Introduction

1.1. Pigs as a domesticated animal

Pigs are widely reared livestock species around the world for production of red meat. Adaptable to any climate and less prone to diseases, they have played a significant role in various cultures around the world, serving as essential sources of food. One of the greatest contribution of pigs in the field of medical sciences is, genetically modified pigs. They are used as an organ xenograft donor as their immune system, organ size and physiological metabolism are considered similar to that of human beings (Xi et al., 2023).

Pigs (*Sus scrofa domesticus* L.), belonging to the family of 'Suidae' are omnivorous, even-toed, ungulate mammal. It is evident that present day domestic pigs are descendants from repeated domestications of wild boar which are believed to have occurred 9000 years before present (YBP) in Asia and Europe (Giuffra et al., 2000; Bokonyi, 1974). According to UN Food and Agriculture Organization (FAO, 2021), China is the highest producer of pig meat with approximately 54.8 million, followed by Europe by 29.7 million and United States by 23.3 million. Pork is one of the easily accessible red meats with superior quality protein and specific nutrients (Ritchie et al., 2017). Pork (9.5 %) has lower environmental effects in terms of greenhouse gas emissions, when compared to dairy (30.1 %) and beef (35.3 %) (Drewnowski, 2024; Shurson and Urriola, 2022). This nutrient-rich, affordable red meat has been highly valued by national and international agencies such as FAO, WHO, and EFSA for its essential role in nutrition and food security (FAO, 2017; Herforth et al., 2020). Pig-meat, comprising over a third of global meat production and its demand is likely to increase in future (MacLeod et al., 2013). In a 100 g of lean pork, according to USDA (2022), it contains considerable quantity of protein, zinc, iron, magnesium, selenium, potassium, sodium, thiamine and vitamins, contributing more than 10 % in the daily human intakes and maintains the quality of the diet (Murphy et al., 2011; An et al., 2019; Nolan-Clark et al., 2013). Recent studies by Wade et al. (2019) and Stettler et al. (2013) stated that consumption of pork provides benefits to cardiovascular and cognitive health, and reduce the risk of metabolic and functional limitations in older adults.

Taste is one of the main criteria that draws attention of the consumers. The sensory characteristics i.e., colour, flavour, juiciness, tenderness and marbling of the pork is

highly correlated with its intramuscular fat content (IMF) (Poklukar et al., 2020). Wu et al. (2022) suggested that, mono-unsaturated fatty acids (MUFA) such as oleic acid and poly-unsaturated fatty acids (PUFA) such as DHA (docosahexaenoic acid) and ALA (alpha-linolenic acid) contribute to taste of the pork and other organoleptic attributes. Furthermore, saturated fatty acids (SFA), another type of fatty acid are primarily linked to obesity, insulin resistance, and cardiovascular disease (Li et al., 2019). However, fat consumption cannot be entirely avoided, as it provides essential nutrients that support overall health and help protect against diseases such as cancer and rheumatoid arthritis (Reyes et al., 2004). Additionally, lipids such as sphingolipids, glycerides and glycerophospholipids are also known to have highly profound benefits to human health (Sun et al., 2020).

Amino acids, on the other hand are the building blocks of protein, providing essential nutrition and contributes to the flavour and taste of meat (Khan et al., 2015; Chen and Liu, 2004). The flavour is due to the degradation of peptides forming Maillard reaction, where a complex reaction occurs between the amino and carbonyl components, bring about different kinds of volatile substances that add flavour and taste to the meat (Jalbout et al., 2007). For instance, according to Shahidi, (2001), the amino acids arginine, valine, histidine, methionine, isoleucine, leucine, tyrosine, tryptophan and phenylalanine are known to bring bitter taste to the meat (Lee et al., 2016). While sweet taste is contributed by serine, alanine, threonine, lysine, glycine and proline (Shahidi, 2001). Salty taste is contributed by sodium aspartate and sodium glutamate and sour are contributed by asparagine, histidine, aspartic acid and glutamic acid (Lee et al., 2016). Previous works determined the organoleptic characters including other biochemical analysis that define the quality of pork in different muscles dissected from different regions of the pig carcass (Kim et al., 2008; Daimari et al., 2022a; Cho et al., 2005; Lin et al., 1985).

Other than the consumption of pork, the consumption of viscera like kidney, liver, intestines (called con-carcass components) are also observed. These viscera are highly consumed in Asian countries including India, France, South Africa, Egypt, Italy and Spain (Zeng et al., 2022; Nollet and Toldra, 2011). These non-carcass components contain high amount of macro- and micro-elements, vitamins, folate etc., required by human body (Pereira and Vicente, 2013; Cordain et al., 2002). They are also rich in essential fatty

acids, particularly arachidonic acid, and the omega-3 fatty acid like EPA and DHA (Park and Washington, 1993; Nicklas et al., 2014). These edible by-products of pig-meat are considered as one of the nutrients dense foods. It plays a significant role for the people who have limited access to other nutritious foods (Oloruntoba and Nathaniel, 2019). There are only a few studies and limited data available about the nutritional composition and its benefits (Seong et al., 2014; Oloruntoba and Nathaniel, 2019; Daimari et al., 2022b).

1.2. Pork production of India

India's contribution to the world in pork production is only 5.23 %, however, the major share to India's pork production comes from the northeastern regions which is about 38.5 % (Livestock census, 2012). The rearing of pigs in this region involves traditional way of rearing by local pork consumers. It is also been observed that, in northeastern regions there is no restriction regarding the consumption of pork and its by-products, thereby there is a huge potential for development of piggery sector in this region. According to data from the Department of Animal Husbandry and Dairying (2019), among the northeastern states of India, Assam has the highest pig population, estimated at 2 million.

Assam is known for its diverse topography delivering a wide range of diverse biodiversity. Geographically, Assam spans a diverse landscape, encompassing both hilly and plain terrain. This geographical diversity makes the region suitable for pig rearing, as pigs thrive in various environmental conditions. In both hilly and plain terrain, pig rearing is regarded as ecologically fit (Banik et al., 2022). The climate in Assam varies across its different regions. The plain areas experience a tropical climate, while the hills exhibit a sub-alpine type of climate. During the winter months, temperatures can drop to as low as 6° C, while in summer, they can rise to a maximum of 39° C. The region receives significant rainfall, with an annual average ranging from 1400 to 3000 mm. The monsoon season, extending from mid-April to mid-September, brings bulk rainfall, with the highest precipitation occurring between June and August. Conversely, the period from November to February typically experiences minimal rainfall. This climatic and geographical diversity contributes to the rich biodiversity of Assam and plays a significant role in

shaping the agricultural practices, ecosystem dynamics, and overall livelihoods of its inhabitants (Deka et al., 2007).

