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Review:
Risks and benefits of introducing double-muscled Belgian Blue cattle to Indonesia’s tropical climate

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Abstract. *Residiwati G, Tuska HSA, Parlindungan O, Siswanti SW, Leemans B, Goossens K, Rochmi SE, Budiono, Budiyanto A, Purwantara B, Lonameo BK, Pascottini OB, Opsomer G, Van Soom A. 2025. Review: Risks and benefits of introducing double-muscled Belgian Blue cattle to Indonesia’s tropical climate. Biodiversitas 26: 2429-2447.* To meet the growing national demand for beef, the Indonesian government has introduced the Belgian Blue (BB), a double-muscled cattle breed originating from Belgium, renowned for its exceptional carcass yield. This initiative represents the first large-scale effort to integrate a temperate taurine genotype into Indonesia’s tropical environment through the use of Embryo Transfer (ET) and Artificial Insemination (AI) technologies. The BB’s pronounced muscle hypertrophy offers considerable potential to enhance national beef productivity, with projected increases in carcass yield. This potentially underscores the benefits of introducing the BB breed in Indonesia. However, its application in tropical systems presents notable challenges. As a pure taurine breed, the BB demonstrates limited adaptability to high temperature and humidity, rendering it highly susceptible to heat stress. In addition, its muscular conformation is associated with an elevated incidence of dystocia, requiring advanced obstetric care, while its intensive nutritional requirements may pose environmental sustainability concerns. This review synthesizes empirical findings from the past decade of field implementation across six (6) Indonesian provinces and benchmarks the performance of BB cattle against local breeds. By critically examining both the opportunities and limitations of BB integration, this paper offers novel insights beyond prior literature centered on European contexts. It concludes by highlighting strategic considerations for policymakers, veterinarians, and farmers to foster a more sustainable and efficient beef production system tailored to Indonesia’s unique agro-climatic conditions.

Keywords: Belgian Blue, double-muscled cattle, Indonesia, sustainable beef production, tropical adaptation

INTRODUCTION

Indonesia, a developing tropical country in South Asia and the world’s largest archipelagic state that has experienced a steady rise in meat consumption driven by population growth, increasing income levels, and evolving consumer preferences (Burrow 2019; Fauzie and Siallagan 2023; Font-i-Furnols 2023; Susanti et al. 2023; Hilmiati et al. 2024). However, despite this growing demand, the country continues to struggle with challenges in achieving self-sufficiency in beef production (Antara and Sumarniash 2019; Hetharia et al. 2022; Widyas et al. 2022; Prasetyo and Al Idrus 2023; Residiwati et al. 2023; Suarsa et al. 2024). In 2023, Indonesia’s local production of beef and buffalo meat recorded a deficit of 374.1 thousand tons. This deficit arose because domestic production amounted to only 442.69 thousand tons, compared to the total demand of 816.79 thousand tons (BPS-Statistics Indonesia 2023). The detailed regional distribution of the cattle population in Indonesia is presented in Figure 1, while the supply and demand dynamics for red meat across regions are illustrated in Figure 2. Although generally local Indonesian beef cattle display multiple interesting characteristics, including a high dressing percentage (54%)

compared with other *Bos indicus* breeds (Tahuk et al. 2018), high adaptability to a tropical environment (Soetanto and Fatchiyah 2023), and a lesser need for nutritious forages (Rohaeni et al. 2024), they still cannot meet the growing demand for beef (Agus and Widi 2018). Further characteristics of Indonesian local cattle are shown in Table 1.

It is challenging to improve beef production quantity and quality in Indonesia to reduce its dependency on imported beef. An accurate profile of the livestock is pivotal for decision-making regarding the potential for the adoption of new genetic technologies and the monitoring of genetic resources in developing countries (Marshall et al. 2019). One of the Indonesian government's actions was the introduction of a double-muscled Belgian Blue (BB) cattle breed starting in 2013. In 2017, Indonesia succeeded in producing the first BB calves in South Asia by transferring embryos imported from Belgium, and since 2019, BB bulls have produced semen locally (Kuswati et al, 2023).

The BB belongs to *Bos taurus* and is characterized by a double-muscled phenotype caused by a deletion within the myostatin gene (Jakaria et al. 2021). As a consequence of that, they present less bone and fat, more muscle, and a higher muscle-to-bone ratio than most other breeds (Deng et al. 2017; Keady et al. 2021; McKimmie et al. 2024). Further, they also yield a higher proportion of tender meat associated with their double-muscled properties (Fiems 2012, et al. 2023; Bittante et al. 2018, 2023). The BB's high feed efficiency and lean meat production have made it popular in regions seeking to optimize beef production (Fiems 2012; Tagliapietra et al. 2018). However, the potential benefits of BB are accompanied by multiple risks. The BB belongs to *Bos taurus* cattle, which are less well adapted to tropical (hot and humid) climates (Baena et al. 2019) when compared to local Indonesian cattle breeds, which belong to *Bos javanicus* and *B. indicus* (Facts and Details 2015).

Table 1. Characteristics of several Indonesian local cattle (adapted from Adinata et al. 2023)

Breed	**Characteristics**
Bali cattle	Indigenous breed from Bali Island; small body size; high adaptability; reddish coat; small dewlap; naturally polled (no hump); low body weight (253.16 kg); cumulative index 2.46.
Rambon cattle	Local breed from East Java; medium body size; varied coat colors; small dewlap; absent or small hump; moderate body weight (309.04 kg); cumulative index 2.59.
Madura cattle	Indigenous breed from Madura Island; small body size; red coat; small dewlap; small hump; low body weight (211.86 kg); cumulative index 2.32.
Ongole Grade cattle	Derived from crossbreeding with Indian Ongole; large body size; white coat; medium to large dewlap; medium to large hump; highest body weight among breeds (333.70 kg); cumulative index 3.06.
Kebumen Ongole Grade cattle	Local development of Ongole Grade; large body frame; white coat; medium to large dewlap and hump; very high body weight (412.76 kg); cumulative index 2.92.
Sasra cattle	Local breed from Central Java; black coat; medium body size; absent hump (most animals); moderate body weight (412.26 kg); cumulative index 2.93.
Jabres cattle	Local breed from Brebes, Central Java; small body size; varied coat colors; small dewlap; absent or small hump; moderate body weight (261.94 kg); cumulative index 2.39.
Pasundan cattle	Local breed from West Java; small body size; black coat predominant; small dewlap; absent hump; moderate body weight (259.18 kg); cumulative index 2.55.

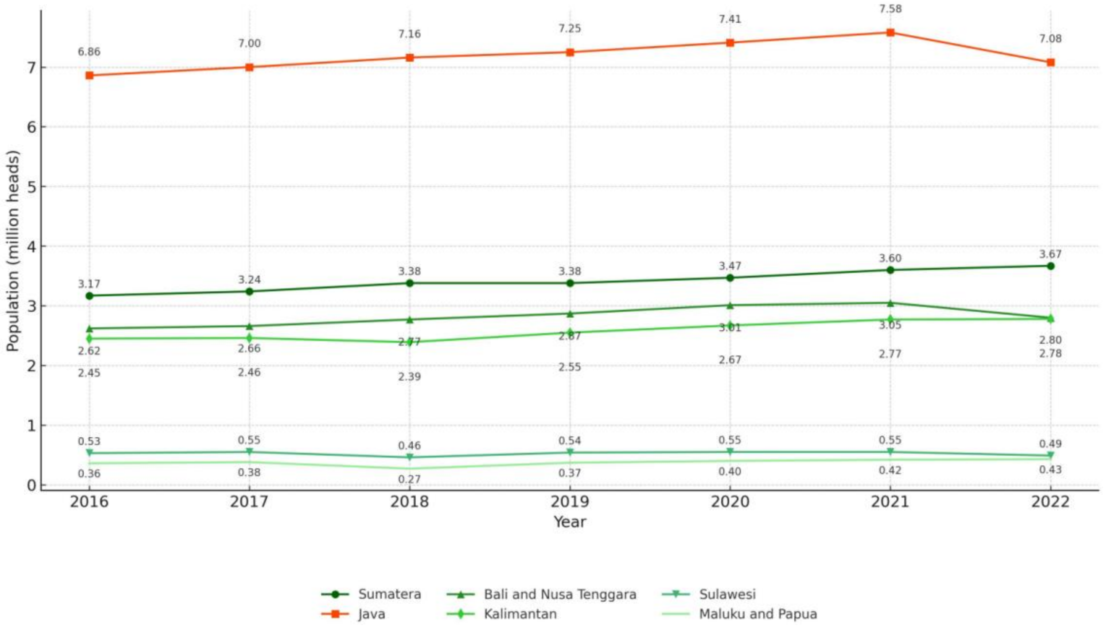

Figure 1. Beef cattle population by region in Indonesia from 2016 to 2022 (BPS-Statistics Indonesia 2023)

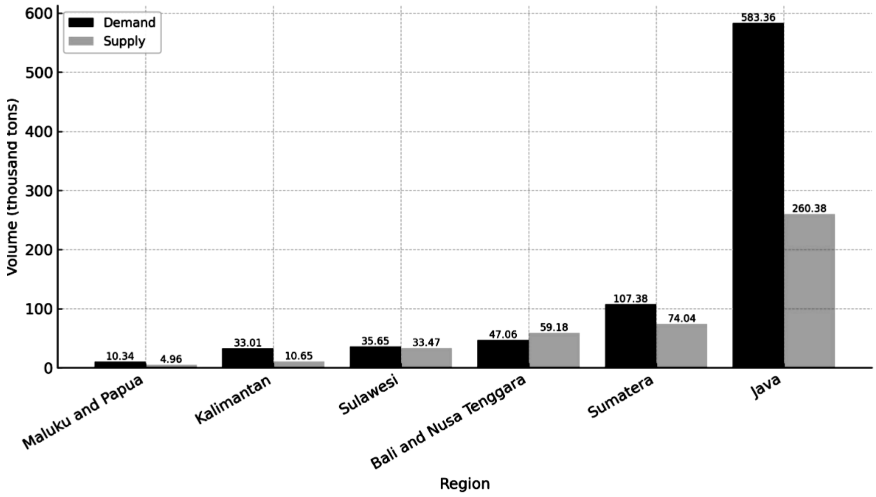

Figure 2. Comparison of beef and buffalo demand versus supply based on region in Indonesia 2023 (BPS-Statistics Indonesia 2023)

Heat Stress (HS) in cattle can be assessed by measuring the combined effects of environmental temperature and relative humidity, called the Temperature Humidity Index (THI) (Lallo et al. 2018; Díaz et al. 2020; Dimov et al. 2020). According to Al-Kanaan et al. (2015) and Seifi-Jamadi et al. (2020), the optimal THI for bull semen production in a European temperate climate range from 50 to 60. Conversely, Indonesia did not exhibit any instances of comfort THI during 2023 and 2024. Notably, the lowest THI was recorded on 29 September 2023 in East Java (68.33; mild discomfort), and the highest was on 12 May 2023 in Sumatra (81.96; danger) (BMKG 2024).

