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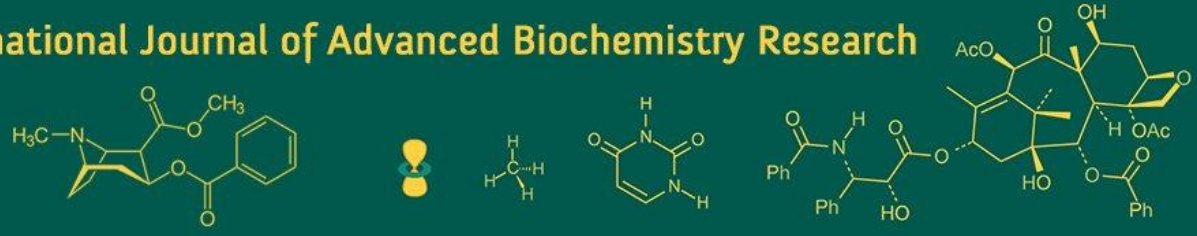

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Histoarchitecture of endocrine pancreas of buffalo, sheep and goat

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Abstract
The present study was undertaken to compare the histomorphological characteristics of the pancreatic islets of Langerhans in buffalo, sheep, and goat. In all species, the endocrine component of the pancreas consisted of irregular clusters of cells interspersed between the acini and surrounded by numerous sinusoidal capillaries. The islets were categorized as large, medium, and small, with average diameters of 80-125 µm in buffalo and sheep, and 80-115 µm in goat. The small islets measured 20-30 µm, 20-25 µm, and 20-26 µm, respectively. The average number of endocrine cells per islet ranged from 47-60, 14-23, and ≤8 in buffalo; 74-85, 16-25, and 4-10 in sheep; and 91-110, 16-26, and 1-10 in goat for large, medium, and small islets, respectively, indicating a higher islet density in goats. Four types of endocrine cells i.e α, β, δ, and PP cells were identified in all species. β cells were the most numerous and centrally located, constituting 69.51 and 67.72% in buffalo, 65.36 and 67.92% in sheep, and 71.81 and 67.62% in goat for large and medium islets, respectively. α cells were fewer and predominantly peripheral (14.13 and 14.98% in buffalo; 20.86 and 14.51% in sheep; 16.68 and 9.90% in goat). δ cells accounted for 11.25 and 10.83% in buffalo, 9.61 and 11.59% in sheep, and 8.14 and 14.89% in goat, while PP cells were least numerous (5.07 and 7.10% in buffalo; 4.15 and 6.09% in sheep; 3.01 and 7.57% in goat). The comparative findings indicate that goats possess more numerous and denser islets, whereas buffalo exhibit larger but fewer islets, reflecting species-specific structural and functional adaptations.

Keywords: Endocrine Pancreas, islets of Langerhans, α-cells, β-cells, δ-cells, PP cells

Introduction
The pancreas is a mixed gland consisting of exocrine acini and endocrine islets of Langerhans, which regulate carbohydrate metabolism through hormone secretion. The islets are composed of α, β, δ, PP, and F cells arranged in irregular cords and supported by a delicate network of reticular and collagen fibres (Getty, 1975; Abunasef *et al.*, 2014) [9, 1]. The cellular proportion, distribution, and architecture of these islets vary among animal species, reflecting metabolic adaptations. In domestic animals, β cells constitute the major cell population (60-80%) and are centrally located, whereas α cells (5-30%) occupy the periphery (Frandson *et al.*, 1992; Delmann and Eurell, 1998) [6, 5]. Mukherjee *et al.* (1988) [15] reported irregularly shaped islets composed of A and B cells in sheep, separated from the acini by thin reticular tissue. Ganguli and Prasad (1995) [8] observed similar features in goats with α cells surrounding centrally placed β cells. Hiratsuka *et al.* (1996) [11] in cattle described dumbbell-shaped islets with regional variations between A- and B-cell zones. In dogs, Watanabe *et al.* (1989) [19] identified neuro-insular complexes with δ-like cells, while Jagapathi *et al.* (2012) [12] reported α, β, and δ cells with distinct cytoplasmic staining in cats.
Microvascular and neural components of islets have also shown species-specific patterns. Weir and Orci (1982) [20] demonstrated a glomerular-like capillary network in rat islets, whereas Ahmed *et al.* (2017) [2] described periinsular and periacinar nerve plexuses in rats. Hafez *et al.* (2015) [10] and Mahesh *et al.* (2017) [14] noted that islet size and connective tissue demarcation varied among cattle, horse, camel, sheep, and goat. Therefore, the present study aimed to provide a detailed comparative histomorphological analysis of pancreatic islets in buffalo, sheep, and goat, emphasizing interspecies variations in islet size, cellular composition, organization, and vascular and neural association.

