturally parasitised piglets at a single dose of 30 mg/kg was safe and highly efficacious against the adult stages of *A. suum*, *Oesophagostomum* spp., *T. suis* and *Metastrongylus* spp. [6, 113]. Experimentally, both Ivermectin and Abamectin administered orally for a period of seven consecutive days at a daily dosage of 100 μg/kg were highly effective against *H. rubidus*, *S. ransomi*, *A. suum* and *M. salmi* [90]. However, the need for prolonged treatment with these anthelmintics may constrain their use by Papuan farmers.

The timing of the administration of anthelmintics may be critical. It was recommended that farmers gave anthelmintic treatment to newly introduced pigs before being mixed with other pigs on a farm [35]. The rainy season might be a suitable time for antiparasitic treatment since the prevalence of nematodes was found to be positively correlated with the amount of rainfall [75]. In Jayawijaya, however, burdens of pig parasites in traditional scavenging systems remain high throughout the year and do not seem to follow the rainfall pattern [3]. Therefore, seasonality may not be relevant for anthelmintic treatment in Papua.

S. zooepidemicus and S. suis

Prevalence

S. zooepidemicus was isolated in 15 % of cases of pig mortality in Jayawijaya but tonsillar carriers in healthy pigs were not detected. In contrast, *S. suis* was isolated in only 2 % of cases of pig mortality in Jayawijaya but the tonsillar carrier rate in healthy pigs was 8 % [127]. Slipranata et al. [165] reported a 24 % cumulative prevalence of *S. suis* in a 15-month longitudinal study, while Salasia et al. [151] reported an 11 % seroprevalence of *S. suis* in a cross sectional survey in Timika using muramidase released protein monoclonal antibody dot blot.

Impact on Pig Performance

S. zooepidemicus caused a fatal outbreak resulting in significant economic losses and remains a threat to the Chinese swine industry [94]. Sporadic zoonotic infections have also been reported from contact with infected horses [184] but zoonotic infection from pigs may be underdiagnosed. *S. suis*, on other hand, is known to be an important disease in modern pig industries and was associated with a fatal zoonotic outbreak in China in 2005 [197]. In pigs, *S. suis* caused ongoing weekly mortalities of 10–20 % of weaners and retarded the growth of affected piglets [185]. However, a study reported that infection of *S. zooepidemicus* and *S. suis* in dead pigs in Jayawijaya was 15 and 2 %, respectively [127] implying that in economic terms, *S. zooepidemicus* could be more important while *S. suis* may not be a major problem for Papuan farmers.

Co-infections

In pigs, fatal infection with *S. zooepidemicus* alone was rare but co-infections with either endoparasites, PCV2, or both, were more common [127]. Co-infection with *S. zooepidemicus* and non-hemolytic *E. coli*, PCV2, or PRRSV was reported in an outbreak in pigs in Vietnam [105].

Streptococcus suis occurs in co-infections with a broad range of pathogens including viruses such as PCV2, PRRS and SIV, and bacteria such as *M. hyopneumoniae*, *Pasteurella multocida* and *Haemophilus parasuis* [22]. The combination of PRRSV, PCV2 and *S. suis* was reported to be common in China [199]. Furthermore, co-infections among different serotypes of *S. suis* are common [39, 185]. It is interesting that a study of mixed infection suggested that *S. suis* serotype 9 partially suppressed the severity of infection with *S. suis* serotype 2 [133].

Transmission

Multiple species including pigs, monkeys, sheep, cows, goats, foxes, birds, rabbits, guinea pigs, dogs and horses potentially act as biological reservoirs for *S. zooepidemicus* [2, 150]. Information of other modes of *S. zooepidemicus* transmission is lacking.

Transmission of *S. suis* infection has been shown to occur effectively through direct nose to nose contact with diseased pigs [128]. Contaminated food has been suspected as a mechanical vector [99]. Airborne transmission of *S. suis* in confinement has been shown to be possible [17, 21]. In the Papua setting where pigs and humans live in close proximity [119], reverse transmission from humans to confined pigs might be possible, as human carriers of *S. suis* have been reported elsewhere [21].

Pathology

Clinically, *S. zooepidemicus* infection in pigs was reported to result in swelling of the joints, respiratory distress and diarrhoea, with most of the pigs dead within a few days. The post-mortem findings were polyarthritis, bronchopneumonia, pleuritis, epicarditis, endocarditis, and meningitis [150] and diffuse haemorrhagic pneumonia (Fig. 4).