The BB crossbreeding program with Indonesian local cattle aims to generate superior offspring with improved growth performance (Putra 2017; Adi et al. 2019; Praharani et al. 2019; Aminurrahman et al. 2021; Chalid et al. 2023). It is evident that, due to the differences between the country of origin and the country of import, it is essential to evaluate the health and performance of BB pure and crossbred cattle in Indonesia to optimize the breeding program in this country. Multiple factors need to be evaluated further before we can conclude that the importation of BB to Indonesia will be beneficial for the beef cattle industry. The novelty of this review lies in its comprehensive and context-specific evaluation of BB cattle introduction in Indonesia's tropical environment. It uniquely synthesizes regional field data from both Indonesia and Belgium, as well as compares AI and ET outcomes under heat stress. Furthermore, this paper integrates climate-based indicators, reproductive management, and veterinary capacity into a practical framework for advancing sustainable BB deployment in tropical livestock systems.

BEEF PRODUCTION SYSTEM IN INDONESIA

The beef production system in Indonesia is predominantly reliant on smallholder farming, which contributes 90% of the country's total output, with around 6.5 million farmers forming the backbone of Indonesia's beef industry. Limited resources, inadequate access to technology, and lower productivity per animal often constrain these small-scale operations. The remaining 10% of cattle production is derived from larger-scale commercial farmers and large beef cattle companies, which are more centralized and technologically advanced in comparison to the smallholder system. However, it is still insufficient to bridge the growing gap between supply and demand. This imbalance has led Indonesia to rely heavily on beef imports to meet the needs of meat consumption (Baker et al. 2017).

In general, beef production in Indonesia can be classified into two major systems: smallholder farming and intensive feedlot systems (Agus and Widi 2018). Smallholder farming is typically characterized by maintaining two (2) to four (4) livestock units, integrating crop and livestock production, and utilizing stall feeding. Additionally, cattle are used to produce meat for urban markets, support crop production with manure and draft power in dry seasons and serve as livelihood assets. The livelihood benefits of keeping cattle also include savings, insurance, buffering, and cultural purposes. The cattle population in Indonesia can be classified into three (3) main breeds: *B. javanicus* (Javanese cattle), *B. indicus* (Indian/Zebu cattle), and *B. taurus* (European cattle). Among these, *B. javanicus* and *B. indicus* predominantly contribute to Indonesian livestock production. *Bos javanicus* is an indigenous breed domesticated from the wild banteng (*B. javanicus*). It includes several local varieties such as Javanese, Balinese, Madura, Aceh, Pesisir, Rancah, Jabres, Galekan, Rambon, and Sumatra cattle (Hartaningsih et al. 1993; Lisson et al. 2010; Sutarno and Setyawan 2016; Said et al. 2017; Agung et al. 2018; Hartatik et al. 2019; Sofyan et al. 2020; Arifin et al. 2023; Finn 2023). On the other hand, *B. indicus* originates from India and was later introduced to other tropical South-Asian countries, including Indonesia. This breed includes Brahman, Ongole, and crossbreeds such as Peranakan Ongole. Taurine breeds (*B. taurus*) were initially bred in European countries, such as British breeds (Aberdeen Angus, Hereford, Shorthorn), French breeds (Charolais, Limousin), and the Swiss Simmental. These breeds were subsequently imported into Indonesia and have adapted, to varying degrees, to the tropical climate, feed resources, and disease challenges in Indonesia (Sutarno and Setyawan 2015).

SOLUTIONS FOR IMPROVING BEEF PRODUCTION IN INDONESIA

Breeding program

A breeding program is becoming a pivotal government policy for improving beef production in Indonesia (Agus and Widi 2018; Priyanto et al. 2023). One of the techniques employed is Artificial Insemination (AI), which is used to enhance the genetic quality of local cattle breeds. Artificial insemination aims to improve genetic performance, with the goal of increasing calves' birth rates, average daily weight gain, and overall profitability. Crossbreeding is a fundamental practice in livestock management for improving genetic structure as well as enhancing the growth rate of animals (Mendonça et al. 2019; Ngadiyono et al. 2019; Labroo et al. 2021; Daulay et al. 2022). In commercial crossbreeding, which is the most common type, the primary objective is to produce high-quality cattle for slaughter that exhibit rapid growth (Favero et al. 2019). For dairy enterprises, one goal of crossbreeding is to produce calves that are well-suited for fattening within a specified period. Studies have shown that the carcass quality and quantity resulting from crossbreeding dairy and beef breeds surpass those of purebred dairy breeds. Several studies have examined the performance and economic traits of beef and dairy purebred cattle compared to beef crossbreeds. Findings indicate that the differences in performance and economic traits between these groups are becoming more pronounced over time (Akbaş et al. 2022).

Since the 1980s, the government has been promoting the intensification of the beef cattle sector by introducing crossbreeding with high-production potential breeds (*B. taurus*, European breeds) through AI, particularly in Java (Widyas et al. 2018). The favored *B. taurus* breeds for crossbreeding with local Ongole cattle in Java are Simmental and Limousin. Intensification refers to the increased use of external inputs and services to enhance the quantity and/or value of output, with one of its crucial goals being to reduce emissions from deforestation and forest degradation (Sutarno dan Setyawan, 2016). However, crossbreeding as a tool for intensification must be supported by better nutrition and management. It also requires a package of innovations, including external inputs such as feed, health and breeding services, credit, and promotion.

Further, the government formally launched a cattle meat self-sufficiency program called *Program Swasembada Daging Sapi* (2001-2005) in 2001. However, the program was ultimately unsuccessful, with the target being delayed three times (2004-2019). Despite these delays, the program underscores the importance of improving domestic beef production, leading to the gradual development of intensive beef cattle-feedlot production systems in Indonesia. This shift toward feedlot systems represents an effort to increase efficiency and production capacity in response to the persistent gap between demand and supply.

In 2016, the government launched a program called *Sapi Indukan Wajib Bunting* (UPSUS SIWAB), which translates to 'a cow must be pregnant'. This program aimed to increase the cattle population by employing two (2) mating systems: AI and natural mating. Certainly, bull fertility plays a crucial role in the success of breeding programs, as a single bull is typically used to mate with multiple cows (Hoflack et al. 2007, 2008). Artificial insemination has, therefore, become a widely used and efficient method in cattle reproduction, allowing cryopreserved semen from one bull to fertilize numerous cows. The government set a target to inseminate four million productive female cattle, aiming for a minimum 75% pregnancy rate, which would result in three million calves. When AI was first introduced in Indonesia, Holstein Friesian cows were primarily used as recipients of semen from superior bulls, including Simmental, Brahman, Charolais, Limousin, Brangus, and Hereford. Today, AI practices are more widespread in Indonesia, with a variety of breeds available and an increasing number of AI facilities across the country (Artificial Insemination Centre of Lembang 2023).

In Indonesia's feedlot industry, the highest variable costs are associated with purchasing fodder and concentrates for finishing cattle. To enhance profitability and reduce the adverse climate and environmental impacts of the beef production sector, utilizing agricultural and industrial by-products as primary feed resources is a key strategy for feedlots. However, most smallholder farmers focus on maintaining breeding stock rather than fattening cattle, as their goal is to keep animals longer to produce progeny for sale and maintain a steady supply of manure for crop farming. The government has been encouraging cattle breeding development to build the national herd. However, most cattle breeders operate under extensive production systems, leading to low beef production rates.

Nationwide, beef cattle productivity in Indonesia remains low due to several factors, including low reproductive performance, with conception rates at only 56%; long calving intervals of 18 to 21 months; high calf mortality rates (5% to 10%); poor body condition scores, all of which contribute to the slow growth of the national herd (Baker et al. 2017). Additionally, despite strict government regulations against slaughtering productive females, farmers often sell 10% to 30% of these females annually, further hindering the growth of the national herd. Collectively, these challenges represent significant constraints to the development of domestic beef production in Indonesia. The environmental impact of livestock production is largely determined by management practices: good management can support sustainable agriculture, while poor management can cause environmental harm. Enhancing the genetic quality of breeds and transitioning to more efficient beef breeds are crucial steps toward improving livestock management.

Feed quality improvement

In both stall-feeding and extensive systems, low-quality feed is commonly used, primarily consisting of crop residues, agricultural by-products, and other non-conventional feedstuffs. Crop residues, which are considered inexpensive and low-quality feeds, are typically less than 55% digestible and deficient in true protein, nitrogen, and minerals. The quality of most grasses in tropical regions is also generally low, with crude protein content ranging from 5.6% to 15.7% and neutral detergent fiber content from 45.2% to 85.4% (Bakrie et al. 1996). One of the main challenges in feeding livestock in rural areas is the shortage of digestible energy. Supplementation is therefore necessary to meet the animals' energy requirements. Table 2 provides an example of feedstuffs used for male Bali cattle fattening on smallholder farms, including their chemical composition and protein levels (% of dry matter) (Tahuk et al. 2018).