Materials and Methods

The present study was conducted on pancreas of domestic animals i.e 15 adult buffalo, 19 sheep, and 18 goats of either sex. The tissue samples of pancreas of buffalo, sheep and goat were collected immediately after their slaughter at municipal slaughter house, Proddatur and Tirupati. The tissue samples of pancreas were taken at different regions of pancreas i.e body, right lobe and left lobe. Then the tissue samples were fixed in 10% Neutral buffered formalin and Bouin's fluid (Singh and Sulochana, 1996) [17]. The fixed tissues were subjected to routine tissue processing and paraffin blocks and sections of 4-5µm thickness and the sections were stained by the following methods for histological study.

1. Standard Haematoxylin and Eosin method for the routine histological study (Singh and Sulochana, 1996) [17].
2. Masson's Trichrome method for demonstration of collagen fibres (Singh and Sulochana, 1996) [17].
3. Gridley´s and Wilders'smethod for reticular fibres (Singh and Sulochana, 1996) [17].
4. Beilschowsky method for nerve fibres (Luna, 1968) [13].
5. Halami's aldehyde fuschin method for different cells types in pancreas (Bancroft and Gamble, 2008) [3].

Results

In the present study, the endocrine portion of the pancreas in buffalo, sheep, and goat consisted of irregular cellular aggregations, the islets of Langerhans, interspersed between the acini and richly surrounded by sinusoidal capillaries. In buffalo, the endocrine tissue was organized into round or polygonal pale cell clumps without a distinct capsule but separated from the surrounding acini by fine reticular fibres extending into the interior of the islets (Fig.1). A well-developed periinsular nerve plexus encircled the islets and extended centrally (Fig. 2). Three types of islets were identified, they were large (80-125 µm), medium (40-55 µm), and small (20-30 µm) and containing 47-60, 14-23, and ≤8 endocrine cells, respectively. The α, β, δ, and PP cells were arranged in anastomosing cords with numerous sinusoids between them. The β cells were most numerous, comprising 69.51% and 67.72% (Table.1) of total islet cells in large and medium islets, respectively; α cells were fewer (14.13% and 14.98%), followed by δ (11.25% and 10.83%) and PP cells (5.07% and 7.10%). The average nuclear diameters of α, β, δ, and PP cells were 3.75-4.26 µm, 4.98-6.28 µm, 4.30-5.43 µm, and 1.93-2.71 µm, respectively.

In sheep, the islets were oval to irregular clusters of pale cells (Fig. 3) separated from the acinar parenchyma by thin reticular tissue and enclosed by a distinct periinsular nerve plexus (Fig. 4). Large, medium, and small islets measured 80-125 µm, 40-50 µm, and 20-25 µm, respectively, and contained 74-85, 16-25, and 4-10 endocrine cells (Table.2). The β cells were predominant and centrally located (65.36% and 67.92% in large and medium islets) (Figs. 3, and Fig.5), while α cells (20.86% and 14.51%) were mainly peripheral but occasionally central while, δ cells were fewer (9.61% and 11.59%), mostly peripheral (Fig.6), and PP cells were least numerous (4.15% and 6.09%) (Fig.3), absent in small islets. The nuclear diameter was greatest in β cells with 4.96-7.51 µm. In addition, few islets also showed giant nucleus in β cells and it ranged between 6.85 to 8.01 µm (Fig.5), followed by α (3.72-4.26 µm), δ (2.65-3.93 µm), and PP cells (2.10-2.73 µm).