Assam is a state with various indigenous communities viz., Bodo, Rabha, Missing, Deori, Sonowal, Karbi, Dimasa, Kuki, Hmar, Hajong etc. (Banik et al., 2020; Thomas et al., 2021). In this region of India, pigs hold a prominent position as the most valued and popular livestock species to be domesticated. They serve as vital income-generating sources for the communities. The popularity and significance of pig farming is favourable, including the adaptability of pigs to diverse environmental conditions, their efficient conversion of feed into meat, and their relatively low maintenance requirements compared to other livestock species. As a result, pig rearing plays a crucial role in the socio-economic improvement of the region, providing livelihoods for many households and contributing significantly to the economy of the families (Chauhan et al., 2016). The type of pig rearing/domestication in Assam is smallholder pig rearing system. Such production system is regarded as economically feasible and sustainable as it is driven by locally available resources, with minimum scientific intervention (Kumaresan et al., 2009). In this type of rearing system, among various livestock production practices, pigs stand out as significant contributors, accounting for approximately 56 % of the global pig population. This substantial share underscores the importance and widespread presence of pig farming in agricultural landscapes worldwide (Riedel et al., 2012). Small-holder pig farming also plays an important role in South East Asian countries such as Vietnam, Thailand, Singapore, Malaysia, Indonesia, Philippines, Cambodia, China etc. In China, recognized as the world's largest producer of pork meat, a substantial portion, ranging from approximately 50 to 80 % of pigs are raised within the small-holder pig production systems (Neo and Chen, 2009).

The pig rearing or domestication type followed by the ethnic groups of Assam, are scavenging and backyard type. In scavenging system, the pigs are moved from one place to another within the breeding tract in the search of food (Banik et al., 2016). In this system, there is no permanent pigsty, but during reproduction and farrowing period, a temporary housing is provided. The herd size is about 120 to 150 cared by large number of pig farmers. However, now-a-days, the scavenging rearing system is declining. Documentation of such types of rearing is not done and if done it is very poorly characterized (Rahman et al., 2020; Banik et al., 2020). While in backyard rearing system

also known as semi-intensive rearing system, the number of pigs is 2 to 7. In this system, half-walled houses are provided made of wood and bamboo, that is situated nearby the residence of the pig owner; special care is taken for the pregnant and diseased animals. In the backyard rearing system, girth tethering is observed more commonly, here the pigs are tied around neck with a rope supported by a tree or concrete rod (Doley et al., 2022).

The pigsty or housing practices preferred by farmers consists of mud floors, and in some cases, cement floors are observed. The enclosures made of bamboo, wooden or cement are built about 4 to 7 feet above ground. The roofs are mostly made of thatch and rice straw, while some also make use of plastic tarpaulin to cover the roof (Doley et al., 2022). Chang-ghar, a temporary traditional basement shelter is made about 3 feet above ground is also observed in most of the ethnic communities (Banik et al., 2020).

1.3. Feed provided in smallholder pig rearing systems

Raising pigs for meat through traditional methods is a common practice in northeast India. Traditional method uses kitchen waste as feed which is an efficient approach for meat production and income generation, particularly benefiting the ethnic communities of this region. For instance, one of the most popular ethnic groups i.*e.,* 'Bodo', are known for their rich culture and other traditional practices (Kalita, P. 2019). They are the largest ethnic community of northeast India, residing mainly in and around Brahmaputra valley of Assam. Their livelihood primarily relies on agriculture, with pig rearing serving as a crucial component alongside rice cultivation. The pig rearers use the locally available and affordable feed sources. The feeds include kitchen waste (such as leftover cooked rice), seasonally available vegetables (like pumpkin, casava and sweet potato etc.) and agricultural by-products like rice-bran and rice-polish.

1.4. Cultural and Economic significance of pigs in smallholder rearing systems

Smallholder pig farming in northeast India is considered culturally and traditionally unique (Das and Bujarbaruah, 2005). Piglets and fattened pigs are highly demanded in markets and for farmers, it is a quick source of income. It also improves the economic status of the farmers and food security. Pigs have the ability to convert kitchen waste into animal protein that can be consumed (Doley et al., 2022; Chauhan et al., 2016). This type of rearing system helps the owners in many ways like, source of protein and

minerals, acts as insurance in the time of scarcity and during periods of emergency. Income generation from pork production including other by-products of pig and processed foods of pork contributes about 56 % of the world's pig production, providing a direct and indirect employment to the pig farmers (Lemke and Zarate, 2008).

Pigs are regarded as economical and sustainable livelihood option. At the same time the pig's excreta can be utilized as a fertilizer to improve the fertility of the soil, therefore helping in the better production of crops (Nguyen et al., 2016; Do et al., 2022; Ho et al., 2022). The feeding of commercial diet or the balanced concentrated feed is not practised by smallholder pig farmers as they are not available all the time due to lack of knowledge of its usage and high cost (Singh et al., 2019). As a result, alternative food sources from kitchen waste are preferred by farmers in rural areas. Its use can be significant for sustainable environment and for the maintenance of system's economic viability.

1.5. Production of pork in northeast part of India

Assam and the other northeastern states of India economically lag behind than other parts of India due to geographical isolation, insufficient infrastructure etc. However, contribution towards India's share of livestock production, especially pork production, the northeast contributes the highest. Livestock farming is the most important income generating farm activities seen in whole of northeast region of India. It is also an important source of protein among the consumers. The consumption of pork, among the animal meat is highly demanded in this region. The estimates of pork-meat production among the northeastern states of India, Assam's performance was the highest for the year 2022-23, with 21.96 metric tonnes (25%), followed by Meghalaya with 17.93 metric tonnes (20%) and Tripura with 17.42 metric tonnes (20%) (Figure 1.a.). The consumption of pork among the northeastern states, Assam has the highest amount of consumption (18789.35 kg), followed by Nagaland (5843.80 kg) (Mahajan et al., 2015). Notably, approximately 90 % of pork consumption in northeast India occurs in rural areas, indicating a significantly higher demand compared to urban regions.

According to recent data, per capita consumption of pork in rural (0.61 kg/annum) area was high than urban (0.09 kg/annum) region (Deka et al., 2007). The slaughter of

pig is generally performed in the local market situated in different districts of Assam. Demand for fresh pork-meat is higher than processed pork. Although consumption of pork is mostly associated with ethnic communities, however with changing food habits and lifestyle, consumption of pork among other communities is also increasing (Deka et al., 2007) in Assam. Though fresh pork-meat is preferred in most occasions, processed meat is also a part of culture and tradition in many ethnic groups of Assam (Shyam, 2015).