In general, the significant agro-residues used as ruminant feed in Indonesia can be categorized as follows: crop residues, such as rice straw, rice husk, sugarcane tops, corn husks, corn stalks, and soybean hulls; agro-industrial by-products, such as cereal bran, coconut cake, palm kernel cake, soybean meal, molasses, biofuel co-products (distillers' dried grains and soluble, pineapple waste, tapioca by-products/*onggok*, and coffee seed pulp); non-conventional feed resources: this category includes feeds not traditionally used in livestock diets, such as banana leaves, cassava leaves, oil palm leaves, palm press fiber, cassava foliage, other tuber foliage, sugarcane bagasse, cottonseed meal, rubber seed meal, cacao pods, fruit and vegetable waste, aquatic plants like seaweed, and former foodstuffs (Devendra and Leng 2011). Examples of non-forage feed resources in Asia are detailed in Table 3.

Additionally, many Indonesian farmers have only basic knowledge of animal husbandry, which presents a significant challenge (Bakrie et al. 1996). Hence, to address this, government programs aim to improve the quantity and quality of feed. Concentrates have been developed to meet the nutritional needs of cattle fattening, and quality forages such as king grass have been introduced. Methods for fermenting agricultural waste, such as rice straw, have also been implemented. Legume trees and herbs, such as *gamal* (*Gliricidia sepium*), have been widely introduced.

Belgian Blue

The double-muscled BB cattle breed originated in central and upper Belgium through crossbreeding between local Belgian dairy cattle and the Durham Shorthorn in the 19th century. The BB is known for its unique phenotype, referred to as ‘double muscling’ (Wilmot et al. 2022; Duarte et al. 2023). In 1992, it was reported that double muscling in BB significantly increases carcass yield (Koesmara et al. 2019; Ceccobelli et al. 2022). The phenomenon is caused by an 11-base deletion in the third exon of the *myostatin* gene, making it a major candidate gene for enhancing animal growth (Aiello et al. 2018; Aji et al. 2020). They have a significantly higher dressing percentage (the ratio of carcass weight to live weight) of around 70% (Coyne et al. 2019), compared to other breeds with 57% (Tahuk et al. 2018). Additionally, the breed produces a significantly lower carbon footprint of around 21 kg CO_2 equivalent per kilogram of meat compared to other beef breeds (27.5-48.5 kg CO_2 equivalent per kilogram of meat), making it a high-yield and climate-friendly option (Belgian Blue Group 2021).

Table 3. Examples of non-forage feed resources in Asia and their nutrient potential (adapted from Devendra 1997)

Types of feed	Nutrient potential
Good quality (>35% crude protein) (e.g., oilseed cakes and meals, cassava leaves)	High-protein, high energy supplement, minerals
Medium-quality (15-35% crude protein) (e.g., coconut cake, palm kernel cake, sweet potato vines)	Medium-protein
Low-quality (<15% crude protein) (e.g., cereal straws and stovers, palm press fiber)	Low-protein, very fibrous

Table 2. The chemical composition of feedstuffs utilized for male Bali cattle fattening on smallholder farms, with various levels of protein (adapted from Tahuk et al. 2018)

Types of feed	DM (%)	OM	ASH	CP	CF	TDN	NDF
Native grass	36.54	84.71	15.29	6.08	32.8	57.3	68.72
Gamal (*Gliricidia sepium*)	24.27	87.56	12.44	24.19	14.51	72.21	32.98
Lamtoro (*Leucaena leucocephala*)	25.25	90.91	9.81	25.65	18.96	79.79	34.11
Turi (*Sesbania grandiflora*)	20.33	85.29	14.71	21.77	13.18	75.06	24.72
King grass (*Pennisetum purpuroides*)	25.24	86.62	13.38	11.98	31.07	46.69	68.09
Banana stem (*Musa x paradisiaca*)	10.40	85.49	14.51	3.31	32.36	54.77	47.65
Banana leaves (*Musa x paradisiaca*)	22.12	91.06	15.01	4.37	8.9	50.69	-
Cassava leaves (*Manihot utilissima*)	24.42	90.34	9.66	24.52	19.47	79.45	-
Corn meal	90.09	98.81	1.19	7.89	1.82	87.66	22.14
Rice bran	90.42	84.49	8.26	6.97	17.37	65.37	54.67

Note: DM: Dry Matter; OM: Organic Matter; CP: Crude Protein; CF: Crude Fiber; TDN: Total Digestible Nutrients; NDF: Neutral Detergent Fiber

Initially, from the early 20th century until the 1950s, selection efforts focused heavily on dual-purpose traits, with considerable emphasis on milk production. However, between 1950 and 1970, the focus gradually shifted toward meat production as farmers prioritized muscular development (Atashi et al. 2022). In the 2000s, BB played a key role in elevating Belgium's beef supply self-sufficiency level to over 157%. It makes the BB highly desirable for crossbreeding programs, significantly boosting meat production in various countries (Agung et al. 2016; Vanderick et al. 2017; Ahmed et al. 2024).

Then, to achieve similar success in tropical regions, it is essential to improve tropical BB crossbreeds by incorporating superior traits and effectively managing them within resource constraints. There are thousands of beef cattle varieties, most of which belong to *B. taurus* or *B. indicus*. Crossbreeding is a highly effective tool, particularly when the parent breeds are genetically distant (e.g., *B. taurus* and *B. indicus*), as it produces crossbred offspring with enhanced growth rates and better adaptability, especially in tropical climates (Abdullah and Meng 2024). Several developing and tropical countries have begun using double-muscled cattle, such as the BB, to improve the genetic quality of beef cattle developed in regional areas to meet national meat demands (Residiwati et al. 2020a, 2021, 2023; Primananda et al. 2021).

However, alongside their genetic distinctiveness, this breed also presents several challenges. Due to their higher body weights, BB cattle require greater phosphorus intake compared to other breeds. Diets characterized by low calcium and high phosphorus levels are known to contribute to the formation of kidney stones. Males are particularly more susceptible to urinary blockages caused by kidney stones than females. Furthermore, animals with Double-Muscled (DM) exhibit a reduction in kidney weight, accompanied by decreases in the weights of both the medulla and cortex. Additional changes, such as decreased bladder capacity and a reduced diameter of Bowman's capsule, have also been observed. These physiological alterations may impair plasma ultrafiltration, thereby increasing the susceptibility of BB cattle to urolithiasis (Hoflack et al. 2006). Belgian Blue cows are prone to calving difficulties, with an incidence of dystocia reaching 90% (Tuska et al. 2022). Dystocia is attributed to the combination of high birth weight and small pelvic size (Kolkman et al. 2009, 2010; Konovalova et al. 2020, 2021; Simões and Stilwell 2021). A proposed solution to this issue is crossbreeding, which can lower birth weights and, consequently, reduce the occurrence of dystocia (Tampubolon et al. 2023). Further, the advantages and disadvantages associated with BB are presented in Table 4.

Belgian Blue importation to Indonesia

One notable action taken by the Indonesian government to improve beef production was the importation of frozen semen and embryos of Belgian Blue cattle (Figure 3) from Belgium in 2013 to establish a breeding program in the country.

Table 4. Multiple advantages and disadvantages of Belgian Blue cattle breeds

Advantages	**Disadvantages**
Young age at first calving (±24 months) (Vanderick et al. 2017)	Higher risk of dystocia (Tuska et al. 2021; Ahmed et al. 2024; Van Loo et al. 2024)
Shorter gestation length (♂ 282.6 days; ♀ 281.6 days) (Ahmed et al. 2024)	Longer calving interval (435 days) (Fiems and Ampe 2015)
Higher average weight as an adult (♂±1100-1250 kg; ♀ ±850-900 kg) (Porter 2020)	Lower field fertility for the bull (Selfi-Jamadi et al. 2020)
Higher birth weight (51.23 kg) (unpublished work)	More sensitive to congenital genetic defects such as muscular dystrophy and urolithiasis (Fiems and Ampe 2015)
More tender meat (Fiems and Ampe 2015)	Higher susceptibility to heat stress (Rahman et al. 2018; Gloria et al. 2021)
Lower fat (3.64%) of the muscle (*longissimus thoracis et lumborum)* (Keady et al. 2017)	More sensitive to respiratory disease (Lowie et al. 2022)
Higher protein content (22.41%) of the muscle (*longissimus thoracis et lumborum)* (Keady et al. 2017)	Prone to exhaustion after severe exercise, which may even terminate in sudden death (Holmes et al. 1973)
Higher carcass yield is around 70% (Fiems and Ampe 2015)	More sensitive to skin infection (Sarre 2012; Meyermans et al. 2022)
Better oocyte quality (Gómez-Guzmán et al. 2024)	Higher caesarean section application (Fiems 2012; Tuska et al. 2021)
Higher feed efficiency (less CO_2 production pro kg of beef produced) (Belgian Blue Group 2021)	Incapable of using low-quality diets efficiently (Fiems and Ampe 2015)

Figure 3. A Belgian Blue bull in the original country, Belgium (personal documentation)

Agung et al. (2016) identified the genetic marker for double muscling in the F1 generation of BB in Indonesia. By 2018, approximately 900 frozen embryos and 1,000 straws of frozen semen were imported and distributed to Embryo Transfer (ET) centers across various islands in Indonesia. These regions exhibit diverse temperature ranges (15°C-32°C) and relative humidity levels (60%-100%). The selected recipients for ET included seven cattle breeds, namely Brahman, Limousin, Simmental, Holstein Friesian, Angus, crossbred Peranakan Ongole, and Simmental Ongole. These recipient cows were required to meet specific criteria, such as having previously delivered a normal birth, a body condition score of 2.75, being at least 1.5 years old, and weighing at least 350 kg at the time of insemination.

Limited observations suggest that the performance of BB crossbreeds is often superior to that of local breeds. During their evolutionary separation from *B. taurus*, *B. indicus* acquired genes that confer thermotolerance at both cellular and physiological levels (Bunning et al. 2019; McManus et al. 2020). Our previous study, which evaluated the effect of crossbreeding of BB semen with beef (Limousin) and dairy (Holstein-Friesian) derived oocytes on embryo development and quality using purebred BB as a control (BB oocytes fertilized by BB sperm), showed that crossbreeding by in vitro fertilization with Limousin oocytes yielded better embryo compared with purebred combination.