In goats, the endocrine tissue appeared as compact clusters of cells among the acini, supported by fine collagen and reticular fibres and richly vascularized (Fig. 7). Nerve fibres and reticular strands extended into the large islets. The number of islets was higher than in buffalo and sheep. The large, medium, and small islets measured 80-115 µm, 45-60 µm, and 20-26 µm, respectively, and contained 91-110, 16-26, and 1-10 endocrine cells (Table.3). The β cells were centrally located and most numerous (71.81% and 67.62%), whereas α cells (16.68% and 9.90%) occurred peripherally and between β cells (Figs. 8, 9, 10). δ cells (8.14% and 14.89%) were present at the periphery and occasionally in the interior (Figs. 8, and 10), while PP cells were few (3.01% and 7.57%), found singly at the periphery (Figs. 8, 9 and 10). The average nuclear diameters of α, β, δ, and PP cells were 3.48-4.76 µm, 5.17-7.44 µm, 3.99-5.43 µm, and 1.93-2.70 µm, respectively.

Comparatively, goats showed the highest number and density of islets with better-defined cellular organization and vascularity, followed by sheep, while buffalo exhibited fewer but larger islets. In all three species, β cells were the predominant endocrine cell type forming the central zone, α and δ cells were fewer and mainly peripheral, and PP cells were the least numerous or absent in smaller islets. The periinsular nerve plexus was distinct in buffalo and sheep, and fine connective tissue fibres supported all islets across the three species. These findings highlight species-specific differences in islet size, cellular composition, and organization among domestic ruminants.

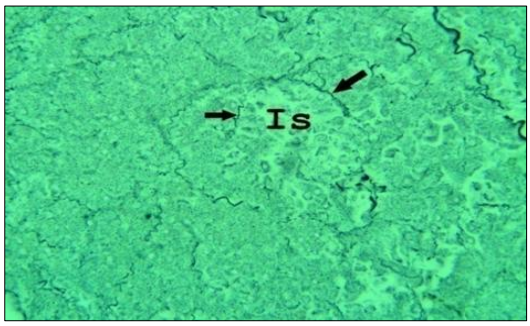

Fig 1: Photomicrograph of pancreas of buffalo showing reticular fibers around the islet of Langerhans. Gridley's x 400

- Is- Islet of Langerhans
- Black arrow- Reticular fibers

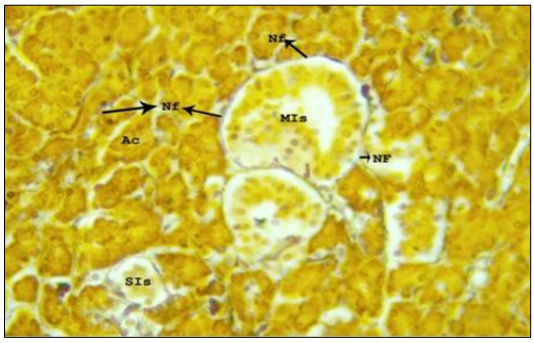

Fig 2: Photomicrograph of pancreas of goat showing nerve fibres around the acini and islet of Langerhans. Bielschowsky's x 400.