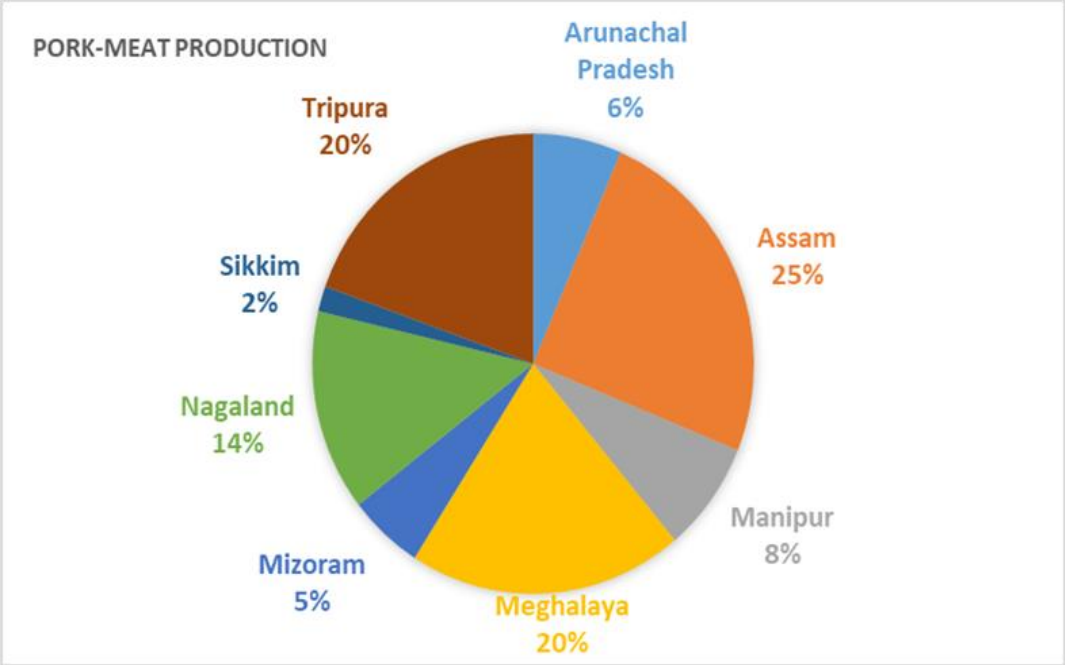


Figure 1.a. Production of pork in northeastern states of India (Source: Basic Animal Husbandry Statistics, 2023).

Taste is one most important criterion, while purchasing meat, and pork is regarded as more tasty, tender than meat of other animals (Borah et al., 2017). The processed pork prepared by ethnic groups is performed to improve its palatability and extend its self-life by making use of traditional methods (Borah et al., 2018). However, the making process may differ from region to region and place to place and among the ethnic groups, due to its availability of the ingredients (Kadirvel et al., 2018). The preservation method used by various ethnic groups is common and basic, like drying, salting, drying plus salting, smoking or by fermenting. The usage of local herbs, roots, leaves, seeds, liquid extracts of vegetable, oils and spices are observed. Most of these processed pork products are kept at room temperature for months and years. One of the most common ways of preserving

excess pork is the pork pickle, which is observed in all the states of northeast India (Hazarika, M. 2013). Traditionally prepared processed pork products by various ethnic groups of Assam are tabulated in Table 1.1.

Table 1.1. Traditionally prepared processed pork products by ethnic communities of Assam.

Local names of the products	**Prepared by (ethnic groups)**	**Description**
Cheu	Deori	Half-boiled pork chunks are combined with salt, chilli and turmeric, followed by roasting over charcoal placed inside bamboo.
Khaophram/ Eg-adin banum	Bodo and Mishing	Semi-cooked boiled pork pieces are mixed together with local spices, followed by roasting over fire until the pork turns brown.
Asan adin	Mishing	Boiled pork pieces are smoked and dried for 2 to 3 days. After smoke-dried, it is wrapped with Phyrnium spp. leaves (Ekkum) and stored for over 2 weeks (mostly during winter).
Eg-adin Luktir	Mishing	The half-cooked and dried pork pieces are combined with dried bamboo shoot, chilli, spices and locally prepared herbs.
Ashikioki	Kuki	Dried pork pieces are either fermented with bamboo shoot or soybean.
Sathu	Hmar, Kuki and Hajong	The fat part of the pork is half-boiled, followed by storing inside the water gourd (sathu) for 4 to 5 days. Later used in various curry.
Saphak	Hmar, Dimasa, Karbi, Hajong and Kuki	The boiled fat pieces are kept in air tight container to be used in variety of curry.
Noausoum	Karbi and Dimasa	Along with boiled pork pieces, boiled rice is spread over and tightly stored in bamboo container and sealed to allow the fermentation process to occur.
Honohein	Karbi and Dimasa	Boiled dried pork is dried and used for curry.
Oma gwran	Bodo	Boiled pork pieces are sun-dried or smoke-dried and stored and used as a curry with medicinal herbs.

Source: Author's collection and research articles (Hazarika, 2013; Borah et al., 2018; Borah et al., 2017).

1.6. Pig breeding and marketing observed in northeast India

There is no specific method or time for breeding of pigs used by the pig farmers in small-holder systems. There is also no maintenance of systematic selection of boars (male pig usually of six months old used for breeding) and sows (female pig ready to reproduce) for breeding to maintain the purebred lines or specific female and male ratios. The pig farmers are more concern regarding the number of piglets and their survivability rather than its genetic composition. In many of the house-holds, a boar is made to breed with 4 to 5 sows naturally, by bringing at the pen or pigsty. The farmers that do not bear boar, they use boar from the neighbours to breed. In certain areas, artificial insemination is also done (Rahman et al., 2008; Shyam et al., 2017; Deka et al., 2007).

The earliest age at which the boars breed naturally is 8 months, while for sows the sexually reproductive age begins between 8 and 9 months. The gestation period lasts for 114 days and can again reproduce after one month of weaning. Pigs, after attaining the desirable age of sexual maturity, the farmers mate the pigs at the month of June to September, which is the ideal time following which they plan to sell the litters born during the month of October to January at high prices starting from December to January. Earlier reports suggest that, heavy and huge litters tend to occur when birth and weaning are performed during post monsoon season (Deka and Bordoloi, 2004; Roychaudhury, 2005), whereas others reported that large numbers of litter size are seen during pre-monsoon (Kalita et al., 2001). Most of the smallholder pig farmers take advantage of high price of the piglets that occurs seasonally. As a result, farmers adopt early weaning practices; therefore, reproductive traits such as weaning age and litter size at birth are considered important for the profitability of pig farming (Banik et al., 2022; Deka et al., 2007).