Neurologic signs may be the most distinguishable in *S. suis* infection [61]. However, the most common clinical signs of *S. suis* infection were reported to be varying levels of coughing and sneezing, and ill thrift, with neurologic signs including lateral recumbency, paddling, ataxia and sudden death being less common [143]. The most common pathology identified during post-mortem was suppurative bronchopneumonia, usually secondary to enzootic pneumonia, and pleuropneumonia. Other gross lesions observed less commonly include valvular endocarditis, arthritis, vaginitis and abortion [1, 153].

Risk Factors

Factors contributing to the emergence of *S. zooepidemicus* in pigs are poorly understood. [127] reported the carriage of *S. zooepidemicus* in confined pigs to be negligible. This suggested that confinement might be preventative for *S. zooepidemicus* infection in pigs.

In contrast, studies of risk factors for *S. suis* infection are abundant. A study in Jayawijaya suggested that carriage of *S. suis* may be more constant in confined pigs than in scavenging pigs [165]. Full confinement of pigs is practiced by only 16 % of farmers in Jayawijaya [126] and this low proportion of confinement likely explains the very low prevalence of *S. suis* in cases of pig mortality. Factors in confinement that allow establishment of *S. suis* in Papuan pigs are unknown.

Accumulation of *S. suis* serotype 2 has been reported to be at a higher level over a long period in confined pigs suffering *S. suis* clinical cases compared to those pigs confined without *S. suis* cases [21]. Airborne transmission of *S. suis* in confinement was demonstrated [17], implying that closed buildings could play a role as a niche for aerosolisation of *S. suis*.

The role of effective ventilation has not been studied in infection with *S. suis*. However, one study suggested that maintaining effective air flow inside pig buildings could reduce respiratory infections [163], which comprised half of the manifestations of *S. suis* infections [1, 143, 153]. The majority of traditional pig farms in Papua, however, are fully closed without even a simple open sided window [126]. Social factors in Papua such as a high occurrence of theft might hamper implementation of ventilation in pig buildings.

Herd size may not be a risk for *S. suis* infection. Among herds within sizes of 14 head to thousands of pigs, the number of groups infected and the total morbidity in the herd were not significantly different [142, 185]. Likewise, pig density may not be consistent with the carrier rate of *S. suis*, for example in a German National Park where the pig density is very low, the carrier rate of *S. suis* of various serotypes was as high as 92 % [15]. This contrasts with Papuan data showing low level of *S. suis* infection in free ranging pigs with low stocking density [127, 165]. The reason for this discrepancy is unknown.

Serotype 2 has been recognised as a dominant cause of clinical *S. suis* infections both in pigs and humans worldwide [61]. Serotype 2 was dominant among strains recovered from diseased pigs in a Chinese study [189] but the carrier rate of serotype 2 in healthy domestic pigs in China was as low as 3 % [198]. In wild pig populations where the pig density is very low, serotype 2 carriage can vary from as much as 58 % in one place to nil in other places [15]. Other studies suggested that herd size influences the carrier rate of serotype 2 [118, 131]. These phenomena imply that the burden of specifically serotype 2 rather than any *S. suis* in general could better express the health status of a herd. The prevalence of *S. suis* type 2 in Papua, however, remains unknown.

Some particular daily farm managements may play some role for prevention of *S. suis* infection. A retrospective study reported that mortality in nursery farms decreased from 20 to 3 % when a regimen of a more constant number of pigs weaned weekly was applied (reflecting less fluctuation in weekly stocking density). Increasing weaning age and weight, lowering pig density, controlling temperature fluctuation, and improvement of sanitation were not correlated with a reduction of pig mortality [185]. Another study suggested that mixing pigs from different litters after weaning increased the risk of *S. suis* serotype 2 infection [118].

Control Measures

Antibiotic use for *S. zooepidemicus* and *S. suis* has been intensively studied. However, susceptibility of Papuan *S. zooepidemicus* strains to antibiotics has not been studied. Reports of antibiotic susceptibility of pig *S. zooepidemicus* strains from other locations are also lacking. Ceftiofur, ticarcillin, trimethoprim-sulfamethoxazole, cephalexin, amoxicillin, ampicillin, penicillin, enrofloxacin and doxycycline, have all been reported to be efficacious against *S. zooepidemicus* in dogs and equines [29, 42, 93].