- Nf - Nerve fibre (periinsular)
- Ac - Acini
- MIs - Medium sized islet of Langerhans
- SIs - Small sized islet of Langerhans

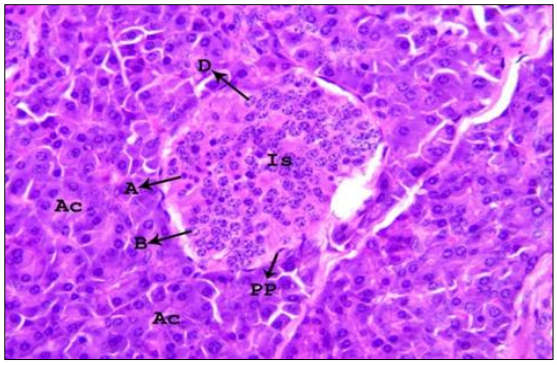

Fig 3: Photomicrograph of pancreas of sheep showing large islet of Langerhans. H & E x 400

- Ac- Acini
- A-Alpha cell
- B- Beta cell
- D- Delta cell
- PP- Pancreatic polypeptide cell
- Is - Islet of Langerhans

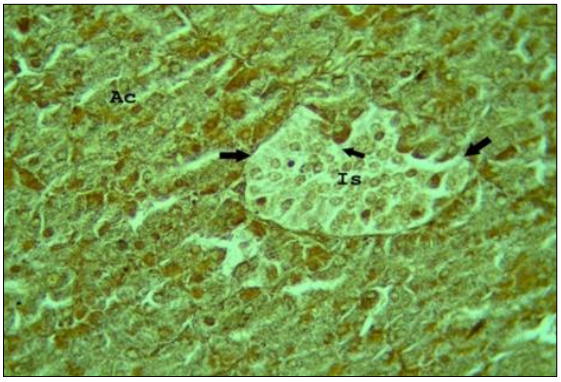

Fig 4: Photomicrograph of pancreas of sheep showing periinsular nerve plexus around the islet of Langerhans. Beilschowsky x 400

- Is- Islet of Langerhans
- Black arrow- periinsular nerve plexus
- Ac - Acini

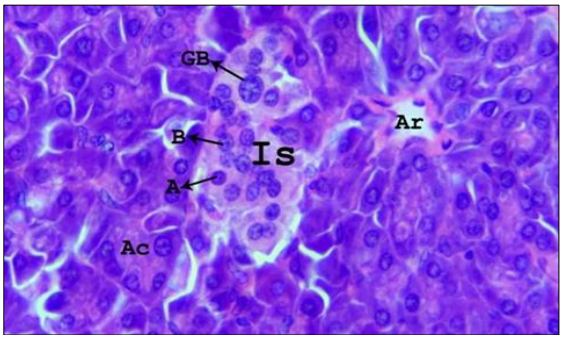

Fig 5: Photomicrograph of pancreas of sheep showing medium sized islet of Langerhans. H & E x 400

- Is- Islet of Langerhans
- Ar- Artery
- A-Alpha cell
- B- Beta cell
- GB- Nucleus of giant beta cell
- Ac- Acini

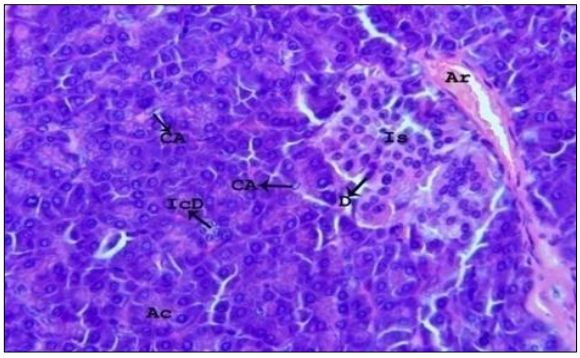

Fig 6: Photomicrograph of pancreas of sheep showing large islet of Langerhans. H & E x 400

- CA- Centroacinar cell
- IcD- Intercalated duct
- Is- Islet of Langerhans
- D- Delta cell
- Ar- Artery (sinusoid)

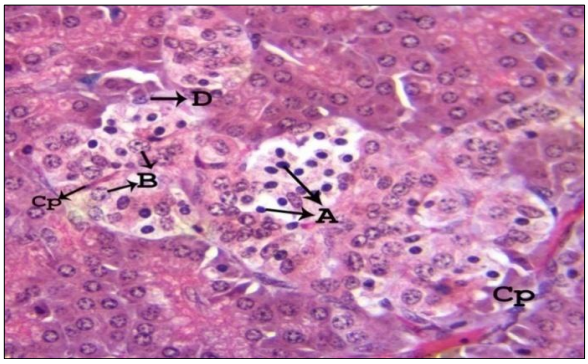

Fig 7: Photomicrograph of pancreas of goat showing Large islet of Langerhans and sinusoids. Masson's Trichrome x 400