1.7. Constraints/limitations of smallholder pig rearing systems in Assam

The smallholder pig rearing system holds an important significance in livelihood of many ethnic groups of Assam. For some, it is the only way of source of income. Even though such rearing system is observed in many parts of northeast India, including other Asian countries, it is lagging behind in terms of other facilities and poor management systems. Some of the major constraints of smallholder pig production system in Assam are:

- According to Nath et al. (2013), the practice of smallholder pig rearing system has high chance of leading to imbalanced nutritional diets causing stunted growth of the pigs, as the farmers cannot afford commercial feed due to their high prices and in most cases, they are not available.
- In such system, a hygienic and suitable housing and shelter is lacking as a result exposing the pigs to pathogenic diseases. They are also exposed to bad weather conditions.
- There is high inbreeding due to increased use of own pig stock and of neighbours, causing low production of piglets and litter size. Therefore, while marketing, the best stock of breeding pigs hardly goes to the market (Nath et al., 2013).
- Even though, pork consumption is high, lacunae are seen between the demand and pork availability. This can be due to the fact that most of the reared pig breeds are non-descript and growth rate is poor resulting with low productivity outcome.
- In this system, infestation by parasites was observed very commonly due to lack of regular deworming process or vaccination among the pig farmers.
- One of the most common pig diseases called swine flu, has affected the pig farmers very badly leading to stunted growth and less market value. It has not only infected one or three, but whole herd of pigs were infected leading to financial loss as well as economic loss to the farmers (Tuyen et al., 2005; Ouma et al., 2013).
- Another most common disease seen in such system is the diarrhoea, causing devastating effects. These types of diseases are observed due to lack of awareness of the farmers, lack of hygienic measures and poor preventive measures of diseases. One of the major constraints of smallholder pig production system is losses related to diseases (Riedel et al., 2012; Phengsavanh et al., 2010).
- The farmers do not give importance to the technology, services and information provided by some institutes or organization of the government, they remain unattended and uncared (Haldar et al., 2017).

1.8. Opportunities for the development of pig farming in Assam

The indigenous pig breeds of India have a huge potential for improvement given that it is diversified and have good reproductive performance (Boro et al., 2016). Even though there are constraints regarding rearing of pigs, which mainly due to lack of knowledge of rearing pigs in systematic way including lack of modern technology and

facilities. However, when given right opportunities, there is a prospect in the field of pig production development. Due to the active participation of local people in the rearing of pigs, their food preferences and absence of any social or cultural taboos against the consumption of pork and its products in Northeast India, there is a scope for pig farming development (Rahman et al., 2020). With the proper guidelines and initiatives from the Government, the farmers can earn a high profit with less death rates of the pigs. As there are no taboos on consumption of pork and its by-products, the small-holder pig farming will play a significant role in the country's pork industry. They can rear pigs to get maximum benefit even in low-cost management system, if given proper knowledge and training. Following are the important factors that should be highlighted to uplift the development of pig rearing system in Assam and northeast India:

- Initiatives taken by the government to educate the farmers on pig management system by conducting training like, maintenance of hygiene by cleaning time-to-time with disinfectants or lime powder to kill harmful bacteria and pathogens, taking care of the litters, pregnant sows etc.
- Keeping records of the animals.
- Time to time services by the veterinarians for assessment of health conditions of the pigs for better productivity.
- Along with the feeding of locally available food stuffs, there should be introduction of concentrated feed too to meet the need of balanced diet.
- Educating the farmers about the importance of vaccinating pigs against swine flu and other diseases such as deworming vaccines to prevent parasitic infections, is essential.
- Introducing the farmers to new technologies and marketing strategies.
- Most of the pigs are fattened to receive good amount of price, therefore it should be encouraged to the farmers to keep both male and female breeding stocks to achieve good numbers of piglets and gaining more profit from simple practice of pig breeding (Halder et al., 2017).

This will not only increase the income of the pig farmers but also improve the economic status of households of various ethnic pig farmers as well as other landless farmers.

1.9. Indigenous pig breeds of India recognized by Indian Council of Agricultural Research-National Bureau of Animal Genetic Resources (ICAR-NBAGR)

In India, there are 14 registered indigenous pig breeds recognized by the Indian Council of Agricultural Research - National Bureau of Animal Genetic Resources (ICAR-NGABR - ISO 9001: 2015), with the aim to preserve their genetic resources to ensure their sustainable utilization and to support livelihood. The registration number and home tract are depicted in Table 1.2. Of the 14 registered pig breeds, seven (7) are from Northeast India. They are Niang Megha, Tenyi Vo, Doom, Zovawk, Mali, Manipur Black and Wak Chambil. Other than these 7 recognized pigs, Ghungroo whose original breeding tract is West Bengal, is reared in Assam.

Table 1.2. Registered Indigenous pig breeds of India.

Sl. No.	Pig breed	Home tract	Accession number
1	Ghoongroo	West Bengal	INDIA_PIG_2100_GHOONGROO_09001
2	Niang Megha	Meghalaya	INDIA_PIG_1300_NIANGMEGHA_09002
3	Agonda Goan	Goa	INDIA_PIG_3500_AGONDAGOAN_09003
4	Tenyi Vo	Nagaland	INDIA_PIG_1400_TENYIVO_09004
5	Nicobari	Andaman & Nicobar	INDIA_PIG_3300_NICOBARI_09005
6	Doom	Assam	INDIA_PIG_0200_DOOM_09006
7	Zovawk	Mizoram	INDIA_PIG_2700_ZOVAWK_09007
8	Ghurrah	Uttar Pradesh	INDIA_PIG_2000_GHURRAH_09008
9	Mali	Tripura	INDIA_PIG_1900_MALI_09009
10	Purnea	Bihar and Jharkhand	INDIA_PIG_PURNEA_09010
11	Banda	Jharkhand	INDIA_PIG_BANDA_09011
12	Manipuri Black	Manipur	INDIA_PIG_MANIPURIBLACK_09012
13	Wak Chambil	Meghalaya	INDIA_PIG_1300_WAKCHAMBIL_09013

14	Andamani	Andaman & Nicobar	INDIA_PIG_3300_ANDAMANI_09014

1.10. Indigenous pig breeds of Assam recognized by ICAR-NBAGR

In order to conserve the genetic diversity of pig, its meat quality characteristics for future livestock expansion and development, it is necessary to put greater importance on the improvement of native pig breeds (Serrano et al., 2008).

The pig breeds reared in smallholder system are native pig breeds that are basically non-descript. Rearing of pigs does not need much maintenance, which is why most of the indigenous community farmers prefer pigs as their source of livelihood. Doom and Ghungroo are indigenous pig breeds that are commonly reared by the farmers. In the field of pig production these breeds are found to be most promising (Banik et al., 2020). These indigenous pig breeds recognized by the ICAR-NBAGR, exhibit better conversion of feed, minimal maintenance costs, resistance to pathogenic diseases, and adaptability to the local climate (Banik et al., 2017). However, Doom and Ghungroo, are crossbred with exotic pig breeds such as Hampshire and Large White Yorkshire to enhance pork productivity, achieve higher growth rates, and improve back-fat thickness. As a result of the high rate of crossbreeding, their populations are declining at an alarming rate. Therefore, it is crucial to conserve and restore these local genetic resources to protect their unique genetic makeup. Preserving these indigenous pig breeds not only safeguards biodiversity but also supports the economic well-being of local farmers. Therefore, for the conservation and utilization of these indigenous pig breeds, it is necessary to study the basic parameters and gather information on different meat quality characteristics currently used by the meat industry (Joo et al., 2013). Such studies will provide a future reference in the development and utilization of meat and its by-products, a great way of promoting local food culture (Gan et al., 2019). Following are the brief descriptions of registered pig breeds reared/domesticated by local pig farmers of Assam. However, it is important to note that, due to high rate of crossbreeding with the exotic breeds, the numbers of these pig breeds are declining at alarming rate.