In comparison, the combination with Holstein-Friesian oocytes produces the lowest rate of blastocyst (Residiwati et al. 2020b). Chalid et al. (2023) showed that BB crossbreed with Indonesian Holstein (BBH) has better performance than other Indonesia local cattle; however, it is still below the body weight and daily gain of BB pure breed calves. Primananda et al. (2021) showed that the BB crossbreed with POGASI has higher productivity performances compared with POGASI calves. Further, Adi et al. (2019) showed BB x Brahman cross has a dominant trait in body posture, especially in the first offspring, compared to Wagyu x Brahman cross.

The BB crossbreeding program also aims to reduce the risk of dystocia, a common issue with pure BB cows. Livestock growth performance is often measured through body weight and size. Linear body measurements in cattle are strongly correlated with reproductive and productive traits. Factors such as breed, age, sex, nutritional conditions, and environmental influences significantly affect these measurements. The BB crossbreeding program is expected to yield offspring with superior growth performance (Yusuf and Priyanto 2024). Additionally, in Indonesia, the BB crossbreeding program is designed to maintain a genetic composition of 25-75% BB. This is achieved through a grading-up strategy using AI. Pure BB bulls, produced via ET, are bred with crossbred females containing 50% BB genetics to create offspring with 75% BB genetics. This strategy minimizes the risk of dystocia during delivery. The characteristics of BB cattle and their crosses in Indonesia are summarized in Table 5 and illustrated in Figures 4.A and 4.B.

Table 5. Characteristics of Belgian Blue cattle in Indonesia

Parameters	Specific characteristics
Birth weight (in average)	Purebred: 50.52 kg; crossbred: 37.43 kg
Caesarean section application (%)	Purebred: 94.12%; crossbred: 0%
Gestation length (in average)	Purebred: 281.05 days; crossbred: 284.28 days
Coat color	White, black, "blue roan" (grayish), the color combination (for crossbred)
Tail, leg, and face color	Various (white, black, and combinations of these colors) (for crossbred)
Other specific characteristics	Have a prominent muscularity (double muscle) in the hindquarter and pelvis (for pure and crossbred)

Figure 4. Belgian Blue crosses in Indonesia. A. Belgian Blue X Holstein Friesian; B. Belgian Blue X Limousin (personal documentation)

PROBLEMS ENCOUNTERED UPON THE INTRODUCTION OF BELGIAN BLUE TO TROPICAL CONDITIONS

Pregnancy rates and calving rates of Belgian Blue

In 2017, the first pure BB calf in Indonesia, named ‘Gatot Kaca,’ was born as a result of ET (Ministry of Agriculture Republic of Indonesia 2017). Since then, Gatot Kaca has produced millions of doses of frozen semen, which have been distributed to several districts in East Java (Purwantara et al. 2018; Kuswati et al. 2023). Additionally, a total of 173 embryos and 794 semen straws from BB have been applied across diverse recipient cow breeds in 12 ET centers across six (6) provinces in Indonesia, including West Sumatra, South Sumatra, West Java, Central Java, East Java, and Aceh. Specific data on the ET centers and the total pregnancies achieved through ET and AI are presented in Figure 5 and Table 6, respectively.

It showed that a total of 509 pregnancies were achieved through ET and AI, with 142 and 367 pregnancies, respectively. The pregnancy rate (the percentage of recipient cows that become pregnant after application) from ET was higher compared to AI, with rates of 82% and 46%, respectively. The higher pregnancy rate from ET compared to AI may be due to the influence of tropical conditions in Indonesia (THI between 58.7 and 80.12), which impacts heat stress. This agrees with several studies that showed in vitro embryo production can improve fertility during heat stress (Vasconcelos et al. 2011).

Berman et al. (2016) stated that the effect of temperature was predominant (accounting for 0.82-0.95 of the variance), while humidity contributed only 0.05 to 0.12 of the THI variances, which is half of the variance observed in animal responses to variable humidity and heat stress. During 2023, Ciney (Belgium) -a region where the importer of BB semen and embryos to Indonesia is located- predominantly experienced THI levels falling within the comfort zone for cattle, with THI minimum on 25 January 2023 (28.57; comfort) and maximum on 10 September 2023 (72.23; discomfort) (Accu Weather 2024; Weather Underground 2024). Conversely, Indonesia did not exhibit any instances of comfort THI during 2023. Notably, the lowest THI was recorded on 29 September 2023 in East Java (68.33; mild discomfort) and the highest on 12 May 2023 in Sumatra (81.96; danger) (BMKG 2024).

Table 6. Total of pregnancy after ET and AI on multiple embryo transfer centers in Indonesia (adapted from Ministry of Agriculture Republic of Indonesia 2021; collected data on 17 September 2020)

Embryo transfer center	Pregnancy after embryo transfer application	Pregnancy after artificial insemination application
Daerah Istimewa Aceh		
BPTU-HPT Indrapuri	0	0
South Sumatra		
BPTU-HPT Sembawa	21	121
Central Java		
BBPTU Baturraden	29	33
STPP Magelang	3	8
West Sumatra		
BPTU-HPT Padang Mangatas	43	48
West Java		
BET Cipelang	31	58
Polbangtan Bogor	2	3
BBPKH Cinagara	3	10
Balitnak Ciawi	8	8
East Java		
BBPP Batu	0	17
Lolitt Grati	2	25
Polbangtan Malang	0	36
Total Pregnancy (TP)	89	205
Total Application (TA)	173	794
Pregnancy Rate (PR = TP/TA x 100%)	51%	26%
Born Calves (BC)	107	348
Calving Rate (CR = TP/BC x 100%)	120%	170%

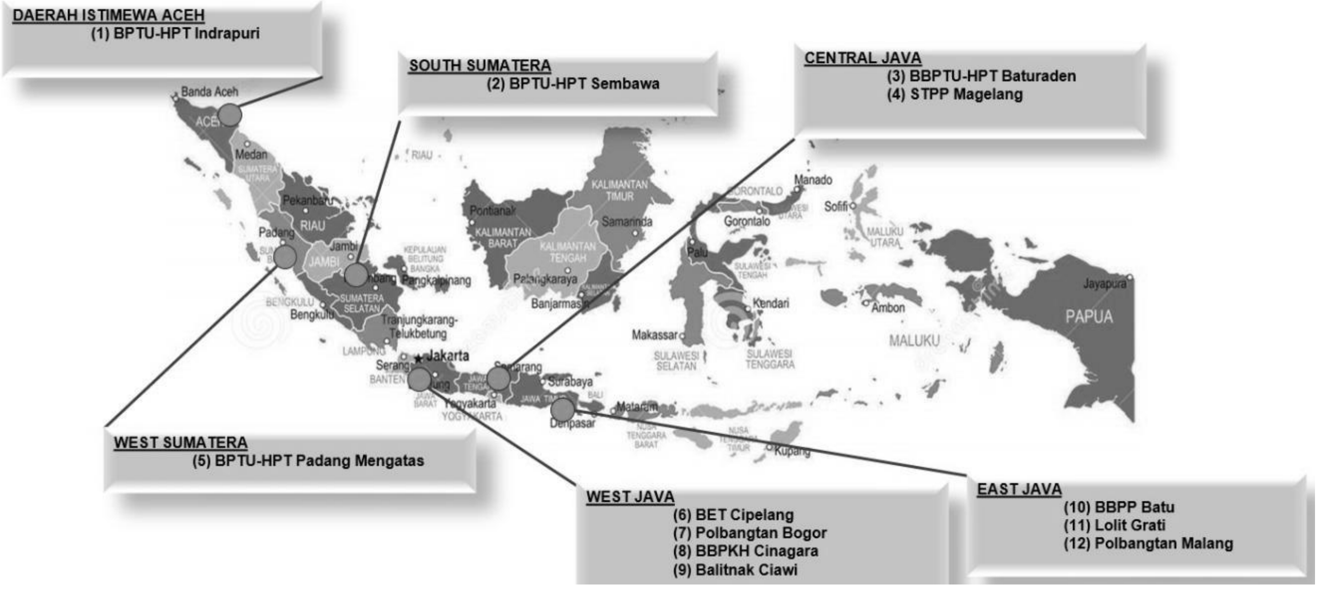

Figure 5. The distribution of 12 embryo transfer centres to introduce Belgian Blue in Indonesia, in six (6) provinces, two (2) regions, Java and Sumatra (Ministry of Agriculture Republic of Indonesia 2021)

The process of ET involves selecting embryos from superior bulls and cows of BB that have already developed to a certain stage of viability before being transferred to local Indonesian recipient cows. This enhances the potential for successful pregnancies compared to AI, where fertilization and early embryo development of BB occur within the cow's reproductive tract under heat stress challenges. This aligns with the findings from Putney et al. (1989), which revealed that the conception rate of ET was higher than that of AI in lactating dairy cows during summer heat stress. The increased pregnancy rate in recipient lactating cows suggests that bovine embryos are sensitive to maternal heat stress during the first 7 days after estrus. In this case, ET may bypass this period of embryonic sensitivity, providing an alternative to AI and partially circumventing heat stress-induced infertility in cattle (Putney et al. 1989).

Interestingly, the total number of calves born from AI was higher than from ET, with 348 and 107 calves, respectively. Additionally, the calving rate (the percentage of recipient cows that successfully give birth to live calves after the application) was higher for AI compared to ET, with rates of 95% and 75%, respectively. This is consistent with the study by Monteiro et al. (2016), which showed that more Holstein heifer calves tended to be stillborn, die, or be euthanized within the first 20 days of life in the ET group compared to the AI group. Several reports have indicated that the lower number of calves born from ET is due to various factors, such as abnormal placental development, heavy fetuses, heavy birth weights, high rates of dystocia, high congenital abnormalities, and high neonatal mortality (Fiems 2012). Furthermore, purebred BB cattle are well-known for their incompatibility in size and shape between the dam and her calf, resulting in a very high incidence of dystocia (Kolkman et al. 2010). However, further studies should be conducted to understand the exact reasons for the lower calving rate in ET compared to AI in BB breeding in Indonesia.