- D - Delta cell
- B - Beta cell
- A - Alpha cell
- Cp - Capillary (sinusoid)

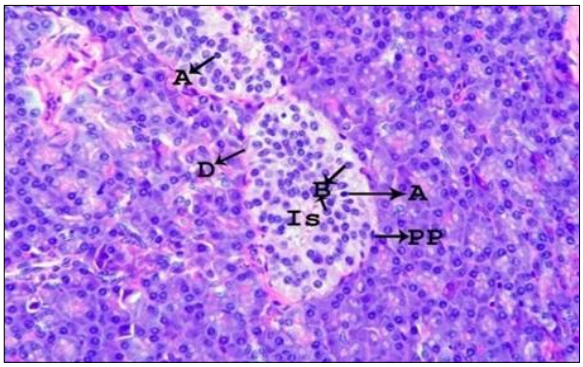

Fig 8: Photomicrograph of pancreas of goat showing Large islet of Langerhans. H & E x 400

- A - Alpha cell
- D - Delta cell
- B - Beta cell
- PP - Pancreatic Polypeptide cell
- Is - Islets of Langerhans

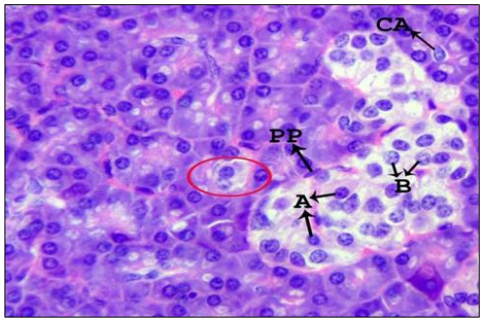

Fig 9: Photomicrograph of pancreas of goat showing medium islet of Langerhans. H & E x 400

- B - Beta cell
- A - Alpha cell
- PP - Pancreatic Polypeptide cell
- CA - Centroacinar cell
- Red circle - Two cell islet

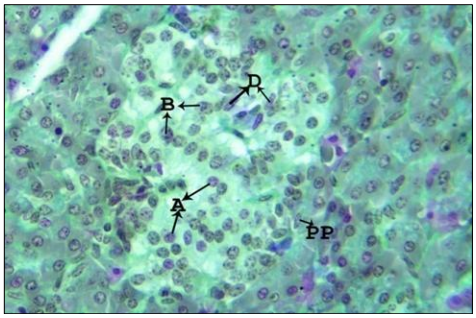

Fig 10: Photomicrograph of pancreas of goat showing different types of cells in large islet of Langerhans. Halami's Aldehyde Fuchsin x 400.

- A - Alpha cell
- D - Delta cell
- B - Beta cell
- PP - Pancreatic Polypeptide cell

Table 1: The average number and percentage of endocrine cells in islets of Langerhans of pancreas in buffalo.

S. No	Type of endocrine cell	Average number of endocrine cells		Average percentage of endocrine cells	
		Large sized islet	Medium sized islet	Large sized islet	Medium sized islet
1	α cells	8 to 10	2 to 4	14.13%	14.98%
2	β cells	35 to 40	12 to 14	69.51%	67.72%
3	δ cells	4 to 6	2 to 3	11.25%	10.83%
4	PP cells	0 to 4	0 to 2	5.07%	7.10%

Table 2: The average number and percentage of endocrine cells in islets of Langerhans of pancreas in sheep.