Doom: Doom (Figure 1.b.) is the sixth registered pig breed of India and first registered breed from Assam with accession number INDIA_PIG_0200_DOOM_09006.

Figure 1.b. Adult Doom pig (sow- female pig)

Figure 1.c. Adult Ghungroo pig (sow- female pig)

The breeding tract of Doom breed is mainly distributed in Dhubri, Goalpara, Bongaigaon, Kokrajhar districts of Assam and regions adjoining Meghalaya state (Zaman et al., 2014; Rahman et al., 2020; Rahman et al., 2021) (Fig. 1.d.). The 'Doom' is the name of the community that rears this particular breed (Banik et al., 2016). This community is economically backward belonging to scheduled caste and their main livelihood is rearing these pigs in migratory scavenging system; however, such system is slowly declining (Banik et al., 2022). Unlike Ghungroo, both the sexes of Doom are ferocious especially during the period of breeding and nursing. They are very aggressive to unknown people (Banik et al., 2022). This breed is most popular among the pig farmers for its ability to thrive in diverse and harsh climatic condition with low input (Rahman et al., 2020).

Ghungroo: Ghungroo (Figure 1.c.) also referred to as Ghoongroo, is the first registered indigenous pig breed of India with accession number INDIA_PIG_2100_GHOONGROO_09001. The breed originates from the 'Dooars' valley of West Bengal of Eastern Sub-Himalayan region. 'Dooars' regions belong to the districts of Darjeeling, Jalpaiguri, Alipurduar and Coachbehar adjoining the states Sikkim and Assam (Fig. 1.d.). Due its high productivity, domestication is observed in all parts of Assam (Thomas et al., 2016b; Khan et al., 2010; Zaman et al., 2013). The breed is known by other names depending the regions and their dialects. They are highly docile, easy to handle and can thrive with the climate differences, rearing systems applied and soil structure. Among the registered indigenous breeds, it has high growth and high prolificacy (Sahoo et al., 2015). Ghungroo has longer barrel (bristles) than other non-descript breeds and large heart-shaped drooping ears (Sahoo et al., 2012). The coprophagy behaviour is rarely observed (Sahoo et al., 2012a; Thomas et al., 2016b). Male Ghungroo pigs are known to grow faster than female pigs (Sahoo et al., 2012a). Major morphological differences observed between Doom and Ghungroo breeds is depicted in Table 1.3.

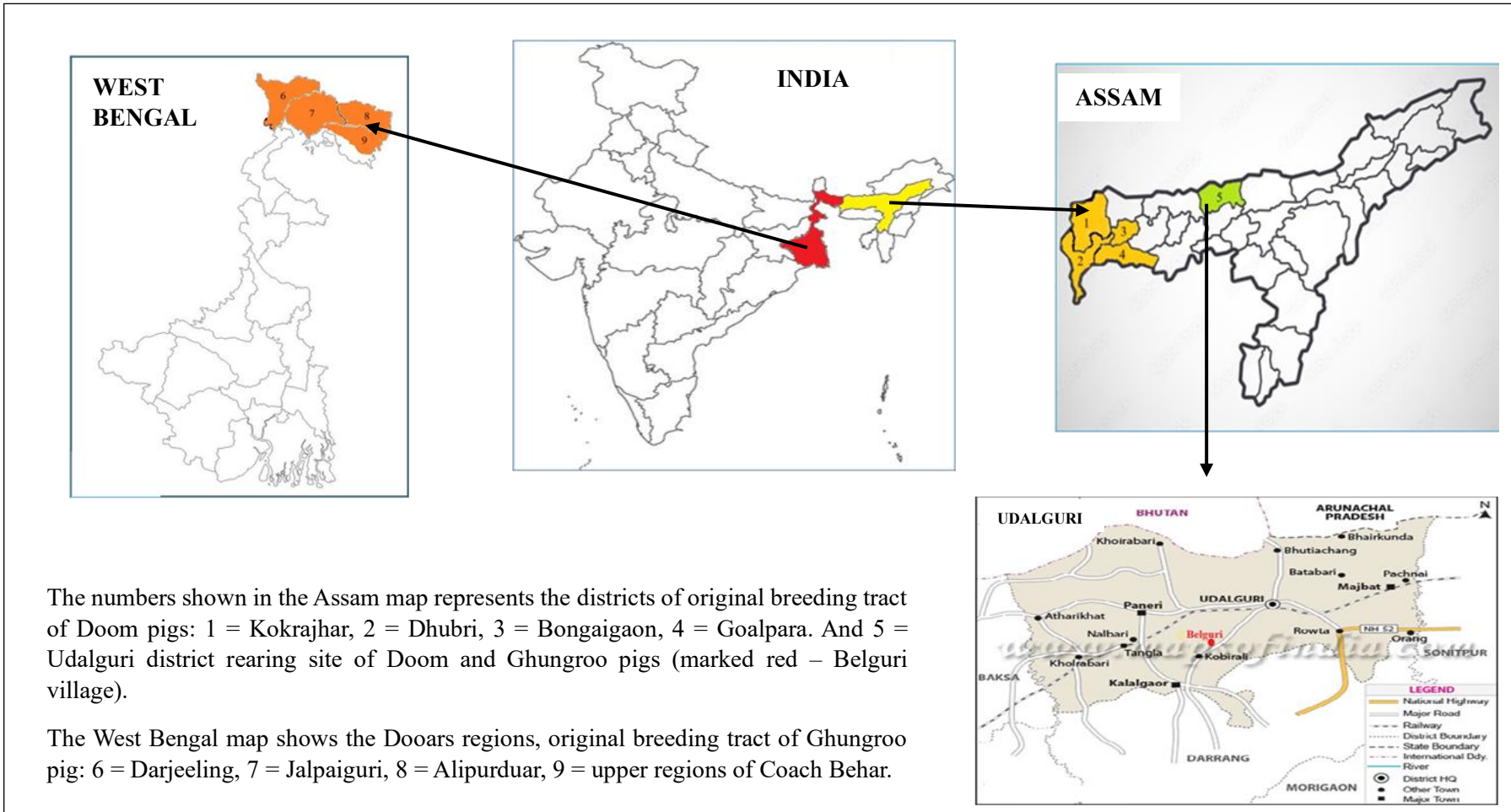
Table 1.3. Major morphological characters of Doom and Ghungroo pigs

Morphological characters	**Doom pig**	**Ghungroo pig**
Body/coat colour	Black	Black
Hair	Thick hair is observed on the crest that extends up-to lumbar region of the pig.	Scanty hair on the crest as well other body parts

Appearance	Small head with appearance with that of wild pig.	Bull-dog type head and folded skin is observed around the neck and face.
Ears	Vertical and erect shaped	Large heart-shaped
Snout	Short and concave	Curved upwardly
Belly	Small, short and straight	Long and shape like cylindrical barrel.
Teats	Females have 5 pairs of teats	Females have 6 pairs of teats
Tail	Straight and short, extends up-to hock joint.	Small and extends up-to hock joint.