Survival rates of Belgian Blue

Data on the survival rate of BB in Indonesia can be seen in Table 7. A total of 79 BB calves died in Indonesia, consisting of 42 purebred and 37 crossbred calves. In total, the survival rate of BB calves from AI was higher compared to those from ET, with 87% and 53%, respectively. Most of the mortality in BB calves in Indonesia resulting from ET occurred between the ages of 3 and 5 months due to respiratory complications, as stated by Ferreira et al. (2024), in which respiratory disease is in high risk for calves. This is consistent with the study by Coopman (2008), which stated that almost 10% of double-muscled BB calves die between birth and 12 months of age due to genetic disorders, with cardio-respiratory problems being a recurring and major issue on BB farms. Further genetic disorders in BB cattle that have been reported include macroglossia, congenital articular rigidity, muscular hypotonia of the limbs, brachygnathia inferior and superior, fertility disorders, acute heart disruption with or without associated respiratory problems, dermatosparaxis, lethal spasticity, and spastic paresis.

Moreover, double muscling makes BB particularly sensitive to high temperatures due to its high metabolic rate and deficient thermoregulatory capacity (Residiwati 2021, et al. 2023). The trend indicates that tropical conditions in Indonesia have a more negative impact on the survival rate of BB calves born via ET compared to AI. This could be because BB crossbreeds exhibit better heat resistance due to genetic inheritance from the mother, who is better adapted to tropical conditions, compared to purebred BB cattle. This agrees with the study by Moura et al. (2021), which compared crossbred and purebred cattle. The study found that under moderate thermal conditions, crossbred *B. indicus* x *B. taurus* cattle exhibited higher levels of heat production, thermal storage, and cutaneous evaporation than purebreds. While *B. indicus* cattle have lower productive performance compared to *B. taurus*, they are recognized for their superior thermal tolerance and ability to cope with hot environments. This suggests that crosses between *B. taurus* breeds (e.g., BB) and *B. indicus* (e.g., several Indonesian local cattle) could provide a win-win solution to mitigate the effects of thermal constraints and improve the productive performance of cattle in hot climates.

Management and heat stress sensitivity of Belgian Blue breeding in Indonesia

The nutritional needs of BB can be assessed using various methods, such as monitoring body weight changes, energy retention, or measurements from calorimetric or respiratory chambers, and may increase with additional physical activity. While their maintenance energy requirement is reported to be 1.5% higher than other breeds, some argue that DM cattle require less energy due to faster glycolytic fiber development and lower protein turnover compared to non-DM cattle. This lower protein turnover, which accounts for approximately 15% of energy expenditure, along with smaller organ sizes that correlate with reduced energy demands, suggests potentially lower maintenance energy needs for BB. However, their high muscle mass and the metabolic activity of lean tissue compared to fat may offset these reductions, resulting in maintenance energy requirements similar to the average of other beef cattle genotypes (Fiems et al. 2015). Further, BBs are known for their slower onset of puberty compared to other breeds but exhibit faster muscle development and greater fat accumulation. However, a study found that BB-fed grass silage for 84 days followed by *ad-libitum* concentration feeding achieved the same carcass fat class as those fed *ad-libitum* concentrate throughout, indicating that a brief period of moderate energy restriction followed by adequate refeeding does not affect carcass fat class in either the BB genotypes (Keady et al. 2021).

Table 7. Survival rate of Belgian Blue after ET and AI on multiple embryo transfer centers in Indonesia

Embryo transfer centre	**Calves Born (CB)**							**Calves Died (CD)**							**Life Calves (LC)**							**Survival Rate (SR) of ET (SR = LC/CB X100%)**	**Survival Rate (SR) of AI (SR = LC/CB X100%)**	**Total survival rate**
	ET			**AI**			**Total**	**ET**			**AI**			**Total**	**ET**			**AI**			**Total**			
	M	**F**	**T**	**M**	**F**	**T**		**M**	**F**	**T**	**M**	**F**	**T**		**M**	**F**	**T**	**M**	**F**	**T**				
Aceh																								
BPTU-HPT Indrapuri	0	0	0	2	2	4	4	0	0	0	0	0	0	0	0	0	0	2	2	4	4	-	100%	100%
South Sumatra																								
BPTU-HPT Sembawa	13	8	21	76	46	122	143	8	5	13	4	2	6	19	3	0	3	72	44	116	119	14%	95%	83%
Central Java																								
BBPTU Baturraden	6	7	13	9	17	26	39	5	4	9	1	2	3	12	1	3	4	8	15	23	27	31%	88%	69%
STPP Magelang	0	1	1	2	1	3	4	0	0	0	1	1	2	2	0	1	1	1	0	1	2	100%	33%	50%
West Sumatra																								
BPTU-HPT Padang Mangatas	16	22	38	23	23	46	84	5	4	9	8	5	13	22	11	18	29	15	18	33	62	76%	72%	74%
West Java																								
BET Cipelang	13	7	20	48	40	88	108	3	1	4	5	3	8	12	6	6	12	36	36	72	84	60%	82%	78%
Polbangtan Bogor	1	1	2	1	0	1	3	0	0	0	0	0	0	0	1	1	2	1	0	1	3	100%	100%	100%
BBPKH Cinagara	3	0	3	9	4	13	16	3	0	3	0	0	0	3	0	0	0	9	4	13	13	0%	100%	81%
Balitnak Ciawi	8	2	10	12	8	20	30	3	1	4	1	2	3	7	5	1	6	11	6	17	23	60%	85%	77%
East Java																								
BBPP Batu	0	0	0	5	2	7	7	0	0	0	1	0	1	1	0	0	0	4	2	6	6	-	86%	86%
Lolit Grati	0	1	1	6	4	10	11	0	0	0	0	1	1	1	0	1	1	6	3	9	10	100%	90%	91%
Polbangtan Malang	0	0	0	3	5	8	8	0	0	0	0	0	0	0	0	0	0	3	5	8	8	-	100%	100%
Total	60	49	109	196	152	348	457	27	15	42	21	16	37	79	27	31	58	168	135	303	361	53%	87%	79%

Note: Adapted from Ministry of Agriculture Republic of Indonesia (2021); collected data on 24 September 2020. ET: Embryo Transfer, AI: Artificial Insemination, M: Male, F: Female, T: Total

The impact of varying climatic conditions on cattle reproduction is well-established, with particular emphasis on the negative effects of heat stress on bull fertility (El-Tarabany and El-Bayoumi 2015; Silanikove and Koluman 2015; Cheng et al. 2016, Lucio et al. 2016; Sabés-Alsina et al. 2017, 2019; Boni 2019; Luceño et al. 2020; Residiwati 2021). Compared to bulls of other breeds, BB bulls exhibit compromised reproductive traits, which appear to be partly linked to their double-muscled traits. This breed typically possesses a small scrotum without a clearly defined scrotal neck (Hoflack et al. 2006). Additionally, as the *B. taurus* breed, double-muscled BB cattle are more vulnerable to heat stress compared to *B. indicus* subspecies or crossbred cattle with *B. indicus* lineage (Gaughan et al. 2010).

The BB is less well adapted to tropical climates when compared to local Indonesian cattle breeds, which belong to *B. javanicus* and *B. indicus.* The BB typically thrives in the moderate sea climate of Belgium (non-tropical), which is very different from the climate in the Indonesian archipelago (tropical). The temperatures and rainfall differ across the archipelago due to changes in elevation and different monsoon patterns. Indonesia has two major seasons: the hot season (September to March) and the rainy season (March or June to September). However, the timing of these seasons differs depending on the area. Moreover, the primary variable in Indonesia's climate is not the temperature or the atmospheric pressure but the rainfall and the high relative humidity. The winds are moderate and generally predictable; monsoons usually blow in from the south and east between June and September and from the northwest between December and March (Facts and Details 2015).

Heat stress in cattle can be assessed by measuring the combined effects of environmental temperature and relative humidity, called the THI (Wang et al. 2018; Hoffmann et al. 2020; Kulaz and Ser 2022; Nam et al. 2024; Tazzo et al. 2024). The THI thresholds for bull semen production in European temperate conditions are much lower than those reported for tropical and subtropical conditions. The optimal THI for bull semen production in a European temperate climate range from 50 to 60 (Al-Kanaan et al. 2015). Additionally, Habeeb et al. (2018) delineate THI thresholds for heat stress in cattle into five categories: comfort (THI<68), mild discomfort (68<THI<72), discomfort (72<THI<75), alert (75<THI<79), and danger (79<THI<84). Historically, Belgium has consistently maintained a lower THI compared to Indonesia. A detailed comparison of temperature, humidity, and THI classification for heat stress on cattle in Belgium and Indonesia can be seen in Table S1 (supplementary).

The temperatures and rainfall vary across the archipelago due to changes in elevation and different monsoon patterns. Indonesia has two major seasons: the hot season (September to March) and the rainy season (March or June to September). However, the timing of these seasons differs depending on the area. Moreover, the primary variable in Indonesia’s climate is not temperature or atmospheric pressure but rainfall and high relative humidity. Winds are moderate and generally predictable; monsoons typically blow in from the south and east between June and September and from the northwest between December and March (Facts and Details 2015). Hence, to mitigate the adverse impacts of thermal stress on cattle productivity, several strategies can be implemented, including genetic selection, environmental modification, and nutritional intervention. In addition, scientific techniques such as cooling systems and sprinkler treatments have been developed to reduce the negative effects of heat stress on animals. It has been reported that within-breed genetic variation exists for thermotolerance, allowing for genetic selection to improve thermotolerance and increase animal resilience and welfare. Furthermore, animal genetic selection for thermotolerance provides a cumulative and permanent solution at a relatively low cost. To date, genetic selection in beef and dairy cattle has been directed toward productive traits, such as growth rate, meat production, milk yield, and milk quality (Hariyono and Prihandini 2022).