In contrast, antibiotic efficacies against *S. suis* isolated from pigs have been extensively evaluated. In Europe, susceptibility of *S. suis* to amoxicillin/clavulanic acid, ceftiofur, enrofloxacin, florfenicol and trimethoprim/sulfamethoxazole is reported for 91 % to 100 % of isolates [46]. Resistance was very high for tetracycline, lincomycin, tilmicosin, erythromycin and tylosin [30]. A similar pattern of resistance was reported in China, with the addition that the antibiotic resistance rate among *S. suis* isolates was very low, below 1 % for cefaclor and ceftriaxone, but high for azithromycin and clindamycin at around 67 % of isolates studied [37]. Intravenous benzylpenicillin and gentamicin followed by oral amoxicillin was successful for the treatment of human case of *S. suis* [177] but their benefit in controlling outbreaks in pig herds has not been apparent [67, 185].

Vaccines against *S. zooepidemicus* infection have been developed only recently. A recombinant vaccine based on the M-like protein was able to protect 70 % of mice [86]. A combined recombinant vaccine against *S. zooepidemicus* and PCV2, based on an M-like protein of *S. zooepidemicus* and a capsid protein of PCV2 was able to protect 87 % of immunised Bama mini-pigs from a dual challenge [87]. However, to date no commercial vaccine is available for *S. zooepidemicus* in pigs.

Vaccine development based on killed organisms (bacterin), subunit protein or live attenuated bacteria has been widely studied for *S. suis*, with varied results. Experimentally, vaccination with *S. suis* serotype 2 bacterins resulted in levels of protection against homologous challenge of 100 % protection from morbidity [192], to 49–71 % for reduced mortality [14, 130], depending on the strain used and the route of vaccination. Experimental vaccination of sows with *S. suis* type 2 bacterin resulted in passive immunity of their piglets, which protected 67 % from morbidity following a homologous challenge at 6 weeks of life [13]. Subunit vaccines using Murein Associated Protein only protected 12 % pigs from mortality after a homologous challenge [14]. Mice immunised with substrate binding protein (Sbp) of *S. suis* type 2 had a 70 % increase in survival from homologous challenge; detailed morbidity however, was not reported [201]. In a mice model, surface-anchored DNA-nuclease (SsnA) of *S. suis* serotype 2 adjuvanted in aluminium hydroxide protected 100 % against mortality after a homologous challenge, with only 33 % of mice suffering mild septicaemic signs (rough coat, moderately swollen eyes, or depression), which subsided after 2 days post-challenge [58]. A mutant strain ΔSsPep/ΔSsPspC of *S. suis* serotype 2 was reported to protect 90 % of mice from mortality against lethal challenge. However, morbidity was not clearly reported [68].

While many experiments have been conducted for *S. suis* type 2 with some promising results, a serotype 9 bacterin completely failed to protect pigs against homologous challenge [48]. Also, serotype 2 bacterin was reported to only cross-protect 33 % of pigs against mortality following infection with serotype 9 [14]. The lack of cross protection was also reported from different strains within serotype 9 [28].

In nature, different strains of *S. suis* can be isolated from a herd or from an animal at the same time [39]. Furthermore, different serotypes can cause clinical disease consecutively, such as in a *S. suis* serotype 7 outbreak. Three months after the introduction of a homologous vaccine subsequent cases of mortality were caused by mixed serotype 4/8 infections [185]. This may hamper the use of *S. suis* vaccines against natural challenges as it may be unknown what level cross protection against different circulating serotypes these vaccines will be able to provide. Practically, effective vaccines against *S. suis* are currently lacking [162]. For Papuan pigs vaccination against *S. suis* may not be warranted since the contribution of *S. suis* to mortalities and its prevalence in healthy pigs was found to be very low [127].

Designing Locally Adapted Controls of Pig Diseases in Papua

Before possible control techniques are introduced to local farmers, it is important to bear in mind that many Papuan farmers have very little knowledge as to what should be

done to reduce the incidence of disease or even what diseases are present or absent from their farms [126]. Therefore, the involvement of the local veterinary authority is vital in introducing farmers to suitable methods of biosecurity, such as a basic knowledge of good farming practices, disease recognition, vaccine application and anthelmintic treatment. Control programs may be introduced firstly to regions with high pig density and regions with available veterinary staff. When a program has achieved observable success in those regions, it may be disseminated to the remaining areas.