1.11. Molecular characterization of pig breeds using '*cytochrome b*' gene as a molecular marker

For effective conservation measures, the identification of unique and indigenous pig breeds is essential, and molecular markers play a crucial role in this process. They help in understanding genetic variation including the identification of breeds. Additionally, these markers provide insights into the evolutionary history and phylogenetic relationships of indigenous breeds and wild pigs at the molecular level. One such molecular marker is the '*cytochrome b*' gene found in the mitochondrial DNA (mt-DNA) of vertebrate animals. *Cytochrome b* (*cyt b*) is one of the regions of mitochondrial DNA that is most commonly used as a molecular marker to establish phylogenetic relationship among the various species and in identification of species (Branicki et al., 2003). *Cyt b* is widely considered one of the useful genes in resolving divergences. It has the potential to effectively discriminate in the identification and characterization of species in the fields of taxonomy and forensic science including molecular evolution (Kuwayama and Ozawa, 2000; Saif et al., 2012; Prusak et al., 2004). The mt-DNA is inherited maternally and is present in large numbers than that of nuclear DNA (Marshall and Parson, 2023). The mt-DNA of pig is of 16 kb in size and contains 37 genes that code for 12S and 16S rRNA, 22 transfer RNA (tRNA) and 13 proteins (Kim et al., 2002; Toro et al., 2000). In animals, the rate of evolution of mt-DNA is about five to ten times higher than nuclear DNA (Brown et al., 1979), therefore making it ideal for establishing phylogenetic relationship between domestic and wild populations of livestock species. Recent data shows that *cyt b*, particularly for mammalian species, shows better result than other loci that are found in the mt-DNA (Tobe et al., 2010; Tobe et al., 2009).



The numbers shown in the Assam map represents the districts of original breeding tract of Doom pigs: 1 = Kokrajhar, 2 = Dhubri, 3 = Bongaigaon, 4 = Goalpara. And 5 = Udalguri district rearing site of Doom and Ghungroo pigs (marked red – Belguri village).

The West Bengal map shows the Dooars regions, original breeding tract of Ghungroo pig: 6 = Darjeeling, 7 = Jalpaiguri, 8 = Alipurduar, 9 = upper regions of Coach Behar.

Figure 1.d. Map showing original breeding tract of Doom and Ghungroo pig breeds and their rearing site (Belguri).

In India, limited data are available regarding use of 'cyt b' as a molecular marker to study genetic diversity, identification and establishing phylogenetic relationship among the wild and indigenous pig breeds of India. Previous reports by Gupta et al. (2013) used '*cytochrome b*' as a marker to establish genetic difference of Indian wild pig (*Sus scrofa cristatus*) and domestic pig (*Sus scrofa domestica*) and its use in wildlife forensics. Another study using D-loop of mt-DNA established genetic difference and phylogenetic lineages among the five registered indigenous pig breeds of India (Laxmivandana et al., 2022). Sharma et al. (2023) in their findings highlighted possible sites of center of pig domestication in India and their dispersal to other continents (Asia, Africa, Europe and Oceania) based on mitochondrial D-loop fragment.

In Assam too, very limited data are available using '*cyt b*' as a marker for identification as well as phylogenetic study. Saikia et al. (2015) and his team performed molecular characterization of *cyt b* gene in indigenous pig. Another study, characterized the complete mitochondrial genome based on D-Loop and utilizing it as identification signature sequence for Indian wild pig (Das et al., 2023).

1.12. Meat quality of crossbred and indigenous pig breeds

Crossbreeding aims to increase the yield of animals and improve the desirable quality of the meat. The crossbreeding of pig breeds has occurred for centuries to improve the pork production.

Pietrain, Hampshire and Duroc are used for the paternal contribution in crossbreeding program due to its leanness, marbling and carcass trait. Meanwhile, breeds such as Landrace, Yorkshire and Large white are commonly used for the maternal contribution in crossbreeding program because of the traits such as large number of litters they produce, numbers of piglets born alive per litter and number of piglets weaned per litter (Harsh and Boler, 2022). Although, these exotic pigs are known for lean meat and high growth rates, their pork meat-quality attributes such as color, flavor, and water holding capacity, pH, marbling and muscle fibre type, are diminishing, leading to pale, soft, exudative (PSE) and dark, firm, dry (DFD) type of meat (Keenan, 2016; Cameron et al., 1990; Kang et al., 2011; Ryu et al., 2008).

PSE meat is a result of combination of two main factors, one decline in the pH just after slaughter and high carcass temperature (above 37°C) (Feiner, 2006). Generally, the pH profile of pork in between 6.5 and 6.7 at 45-minute postmortem, whereas in PSE meat, the pH may drop to 6.0 or lower. PSE meat is pale in color, appear wet and its texture are very soft, caused due to denaturation of protein and leading to loss of water holding capacity (Feiner, 2006). DFD (Dark, Firm, Dry), also called dark-cutting meat, has a pH higher than 6.4 at 45 minutes post-mortem and above 6.0 at 24 hours post-mortem (Warriss, 2000; Viljoena et al., 2002). To describe the DFD, butchers are known to use the phrase, 'the meat does not come off the knife' (Feiner, 2006).

On the other hand, the indigenous breeds are known for their slow growth, resilience, hardiness, disease-resistant and ability to thrive within the local climate and feed resources. They possess unique genetic traits that can add potential contribution to sustainable agriculture and the development of rural communities through increased food security, economic opportunities, and cultural identity. Genetically, indigenous pig contains more of oxidized muscle fibres, resulting in superior meat quality. However, such breeds tend to exhibit slower growth rate (Chen et al., 2020). While crossbred pigs' results in low meat quality because of high number of glycolytic fibre (Poklukar et al., 2020; Chen et al., 2020). High glycolytic fibre causes rapid muscle growth, contributing to faster growth rate. However, meat from such pigs is more prone to PSE (pale, soft and exudative), affecting the market value. For example, an autochthonous breed of Spain - Mangalica/Mangalitsa is one of the fattest pigs in the world. It is known to have softer and succulent meat with distinct palatable flavor (Parunovic et al., 2013). It has high amount of fat deposition and reduced lean meat than commercial pigs (Vranic et al., 2015). Again, the Tibetan pigs of China are found in the high altitudes of the Qinghai-Tibetan Plateau about 3000 and 4300 meters above sea level. The ability of Tibetan pigs to acclimatize to the high-altitude environment is a distinctive trait that is absent in other pig breeds (Li et al., 2013). They have long and straight snout with skin covered with long and straight bristles. These bristles protect them from cold temperatures.