Heat stress impacts ruminant livestock production at varying levels, especially in the context of the ongoing climate crisis. The drastic effects of global climate change-associated heat stress in ruminant livestock necessitate a thorough evaluation of animal performance supported by effective monitoring systems. In this climate-smart, digital age, the adoption of advanced AI technologies is gaining traction for efficient heat stress management. AI has significantly penetrated the climate-sensitive ruminant livestock sector due to its promising scope in assessing production risks and the climate resilience of ruminant livestock. Significant improvements have been achieved with the adoption of novel AI algorithms to evaluate the performance of ruminant livestock. These AI-powered tools are robust and competent, capable of expanding the evaluation of animal performance and minimizing the production losses associated with heat stress in ruminant livestock. Advanced heat stress management through automated monitoring of heat stress in ruminant livestock, based on behavior, physiology, and animal health responses, has been widely accepted. This success is due to the evolution of technologies like Machine Learning (ML), neural networks, and Deep Learning (DL). AI-enabled tools, which involve automated data collection, pre-processing, data wrangling, algorithm development, and model deployment, assist livestock producers in decision-making based on real-time monitoring. These tools also act as early-stage warning systems to forecast disease dynamics using predictive models. Due to their convincing performance, precision, and accuracy, AI models have been incorporated into climate-smart livestock production systems, enabling the successful reduction of heat stress in ruminant livestock, and ensuring sustainable livestock production that safeguards the global economy (Rebez et al. 2024). The BB cattle rearing system in Indonesia is carried out in various conditions, ranging from hot and moderate to cold climatic environments. Our limited observation has indicated that purebred BB cattle grow optimally in low to moderate temperatures in Indonesia (15°C-25°C), while they require special care in ambient temperatures exceeding 25°C. These efforts include providing a supportive environment, such as air conditioning, to ensure they can move comfortably. Interestingly, BB crosses can grow optimally at both low and high temperatures (15°C-32°C) without any special treatment.

In Indonesia, the maintenance of BB cattle is done intensively, with the animals kept in pens equipped with rubber mats (Figure 6), with the feed consisting of forage and concentrates. Furthermore, the composition of the feed ingredients is adjusted to the potential and capabilities of each region while ensuring that the dietary intake is adequate for the growth and development of BB cattle. Routine care is provided for the prevention and treatment of cattle health issues, including a program for controlling endoparasites (every six months) and ectoparasites (as needed). Treatment for livestock is based on their health status and condition, while surveillance tests are conducted twice a year to monitor for infectious diseases in accordance with biosecurity measures. Besides, another technical thing that we need to consider during BB breeding in Indonesia is enhancing the skills of Veterinarians for doing Caesarean Section (CS) to prevent dystocia due to their oversized fetus.

In Belgium, the parturition of BB cows is mainly performed by elective CS, with approximately 90% (Tuska et al. 2021). However, the CS may influence colostrum production characteristics. Our study conducted in Belgium showed that the duration of CS (longer CS), parity (primiparity), and calving season (in summer) had a significantly negative impact on the colostrum production of BB cows. On the other hand, colostrum is pivotal for transferring passive immunity in neonatal calves (van Hese et al. 2022). Both colostrum quality and quantity can be influenced by intrinsic and extrinsic factors (including duration of CS), which should be considered while feeding newborn BB calves delivered via CS (Tuska et al. 2021).

Environmental condition, especially differences in temperature and humidity, also plays an important role in the growth of BB calves. Our previous study showed that the type and environmental factors, such as breeding season, impact neonatal morphometrics of BB in Belgium. It showed that calves born in spring had a longer diagonal length than those born in autumn. The tibial length of calves born in spring was longer than those born in autumn or summer. Calves born in autumn have a shorter head diameter than those born in summer or winter. Shortly, the birth season influences the morphometrics of neonatal BB calves, with a tendency for spring to be associated with the largest body size (Tuska et al. 2022).

Several strategies need to be implemented to mitigate the adverse impacts of thermal stress on cattle, including genetic selection, environmental modification, and nutritional intervention. In addition, scientific techniques such as cooling systems and sprinkler treatments have been developed to reduce the negative effects of heat stress on animals. It has been reported that within-breed genetic variation exists for thermotolerance, allowing for genetic selection to improve thermotolerance and increase animal resilience and welfare. Furthermore, animal genetic selection for thermotolerance provides a cumulative and permanent solution at a relatively low cost. To date, genetic selection in beef and dairy cattle has been directed toward productive traits, such as growth rate, meat production, milk yield, and milk quality (Hariyono and Prihandini 2022).

Subfertility induced by heat stress in Belgian Blue and recommendations.

The impact of heat stress on male fertility is complex and multifactorial, with the fertilizing ability of spermatozoa being affected by several pathways. Among the most significant changes are the increase and accumulation of Reactive Oxygen Species (ROS), which cause lipid peroxidation and impair motility. The exposure of DNA during the cell division of spermatogenesis makes it vulnerable to both ROS and apoptotic enzymes. The subsequent post-meiotic DNA condensation makes restoration impossible, ultimately harming later embryonic development. Mitochondria are also susceptible to the loss of membrane potential and electron leakage during oxidative phosphorylation, which lowers their energy production capacity under heat stress. Although cells are equipped with defense mechanisms against heat stress, intense heat insults can lead to cell death. Heat Shock Proteins (HSPs) belong to a thermostable, stress-induced protein family that eliminates protein clusters and is essential for proteostasis under heat stress (Capela et al. 2022).

Figure 6. Pens type of Belgian Blue in Indonesia

Heat stress has long been recognized as a potential cause of subfertility in dairy cattle and beef cattle breeds (Dash et al. 2016; Wolfenson and Roth 2019; Sammad et al. 2020). Reductions in dry matter intake (Janine et al. 2021), lower feed conversion efficiency (Lees et al. 2019), poor reproduction (Residiwati et al. 2020a), and decreased immunity (Bagath et al. 2019) are commonly observed when cattle are exposed to thermal stress. Additionally, Rahman et al. (2011) stated that BB bulls are more susceptible to subfertility due to heat stress compared to the dairy breed (Holstein Friesian) because of their smaller scrotum with a lower distal neck (Rahman et al. 2011). BB is assumed to be more vulnerable to heat stress than most other breeds due to diminished oxygen transport effectiveness. This condition is typically caused by the relatively small volume of their heart and lungs compared to their body volume, which is a result of the mutated myostatin gene (Van Laer et al. 2015).

A number of environmental factors can cause heat stress, such as temperature, relative humidity, and solar radiation. Other factors, such as solar radiation on the animal, may be less readily available, but they either have a direct effect on the animal or may predispose certain behavioral patterns that contribute to heat stress, such as reduced time spent feeding and lowered water consumption (Morrell 2020). High ambient temperature induces an increase in body temperature, leading to lower production and impaired reproductive outcomes. Ruminants exhibit relatively higher sensitivity to heat stress than other mammals due to their extra thermogenic activity caused by forage rumination and rumen fermentation. Bulls exposed to summer heat stress show an increase in respiratory rate and rectal temperature, a reduction in testis weight, alterations in testosterone production, and a decrease in sperm concentration, motility, and plasma membrane integrity. There is also an increased possibility of mutations in sperm DNA as well as morphologically abnormal spermatozoa. These factors can adversely affect bovine embryo development, leading to lower conception and fertility rates (Seifi-Jamadi et al. 2020). Heat stress has been established as a cause of subfertility in animals, with detrimental effects on the formation and function of gametes, as well as embryonic and fetal development. Elevations in temperature associated with global climate change are concerning for animal agriculture, particularly in countries with moderate climates, and especially when it relates to bovine fertility, given the economic importance of cattle in modern farming systems (Luceno et al. 2020).

Quantifiable measures, such as physiological, behavioral, and biological responses to heat stressors, have been distinguished as markers of heat stress conditions in animals (Lees et al. 2019). Two fundamental strategies are commonly utilized to assess the need for protection against heat stress: animal-based or weather-based measures (van Laer et al. 2015). Animal-based measures imply detecting the need for heat stress protection for the animals by looking at the animal itself, such as evaluating their panting score (Gaughan et al. 2010). The panting score is measured by assessing diverse signs of breathing difficulties on a 0-4.5 scale (Table 8), where PS 0 describes an animal under no heat load and PS 4.5 means a severely heat-stressed animal. Changes in PS, i.e., from 0 to 4.5, as the animal is heat-challenged, are a good marker of the animal's changing heat-load status (Gaughan et al. 2009).

Another way to distinguish the necessity of heat stress protection for animals is by weather-based measurement with the more recent climatic indices, such as the THI (Hoffmann et al. 2020). Both high temperature and high humidity can be an issue for cattle within the tropics: the THI is a measure that accounts for the combined effects of environmental temperature and Relative Humidity (RH) with distinctive weightings for different species. It is an indicative measure of 'the sum of forces external to the animal that acts to displace body temperature from its set point' to assess the risk of heat stress and prevent major effects (Lallo et al. 2018). The equation utilized was THI = ambient temperature (F) - (0.55 - (0.55 x (RH/100)) x (ambient temperature - 58), with the categories for beef cattle: normal <74; alert 75-78; danger 79-83; and emergency >84 (Habeeb et al. 2018).

To diminish the heat stress conditions for cattle, handling cattle early in the morning before temperatures get too high is always recommended (Eirich 2023). The animal's core temperature peaks around two hours after the environmental temperature peaks and takes four to six hours to return to the average temperature. Hence, it is better to work with cattle in smaller groups during elevated environmental temperatures, so they do not stand in the holding area for longer than 30 minutes. The shaded pens and good airflow are efficient in reducing the heat. In addition, a sprinkler system may assist in cooling the area if the water droplet size is large.

Moreover, it is recommended to never over-crowd working facilities and handle cattle slowly using low-stress methods. Livestock movements should be brief during hot seasons. A proper pen can reduce unnecessary movements and potential heat stress in cattle. Moving heavier cattle closer to loading facilities all through the feeding period can help manage heat effects (heavier cattle need more energy for moving and, therefore, are more vulnerable to heat stress) (Eirich 2023).