In all control approaches, the confinement of pigs should be a prerequisite and accompany any disease control program. Confinement has been shown to reduce the risk of parasitism, CSF, infection with *S. zooepidemicus* as well as pig cysticercosis in Papua [3, 9, 127]. Furthermore, without proper confinement, other interventions such as vaccination may be more difficult to assess; pigs may have an increased chance to be infected with other pathogens just after the vaccine administration and the owner could believe that the sickness or death which occurs post-immunisation is due to vaccination. Confinement was reported to increase the risk of PCV2 infection [183] and *S. suis* infection elsewhere [17]. However, the confinement prevented pigs from being exposed to co-factors of PCV2 infection such as CSFv and *Metastrongylus elongates*, which are necessary for PVCD to emerge [103, 127]. In the case of the small scale pig farms in Papua, the positive effects of confinement for pig health maybe outweigh its potentially negative impacts.

In addition to the pig confinement campaign, farms can be expected to be an open population where new pigs move in and out. Therefore, any new incoming pig may need to be quarantined and monitored for signs of sickness and for prior treatments such as vaccination and anthelmintic treatment before being allowed to be mixed with other animals in the farm. Further, applied feed processing technologies should be implemented on pig farms to improve feed quality in confinement pig farms to reduce the problem of feed provision in confined pig farming systems.

Control of classical swine fever should be the first priority after confinement is initiated. Classical swine fever is clearly the most economically important pig disease in Papua currently. The history of big outbreaks in three regions in Papua shows how devastating this pathogen is while other diseases are presenting more subclinically or with lower prevalence. Vaccination against CSFv would be an important option, potentially helping to improve overall pig performance in Papua. Vaccination of sows a week before insemination, using an injectable preparation and their piglets at 5 weeks of age may be conducted year round to achieve complete protection of a farm.

Vaccinations have been conducted in regions such as Timika and Jayapura. While it seemed to have become routine in the city, its delivery in the rural areas apparently faces logistical problems that affect proper field transport of the vaccines during mass administration, where vaccines sometimes were seen to be kept in a box with warm temperature. The temperature of vaccine during storage and transport is a critical factor in vaccine quality maintenance. However, recent studies indicated that suboptimal temperature of vaccine during storage and field transports were likely a problem in hot climates of tropical areas. In India, at all storage and transport levels, up to 18 % of the total time vaccines were kept in suboptimal condition, either subzero or above 8 °C, with up to 88 % of total boxes observed affected. Temperatures above 8 °C were more common [122]. Another study in New Guinea reported suboptimal vaccine temperature with freezing as a more common finding [191]. In Papua, even in the city area, there has not been an evaluation of the cold chain for the CSF vaccine.

Annual surveillance needs to be undertaken in monitoring the effectiveness of CSF vaccination. In this regard, the Disease Investigation Centre (DIC) Maros, the central laboratory at Sulawesi which covers animal disease control in Papua, should prioritise regions in Papua with high pig density in their survey and share the result of a survey promptly with local veterinary authorities so as action plan for the control strategies in the coming year can be based on the most updated evidence. Furthermore, updated scientific information on pig diseases, diagnoses and control methods should be disseminated by the central laboratory to local veterinarians regularly. Prioritisation of particular regions for disease control is important for DIC Maros, as this diagnostic laboratory covers a large area of 10 provinces in Eastern Indonesia.

It is difficult to assess the subclinical infection status of a pig prior to CSF vaccination and a clinical sickness could occur post-vaccination. While confinement reduces the risk of exposure of animals to pathogens post-vaccination, there is still a risk of vaccine failure or post-vaccinal adverse effects due to a subclinical infection prior to vaccination. Informed consent prior to vaccination and good communication between the veterinary authority and farmers is crucial, especially when a case of post-vaccinal adverse effects occur.

Eradication of CSFv through a test and cull strategy is currently impossible in Papua for several reasons: CSFv is currently widespread in the province and might have crossed provincial borders; there are currently no regulations in place to control transport of pigs or to isolate an endemic location from other areas; the population of wild pigs and their distribution is unknown; seroprevalence is greater than 50 % making the cost of culling prohibitive; the majority of domesticated pigs scavenge freely, facilitating transmission among pigs through direct contact;

currently there is not available a simple rapid diagnostic tool; the capability of local government to pay and manage compensation is also doubtful given that even less expensive program; vaccination, have not been run properly and the willingness of farmers to cooperate in letting their pigs be slaughtered is unknown.

A series of studies to answer abovementioned gaps in knowledge are needed before we can construct a pathway towards an effective test and cull policy to eradicate CSFv from Papua. Vaccination, therefore, is currently a more reasonable approach than test and cull, as the cost per animal is much lower and vaccination provides insurance from economic loss.