Furthermore, the meat of Doom pig of Assam is highly demanded in the markets of northeast India. Due to its taste, good meat texture and palatability, the meat of Doom is sold in higher prices than other commercial pigs (Daimari et al., 2022b). Along with

the consumption of Doom meat, Ghungroo pig meat is also preferred. Ghungroo pigs are primarily reared for fattening, with the aim of increasing their market value.

Interestingly, indigenous pig breeds are highly adaptable to various climatic conditions and provide a reliable regular source of income for local and small pig rearers. To preserve their unique meat quality traits and ensure their sustainability, it is crucial to conduct a thorough scientific study on their distinct characteristics and implement strategic preservation efforts. Additionally, the Indian Council of Agricultural Research - National Bureau of Animal Genetic Resources (ICAR-NBAGR) Karnal, India has recognized Indian indigenous pig breeds with the aim to preserve their genetic resources to ensure their sustainable utilization and to support livelihood.

1.13. Meat quality studied in muscles and viscera

According to FAO-OECD (2021-2030), pork is the highest consumed meat globally accounting for about 34 % followed by beef (20%) and sheep meat (5%). Listrat, (2016) listed four terms that define the quality of any meat type: healthiness (i.e., the nutritional quality), satisfaction (organoleptic quality), security (hygienic quality) and serviceability (east to use and affordable prices). Satisfaction is primarily perceived by consumers based on their visual sensory quality that include the color, texture and juiciness as well the flavor (Ngapo et al., 2007). On the other hand, the nutritional qualities are the nutritive values of moisture, fats, proteins and carbohydrate of meat.

The aroma, flavor, juiciness, tenderness and the dietary factors are altogether known as the organoleptic characteristics. These characteristics are known to be affected by the intramuscular fat content and composition (Mourot and Hermier, 2001). The intramuscular fat content (IMF) that determines the physical and nutritional characteristics show variation in different muscles of pork (Realini et al., 2013; Dominguez et al., 2014). Even though the intramuscular fat content is one of the most important compositional traits to determine meat quality as it is known to increase the palatability qualities of a meat and its by-products (Dominguez et al., 2014; Kauffman et al., 1964). However, there are other factors that affect the fat composition of the porcine intramuscular fat, they are location of the tissues in the carcass (Kloareg et al., 2007), feed composition, breed, sex, age and slaughter conditions (Guo et al., 2019).

There are three types of fats observed in pigs - intermuscular or seam fat, subcutaneous fat and intramuscular or marbling (Figure 1.e.). The intramuscular fat or marbling is estimated from the dissection of *longissimus thoracis et lumborum* (LTL) muscle from the loin region of pig carcass, which is known to provide the whole carcass estimate (Konarska et al., 2017). However, there are standard pork primal cuts that include ham, loin, bacon, spare ribs, picnic shoulder, boston butt and jowl (Thomas et al., 2016b; Kim et al., 2008). Each of these pork cuts differs from each other as they are formed of different muscle fibers, connective tissue and also its intramuscular fat content varies (Listrat, 2016). For instance, the ham region contains muscles such as *biceps femoris*, *gracilis*, and *tensor fasciae latae*; the loin contains the *longissimus dorsi* muscle, while the shoulder region of the pig carcass includes the *latissimus dorsi* and *triceps brachii* muscles (Figure 1.f.) (Kim et al., 2008; Daimari et al., 2022a). Therefore, it is important to study these six muscles of these standard pork cuts. There are reports on the differences in the composition of muscles from pigs (Dickerson and Widdowson, 1960; Lawrie, et al., 1963; Warner et al., 1993), but how much they vary from one another based on breed, size or nutritional traits are lacking. From the nutritional and health perspective too, the availability of necessary nutrients from the different porcine muscles has only been put forwarded or appreciated by authors, but not studied thoroughly nor have received any attention (Purchas et al., 2009). These studies may include low concentrations of some fatty acids (Enser, 2001) and muscle components other than fatty acids that might contain the potential bioactive components (Purchas et al., 2004). The offal or viscera are edible part of the animal that is not skeletal muscle; they include the heart, liver, spleen, lung, stomach, kidney and pancreas etc. These non-carcass components constitute up-to 10 % of the live weight of the pig (Ockerman and Basu, 2004). The consumption of pig's viscera as food is seen many parts of the world (Mi et al., 2020; Nikolic et al., 2017; Gasparik et al., 2017; Oloruntoba and Nathaniel, 2019). In Assam too, the viscera of pig are highly consumed by the locals, however their nutritional composition is very poorly documented in literatures. They are highly nutritious, contains nutrient complexes such as folate, choline and vitamin B12, mineral and high-quality proteins (Oloruntoba and Nathaniel, 2019; Lynch et al., 2018; Kicinska et al., 2019). Furthermore, these organ meats consist of high amounts essential fatty acids, mainly the omega 3 fats, arachidonic acid, EPA and DHA which are crucial for the normal

Figure 1.e. Showing the different types of fat observed in pork.