Table 8. Panting Score (PS) and breathing condition (adapted from Gaughan et al. 2009)

PS	Breathing condition
0	No panting.
1	Slight panting, mouth closed, no drool, easy to see chest movement.
2	Fast panting, drool present, no open mouth.
2.5	As for 2, but occasional open mouth panting, tongue not extended.
3	Open mouth and excessive drooling, neck extended, head held up.
3.5	As for 3, but with tongue out slightly and occasionally fully extended for short periods.
4	Open mouth with tongue fully extended for prolonged periods + excessive drooling. Neck extended and head up.
4.5	As for 4, but head held down. Cattle "breath" from the flank. Drooling may cease.

Under heat-stressed conditions, supplementation of the ration with commercially available omega-3 fatty acids daily for bulls can mitigate adverse effects. When heat stress cannot be avoided despite proper cooling frameworks in the stable of breeding bulls, stop of semen collection until it cools down can become a practical solution, even though the effect of heat stress will remain visible in semen quality at 14 to 42 days after heat exposure (Silanikove and Koluman 2015). In brief, additional consideration should be paid for their excellent maintenance and feed. In addition, due to the maturation rate of the double-muscled meat (post-slaughter) being faster than the original meat and their carcass being exceptionally lean, they require better management than non-double-muscled cattle (Fiems and Ampe 2015). Since Indonesian consumers favor meat that is soft, sweet, tender, and flavorful (L'Huillier and Primrose 2018), good slaughter conditions are required to anticipate heat toughening to obtain good performance, health, and lean meat with good carcasses' tenderness, flavor, and juiciness (Ramos et al. 2024).

This review highlights the dual nature of BB cattle. At the same time, they provide outstanding carcass yields, feed efficiency, and lean meat production, and they also present considerable challenges related to tropical adaptation, heat stress susceptibility, dystocia, and other management complexities. Crossbreeding BB with Indonesian local breeds emerges as a viable strategy to harness the genetic advantages of BB while mitigating environmental and physiological constraints. Then, maintaining BB genetics between 25-75% through AI and ET allows for improved growth performance and resilience to tropical conditions. Comparative analysis of ET and AI methods shows that while ET yields higher pregnancy rates under heat stress, AI provides better calving outcomes and survival rates. Ultimately, the successful implementation of BB breeding programs in Indonesia requires a comprehensive study encompassing genetic selection, advanced veterinary support, climate-adapted housing, precise nutrition, and integration of modern technologies such as AI-based livestock monitoring. By balancing these factors, Indonesia can enhance its beef production sustainably while reducing dependency on imports and improving national food security.

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Table S1. The detailed comparison of temperature, humidity, and THI classification for heat stress on cattle in Indonesia and Belgium

INDONESIA

POLBANGTAN MALANG, East Java, Indonesia
BPPP BATU, East Java, Indonesia
LOLIT GRATI, East Java, Indonesia

Station : East Java Climatology Station

Date	T_avg	RH_avg	THI
01/01/2023	25,1	69	73,91
02/01/2023	24,7	78	74,23
03/01/2023	24,6	78	74,07
04/01/2023	25,4	74	74,90
05/01/2023	25,2	76	74,80
06/01/2023	24,5	82	74,31
07/01/2023	24,2	82	73,82
08/01/2023	24,4	78	73,75
09/01/2023	24,8	71	73,67
10/01/2023	25,5	72	74,84
11/01/2023	24,8	75	74,08
12/01/2023	25	69	73,76
13/01/2023	24,1	74	72,89
14/01/2023	24,2	81	73,72
15/01/2023	24,4	83	74,24
16/01/2023	23	90	72,55
17/01/2023	24,3	85	74,28
18/01/2023	24,6	82	74,47
19/01/2023	23,5	79	72,42
20/01/2023	23,3	85	72,62
21/01/2023	24,3	80	73,79
22/01/2023	24,9	78	74,54
23/01/2023	24,8	76	74,18
24/01/2023	25,2	80	75,23
25/01/2023	24,1	81	73,56
26/01/2023	22,5	94	72,02
27/01/2023	23,3	89	72,98
28/01/2023	23	92	72,72
29/01/2023	23,6	86	73,21
30/01/2023	24,1	88	74,23
31/01/2023	24,5	82	74,31

Date	T_avg	RH_avg	THI
01/02/2023	23,6	88	73,39
02/02/2023	24,4	83	74,24
03/02/2023	25,1	72	74,23
04/02/2023	24,4	77	73,65
05/02/2023	23,5	81	72,60
06/02/2023	23,2	87	72,63
07/02/2023	23,6	84	73,03
08/02/2023	24,3	84	74,18
09/02/2023	23,2	87	72,63
10/02/2023	23,7	86	73,38
11/02/2023	23,9	83	73,43
12/02/2023	23,2	86	72,55
13/02/2023	23,6	86	73,21
14/02/2023	24,4	87	74,64
15/02/2023	22,4	94	71,85
16/02/2023	23,3	90	73,06
17/02/2023	23,6	86	73,21
18/02/2023	24,3	84	74,18
19/02/2023	24	84	73,69
20/02/2023	23,8	84	73,36
21/02/2023	24,2	86	74,21
22/02/2023	23,8	84	73,36
23/02/2023	24,1	84	73,85
24/02/2023	24,7	81	74,53
25/02/2023	24,1	82	73,66
26/02/2023	22,9	83	71,80
27/02/2023	24,3	76	73,40
28/02/2023	24	82	73,50

Date	T_avg	RH_avg	THI
01/03/2023	23,2	87	72,63
02/03/2023	22,5	91	71,78
03/03/2023	24,6	81	74,37
04/03/2023	23,9	78	72,96
05/03/2023	23	86	72,21
06/03/2023	24,3	84	74,18
07/03/2023	23,6	69	71,67
08/03/2023	23,7	76	72,46
09/03/2023	24,5	74	73,51
10/03/2023	23,9	78	72,96
11/03/2023	25,1	76	74,65
12/03/2023	24,4	70	72,96
13/03/2023	23,2	74	71,51
14/03/2023	23,6	82	72,85
15/03/2023	24,4	72	73,16
16/03/2023	24,3	79	73,69
17/03/2023	25,1	76	74,65
18/03/2023	24,6	81	74,37
19/03/2023	25,3	78	75,18
20/03/2023	24,8	79	74,49
21/03/2023	24,9	80	74,75
22/03/2023	25,5	78	75,49
23/03/2023	24,2	86	74,21
24/03/2023	23,3	88	72,89
25/03/2023	24,3	82	73,98
26/03/2023	23,8	84	73,36
27/03/2023	23,5	88	73,22
28/03/2023	23,5	84	72,87
29/03/2023	23,9	86	73,71
30/03/2023	24,3	78	73,59
31/03/2023	24,2	80	73,63

Date	T_avg	RH_avg	THI
01/04/2023	22,9	86	72,05
02/04/2023	22,8	89	72,13
03/04/2023	23,3	86	72,71
04/04/2023	23,1	91	72,81
05/04/2023	23,6	86	73,21
06/04/2023	22,7	91	72,12
07/04/2023	24,3	82	73,98
08/04/2023	23,3	80	72,19
09/04/2023	24,2	78	73,44
10/04/2023	23,6	87	73,30
11/04/2023	23,9	84	73,52
12/04/2023	24,2	86	74,21
13/04/2023	22,5	90	71,70
14/04/2023	23,6	81	72,76
15/04/2023	23,6	81	72,76
16/04/2023	24,6	80	74,27
17/04/2023	24,4	82	74,15
18/04/2023	23,9	83	73,43
19/04/2023	25,4	74	74,90
20/04/2023	25,5	74	75,05
21/04/2023	24,8	81	74,69
22/04/2023	24,2	87	74,30
23/04/2023	25,2	78	75,02
24/04/2023	25,2	79	75,12
25/04/2023	25,1	74	74,44
26/04/2023	25,4	79	75,44
27/04/2023	25,4	79	75,44
28/04/2023	24,4	84	74,34
29/04/2023	23,2	89	72,81
30/04/2023	24,1	82	73,66

STPP MAGELANG, Central Java, Indonesia
BBPTU-HPT Baturaden, Central Java, Indonesia

Station : DI Yogyakarta Climatology Station

BBPKH CINAGARA, West Java, Indonesia
BET CIPELANG, West Java, Indonesia
POLBANGTAN BOGOR, West Java, Indonesia
BALITNAK CIAWI, West Java, Indonesia

Station: : Bandung Geophysic Station

Date	T_avg	RH_avg	THI
01/01/2023	22,6	83	71,31
02/01/2023	23,8	75	72,52
03/01/2023	23,5	77	72,24
04/01/2023	23,5	76	72,15
05/01/2023	23,7	79	72,74
06/01/2023	null	null	null
07/01/2023	null	null	null
08/01/2023	24,5	73	73,41
09/01/2023	24,5	73	73,41
10/01/2023	24,6	77	73,97
11/01/2023	25,1	69	73,91
12/01/2023	24,9	74	74,13
13/01/2023	24,2	72	72,86
14/01/2023	24,5	73	73,41
15/01/2023	25,1	72	74,23
16/01/2023	25	69	73,76
17/01/2023	24,3	78	73,59
18/01/2023	23,6	80	72,67
19/01/2023	24,1	77	73,18
20/01/2023	23,3	78	72,01
21/01/2023	23,2	81	72,11
22/01/2023	25	72	74,07
23/01/2023	24,6	76	73,87
24/01/2023	24	74	72,74
25/01/2023	22,6	82	71,23
26/01/2023	23,8	73	72,34
27/01/2023	23,6	78	72,49
28/01/2023	22,1	90	71,02
29/01/2023	23	84	72,04
30/01/2023	24	78	73,12
31/01/2023	24,4	75	73,46