Culling may be still important for CSF-PI pigs which continuously shed virus. A PI-culling program should include educating farmers on the clinical signs of suspected PI pigs which are usually stunted, and the role of PI pigs in CSF transmission. Voluntary culling by knowledgeable farmers should be prioritised, rather than implementing a government-subsidised forced test and cull.

Even if pigs are confined and CSF is controlled, parasitism would still be a problem, especially species with a direct life cycle such as *T. suis* and strongyle parasites. It has been documented that the prevalence of *T. suis* and strongyle parasites in fully confined pigs were 8 and 22.5 %, respectively [127]. Anthelmintic treatment is still needed, especially for newly introduced pigs during the quarantine period. In addition, it was recommended to treat sows and gilts at breeding and just before farrows and their progeny twice during the weaning and fattening period [146]. This regime, however, may be too much for most Papuan farmers who are not well educated and may have limited access to veterinary services. A simpler anthelminthic regimen needs to be set up following a governmental program of monitoring of the level of parasitism in confined pig systems. The frequency of monitoring can be adjusted to the available budget but an initial arbitrary frequency of twice a year can be used. Veterinary preparations of Oxfendazole should be made available for farmers when needed.

For bacterial infections, as farm size is small, the use of antibiotics to treat sporadic cases may be useful after a diagnosis of *S. zooepidemicus* or *S. suis* has been made by a veterinarian [77, 177]. Suitable antibiotics for both pathogens, such as Amoxicillin/clavulanic acid, enrofloxacin, or trimethoprim/sulfamethoxazole may be used [29, 42, 46, 93].

Education, although there have been ongoing debate on its effectiveness in pig disease control such as that in cysticercosis control [85], was indicated to increase the rate of pig confinement in Peru and Mexico [43, 154]. A training program was also reported to be success in disseminating feed processing technologies in Jayawijaya [98]. Therefore, education on good farming practice should accompany any other control methods. It is always important to build a good relationship with elders of a community in rural area before a program started. Once a program is approved by the elders, it may be intensified by developing a systematic pig farming educational program that builds proper understanding by local farmers on what they should do to reduce pig disease and mortality.

Continuous education programs for farmers should at least include emphasising the benefits of confinement and applied feed processing technologies such as heat treatment and ensiling. Other subjects include increasing the frequency of feeding, regular cleaning of pig pens, anthelmintic treatments, CSF vaccination, the identification of clinical signs of various diseases, recognition of gross pathology and the reporting mortality cases. The culling of suspected CSF PI piglets may also be an important subject to address. An evaluation is needed on how to improve the quality of training methods in times to come.

Knowledge of the ecology and epidemiology of pig diseases in Papua is still largely lacking. Future studies should be aimed at field trials and evaluation of the proposed methods of disease control in Papua. Suitable programs to educate farmers on good pig husbandry as a prerequisite for other control measures warrants development. Further study is needed to adjust the timing of vaccination using oral preparations, as protection will only be complete after 28 days post-vaccination [116]. This knowledge is important as the implementation of oral vaccination will minimise the need to train vaccinators. The impact of subclinical PCV2 infection on weight gain and reproductive performance of confined pigs needs further investigation. At the regional level, investigation is needed of the role of pig products imported into Papua in transmission of CSF and PCV2. Further, information on pig movements among the regions of Papua would assist in determining priority regions for future surveillance programs for CSF and PCV2. In addition, the epidemiology of pig diseases identified as of national priority in Papua, such as PRRS, H1N1 influenza and toxoplasmosis warrants further study.

Conclusions

Pig production is important for traditional communities in Papua, but high levels of pig disease and mortality constrain production and may also impact human health. A few major diseases and pathogens have been identified, namely CSF, cysticercosis, PCV2 infection, parasitism from *T. suis*, strongyle parasites and *S. zooepidemicus*. CSF, cysticercosis and helminthiasis are the high priority diseases to control. Using the three elements of

confinement, CSF vaccination and regular anthelmintic treatment would reduce natural infections. PCV2 infections, however, may remain as high as 30 %. Future studies should be aimed at a field trial of the proposed methods of disease control in Papua, an improved understanding of the effect of PCV2 infection in confined pigs as well as an understanding of the effects of the movement of pig products into and amongst the regions in Papua.

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Compliance with Ethical Standards

Conflict of interest None of the authors of this paper have a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

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