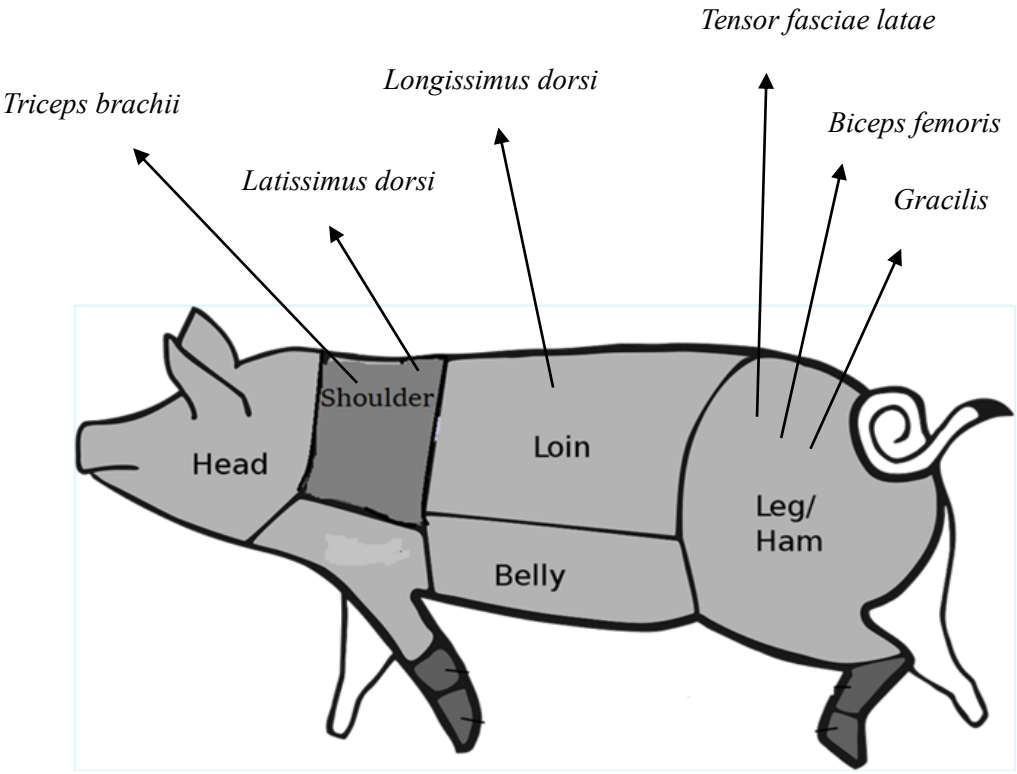


Figure 1.f. Regions of pig carcass from where the six muscles have been dissected

functioning of the heart (Cordain et al., 2002; Park and Washington, 1993; Nicklas et al., 2014). Considering the high demand for protein with the increasing population, these visceral products will compensate the shortcoming of staple foods (Umaraw et al., 2015; Zeng et al., 2022). It can also contribute to the nutritional improvement of those people with limited access to nutrient dense foods (Oloruntoba and Nathaniel, 2019; Maysonnave et al., 2020). The study of viscera is an upcoming theme of nutrition sciences that has stirred up the interest of the scientist and researchers around the world due to its high nutrition factors (Maysonnave et al., 2020; Seong et al., 2014). The viscera that are taken as food lack a definite scientific data or information. Awareness of its nutritional information may help in the promotion of consumption and its proper utilization in future.

Meat and its by-products are highly valuable in the human diet, providing high-quality protein, essential amino acids, fatty acids, energy, and vital micronutrients like zinc, iron, and B vitamins (Higgs, 2000; Bohrer, 2017). Animal proteins are considered superior to plant proteins due to their rich essential amino acid profile (Milton, 1999). Essential fatty acids, particularly omega-3 PUFA's, support brain function, vision, cardiovascular health, and healthy aging. Stearic acid, a saturated fatty acid from meat, can be converted into oleic acid, known for its health benefits (de-Tonnac et al. 2018; Calder and Yaqoob, 2009; Swanson et al., 2012). Additionally, meat supplies key vitamins and minerals, including zinc, selenium, magnesium, and potassium, which are crucial for metabolism but can be harmful in excess (Pereira and Vicente, 2013). Microelements such as copper, iron, and manganese, though required in smaller amounts, are essential for nervous and reproductive system functions, enzyme activities, and energy metabolism. Deficiencies can lead to serious health issues (Ali, 2023). Furthermore, these minerals are also known to get accumulated in the muscles through feed, drinking water and soil. Along with essential elements, there is high chance of accumulation of potentially toxic trace elements like arsenic (As), cadmium (Cd), lead (Pb) and nickel (Ni). The World Health Organization (WHO, 1993) has stated that lead intake occurs through drinking water and is known to accumulate in the skeleton. Soil is also an important medium through which these toxic elements can get accumulated, as pigs tend to exhibit rooting behaviour even when they have sufficient food available (Beattie and O'Connell, 2002).

Therefore, it is also important to study the concentration of elements separately in feed, drinking water and soil samples. Other than consumption of pork, human beings also share same ecosystem which will not reflect the level of environmental contamination but also provides critical insights into the potential health risks posed to humans (Palazzo et al., 2021; Malmsten et al., 2021).

1.14. Research Gap

Despite the growing interest in pig genetics and meat quality, huge gaps remain in the information on Doom and Ghungroo, which are the registered indigenous pig breeds of India. Broadly, the identified gaps are -

- Absence of comprehensive studies on meat quality and molecular characterization of Doom and Ghungroo pig breeds.
- Limited research is available on the assessment of meat quality across different muscles based on primal cuts, including visceral parts.
- There is notable lack of molecular studies utilizing the '*cytochrome b*' gene as molecular marker.

Therefore, understanding these gaps by investigating the nutritional characteristics and molecular characterization of Doom and Ghungroo pig breeds is important for their scientific evaluation, sustainable utilization and conservation. The following are the aims and objectives put forwarded to fulfil the study:

1.15. Objectives

- Morphological authentication and molecular characterization of Doom and Ghungroo pig breeds.
- Nutritional analysis of kitchen waste as trial diet
- Observation of body weight and other growth parameters under control and trial diet.
- Meat quality analysis of pork muscles and viscera after feeding period of control and trial diets.
- Study the correlation between minerals composition between muscles and viscera of Doom pig with feed, drinking water and soil.

1.16. Specific Objectives

Specific objectives of the study are:

- Morphological authentication and molecular characterization of Doom and Ghungroo pig breeds.
    a. Morphological authentication of the domesticated pig breeds i.e., Doom and Ghungroo pig breeds of Assam.
    b. Molecular identification of Doom and Ghungroo pig breeds by '*cytochrome b*' molecular marker.
    c. Assessment of genetic distance of Doom and Ghungroo pig breeds based on molecular marker '*cytochrome b*'.
    d. Assessment of phylogenetic relationship of Doom and Ghungroo pig breeds based on molecular marker '*cytochrome b*'.
- Nutritional analysis of kitchen waste as trial diet
    a. Analysis of proximate composition.
    b. Analysis of amino acid and fatty acid composition.
    c. Analysis of macro- and micro-elements, trace and potentially toxic trace elements.
- Observation of body weight and other growth parameters under control and trial diet.
    a. Measurement of body weight, chest girth, height at wither, paunch girth and body length.
- Meat quality analysis of pork muscles and viscera after feeding period of control and trial diets.
    a. Analysis of pH (pH_{45} and pH_{μ}) level in muscles and viscera
    b. Analysis of proximate composition in the six muscles and viscera of Doom and Ghungroo pig breeds.
    c. Analysis of amino acid and fatty acid composition in six muscles and viscera of Doom and Ghungroo pig breeds.
    d. Analysis of macro- and micro-elements, trace and potentially toxic trace elements in six muscles and viscera of Doom and Ghungroo pig breeds.

- Study the correlation between minerals composition between muscles and viscera of Doom pig with feed, drinking water and soil.
    a. Analysis of macro- and micro-elements, trace and potentially toxic trace elements in drinking water and soil of rearing site
    b. Study the correlation of macro- and micro-elements, trace elements, and potentially toxic trace elements between tissues (muscles and viscera) and feed, drinking water, and soil.