Date	T_avg	RH_avg	THI
01/02/2023	23,4	80	72,35
02/02/2023	23,6	78	72,49
03/02/2023	23,1	80	71,87
04/02/2023	24,2	72	72,86
05/02/2023	24,5	62	72,32
06/02/2023	24,2	68	72,47
07/02/2023	24,7	71	73,52
08/02/2023	23,8	78	72,80
09/02/2023	23,4	72	71,64
10/02/2023	23,1	81	71,95
11/02/2023	22,7	83	71,47
12/02/2023	21,3	91	69,73
13/02/2023	23,4	76	71,99
14/02/2023	22,4	85	71,14
15/02/2023	23,9	74	72,59
16/02/2023	22,9	81	71,63
17/02/2023	23,9	80	73,15
18/02/2023	24,1	76	73,09
19/02/2023	24,2	78	73,44
20/02/2023	23,8	77	72,71
21/02/2023	23,9	78	72,96
22/02/2023	23,3	82	72,36
23/02/2023	23,4	82	72,52
24/02/2023	21,8	92	70,66
25/02/2023	22,2	88	71,04
26/02/2023	22,4	86	71,22
27/02/2023	21,9	88	70,53
28/02/2023	22,7	84	71,55

BBPTU-HPT Padang Mengatas, West Sumatra, Indonesia

Station : Padang Panjang Geophysic Station

Date	T_avg	RH_avg	THI
01/01/2023	22,7	84	71,55
02/01/2023	22,4	87	71,30
03/01/2023	22,5	88	71,54
04/01/2023	23	81	71,79
05/01/2023	23	87	72,30
06/01/2023	21,3	94	69,93
07/01/2023	21,2	96	69,89
08/01/2023	21,9	94	70,98
09/01/2023	22,8	89	72,13
10/01/2023	22,6	88	71,71
11/01/2023	22,9	86	72,05
12/01/2023	23,8	76	72,62
13/01/2023	23,4	77	72,08
14/01/2023	22,9	86	72,05
15/01/2023	21,8	94	70,80
16/01/2023	22,8	91	72,30
17/01/2023	21,6	93	70,38
18/01/2023	23,6	81	72,76
19/01/2023	23,1	78	71,69
20/01/2023	23	86	72,21
21/01/2023	23,1	86	72,38
22/01/2023	22,2	88	71,04
23/01/2023	21	93	69,35
24/01/2023	21,5	89	69,93
25/01/2023	23,5	79	72,42
26/01/2023	22,9	85	71,96
27/01/2023	20,5	95	68,60
28/01/2023	21,8	89	70,44
29/01/2023	22,5	85	71,30
30/01/2023	24,1	77	73,18
31/01/2023	23,1	81	71,95

Date	T_avg	RH_avg	THI
01/02/2023	23,2	90	72,89
02/02/2023	23,4	86	72,88
03/02/2023	23,4	86	72,88
04/02/2023	22,7	85	71,63
05/02/2023	21,1	93	69,52
06/02/2023	23,3	76	71,84
07/02/2023	24,6	67	72,96
08/02/2023	23,9	77	72,87
09/02/2023	23	86	72,21
10/02/2023	23,5	77	72,24
11/02/2023	20,8	92	68,94
12/02/2023	21,8	86	70,22
13/02/2023	21,4	94	70,11
14/02/2023	22,7	90	72,04
15/02/2023	23	87	72,30
16/02/2023	23	80	71,71
17/02/2023	23,7	78	72,64
18/02/2023	24,5	81	74,21
19/02/2023	22,7	92	72,21
20/02/2023	22,8	88	72,05
21/02/2023	21,8	91	70,58
22/02/2023	22	91	70,93
23/02/2023	23,3	88	72,89
24/02/2023	22,5	91	71,78
25/02/2023	24,7	75	73,92
26/02/2023	24,2	69	72,57
27/02/2023	23,6	80	72,67
28/02/2023	22,5	89	71,62

BPTU-HPT Sembawa, Sumatra, Indonesia
BPTU-HPT Indrapuri Aceh, Sumatra, Indonesia

Station : Meteorology Station of Sultan Mahmud Badaruddin II

Date	T_avg	RH_avg	THI
01/01/2023	26,8	84	78,28
02/01/2023	26,7	82	77,88
03/01/2023	25	90	75,96
04/01/2023	25,1	85	75,60
05/01/2023	26,4	84	77,63
06/01/2023	26,7	84	78,12
07/01/2023	26,9	86	78,69
08/01/2023	26,9	84	78,45
09/01/2023	26,3	85	77,58
10/01/2023	28,4	80	80,36
11/01/2023	26,3	84	77,46
12/01/2023	27,4	82	79,01
13/01/2023	27,4	78	78,50
14/01/2023	27,7	80	79,24
15/01/2023	26,2	90	78,00
16/01/2023	27,5	80	78,92
17/01/2023	25,7	89	77,03
18/01/2023	26,2	84	77,30
19/01/2023	25,3	89	76,36
20/01/2023	25,8	88	77,09
21/01/2023	26,4	85	77,74
22/01/2023	26,9	86	78,69
23/01/2023	25,8	88	77,09
24/01/2023	26,6	82	77,71
25/01/2023	26,1	83	77,02
26/01/2023	25,8	84	76,64
27/01/2023	26,6	86	78,20
28/01/2023	26,2	87	77,65
29/01/2023	26,1	83	77,02
30/01/2023	26,2	84	77,30
31/01/2023	25,6	90	76,98

Date	T_avg	RH_avg	THI
01/02/2023	26,4	86	77,86
02/02/2023	27,4	84	79,27
03/02/2023	27,3	85	79,23
04/02/2023	27,7	83	79,63
05/02/2023	27,6	79	78,94
06/02/2023	27,3	82	78,85
07/02/2023	27,1	83	78,65
08/02/2023	28	79	79,58
09/02/2023	28,1	81	80,01
10/02/2023	28,3	81	80,33
11/02/2023	28,1	81	80,01
12/02/2023	26,8	81	77,92
13/02/2023	28,5	76	79,96
14/02/2023	28,2	82	80,31
15/02/2023	26,7	84	78,12
16/02/2023	27,3	79	78,47
17/02/2023	27,3	77	78,21
18/02/2023	27,4	81	78,88
19/02/2023	26,7	86	78,36
20/02/2023	24,7	92	75,65
21/02/2023	26,2	86	77,53
22/02/2023	26,6	82	77,71
23/02/2023	25,9	86	77,03
24/02/2023	26,4	89	78,22
25/02/2023	25,7	86	76,70
26/02/2023	26,5	85	77,91
27/02/2023	24,9	92	75,99
28/02/2023	25,6	88	76,75

BELGIUM

Station : Liege Airport Station

Date	T_avg	RH_avg	THI
01/01/2023	11	70	52,82
02/01/2023	8	85,1	47,35
03/01/2023	5,5	85	43,23
04/01/2023	9	87,5	48,87
05/01/2023	10	87,4	50,55
06/01/2023	9	87,4	48,88
07/01/2023	8,5	76,2	48,70
08/01/2023	6,5	80,8	45,21
09/01/2023	4	85,3	40,72
10/01/2023	3,5	86	39,82
11/01/2023	8,5	81,9	48,37
12/01/2023	7,5	86,4	46,44
13/01/2023	6,5	79,2	45,34
14/01/2023	7	86	45,63
15/01/2023	4	78,5	41,42
16/01/2023	3	84,9	39,11
17/01/2023	-1	83	32,80
18/01/2023	-2	81,3	31,44
19/01/2023	0	86,1	33,99
20/01/2023	1	94,7	34,51
21/01/2023	-2	92,9	29,56
22/01/2023	-2	96,1	29,03
23/01/2023	-0,5	94,3	31,94
24/01/2023	-0,5	85,7	33,22
25/01/2023	-2,5	93,6	28,57
26/01/2023	-0,5	98,8	31,28
27/01/2023	2	90,1	36,82
28/01/2023	-3,5	80,1	29,24
29/01/2023	-2,5	83,6	30,25
30/01/2023	3,5	84,3	40,00
31/01/2023	3	90,3	38,50

Date	T_avg	RH_avg	THI
01/02/2023	5	82,7	42,62
02/02/2023	6,5	85,1	44,87
03/02/2023	7,5	86,3	46,44
04/02/2023	7	95,3	44,95
05/02/2023	4	87,6	40,48
06/02/2023	2,5	90,6	37,61
07/02/2023	1	77	36,86
08/02/2023	1	49,7	40,49
09/02/2023	0,5	59,6	38,48
10/02/2023	2,5	78,9	39,00
11/02/2023	4,5	93,5	40,74
12/02/2023	4,5	91,8	40,91
13/02/2023	5	79,5	42,92
14/02/2023	6	69,6	45,34
15/02/2023	7,5	61,3	48,16
16/02/2023	7	75,2	46,43
17/02/2023	10,5	84,1	51,52
18/02/2023	8,5	90,6	47,85
19/02/2023	7	88,6	45,44
20/02/2023	6,5	87,1	44,71
21/02/2023	7,5	92,8	46,00
22/02/2023	7	81,7	45,95
23/02/2023	6	93,6	43,34
24/02/2023	4	88,2	40,42
25/02/2023	2	75,9	38,57
26/02/2023	-0,5	68,8	35,72
27/02/2023	0	71,1	36,13
28/02/2023	-0,5	66,9	36,00

Nb:

T_avg	: Average of Temperature
RH_avg	: Average of Relative Humidity
Null	: no data record available

Classification of THI thresholds for heat stress in cattle based on Habeeb et al. (2018):

- 🟩 : comfort (THI < 68)
- 🟦 : mild discomfort (68 < THI <72)
- 🟨 : discomfort (72 < THI < 75)
- 🟧 : alert (75 < THI < 79)
- 🟥 : danger (79 < THI < 84)

Data Source of Temperature and Humidity:

Accu Weather, 2024. Accu Weather Ciney, Namur. https://www.accuweather.com/en/be/ciney/30023/may-weather/30023?year=2023 (Accesses May, 9th 2024)

Weather Underground, 2024. Grâce-Hollogne, Liege, Belgium Weather Histor. https://www.wunderground.com/history/monthly/be/gr%C3%A2ce-hollogne/EBLG/date/2023-12 (Accesed May, 9th 2024)