S. No	Type of endocrine cell	Average number of endocrine cells		Average percentage of endocrine cells	
		Large sized islet	Medium sized islet	Large sized islet	Medium sized islet
1	α cells	15 to 17	2 to 5	20.86%	14.51%
2	β cells	50 to 56	12 to 15	65.36%	67.92%
3	δ cells	6 to 8	2 to 4	9.61%	11.59%
4	PP cells	0 to 2	0 to 1	4.15%	6.09%

Table 3: The average number and percentage of endocrine cells in islets of Langerhans of pancreas in goat.

S. No	Type of endocrine cell	Average number of endocrine cells		Average percentage of endocrine cells	
		Large sized islet	Medium sized islet	Large sized islet	Medium sized islet
1	α cells	15 to 18	2 to 5	16.88%	9.90%
2	β cells	65 to 78	14 to 16	71.81%	67.62%
3	δ cells	9 to 11	0 to 3	8.14%	14.89%
4	PP cells	2 to 3	0 to 2	3.01%	7.57%

Discussion

The present study revealed detailed comparative observations on the histomorphology of the pancreatic islets of Langerhans in buffalo, sheep and goat, highlighting remarkable interspecies variations in their organization, cellular composition, and vascularization. In all three species, the endocrine part of the pancreas consisted of irregular cellular aggregations interspersed between exocrine acini and richly supplied with sinusoidal capillaries, which is in agreement with the classical descriptions of Getty (1975) [9], Frandson *et al.* (1992) [6] and Delmann and Eurell (1998) [5]. The islets in buffalo, sheep and goat were not encapsulated but were separated from the surrounding acinar tissue by thin strands of reticular fibres, corroborating the findings of Mukherjee *et al.* (1988) [15] in sheep and Ganguli and Prasad (1995) [8] in goats. The general parenchymal arrangement showed cords or clumps of endocrine cells surrounded by delicate vascular channels, as also described by Weir and Orci (1982) [20] in rats and Bosco *et al.* (2010) [4] in humans.

In buffalo, the islets were relatively larger and fewer, measuring between 80 and 125 µm in diameter with 47-60 endocrine cells per islet, while in sheep, the islets were oval to irregular and contained 74-85 cells, and in goat, they were smaller but more numerous, measuring 80-115 µm in diameter with 91-110 cells. Such interspecies variations in islet size and distribution agree with the observations of Hafez *et al.* (2015) [10] and Mahesh *et al.* (2017) [14], who suggested that smaller and more numerous islets, as seen in goats, reflect higher metabolic rates and greater insulin requirements. The cellular composition of the islets in all species followed the typical ruminant pattern consisting of β, α, δ and PP cells arranged in anastomosing cords separated by sinusoidal capillaries. Quantitatively, β cells formed the major population, constituting 69.51 and 67.72 per cent in large and medium islets of buffalo, 65.36 and 67.92 per cent in sheep, and 71.81 and 67.62 per cent in

goat. This predominance of β cells confirms the earlier reports of Frandson *et al.* (1992) [6] and Delmann and Eurell (1998) [5], who stated that β cells represent 60-80 per cent of total islet cells in domestic mammals. The comparatively higher β cell percentage in goat indicates greater insulinogenic activity consistent with its higher metabolic rate.

The α cells were fewer in number and located mainly at the periphery of the islets, accounting for 14.13 to 14.98 per cent in buffalo, 14.51 to 20.86 per cent in sheep and 9.90 to 16.68 per cent in goat, which supports the peripheral localization described by Mukherjee *et al.* (1988) [15] and Ganguli and Prasad (1995) [8]. These cells showed acidophilic cytoplasmic granules and round nuclei characteristic of glucagon-producing α cells, as noted by Getty (1975) [9]. The peripheral arrangement of α cells surrounding central β cells supports the concept proposed by Bosco *et al.* (2010) [4] that this structural pattern facilitates paracrine regulation of hormone secretion. The δ cells were less frequent, comprising 11.25 to 10.83 per cent in buffalo, 9.61 to 11.59 per cent in sheep and 8.14 to 14.89 per cent in goat. Similar localization of δ cells between α and β cells was reported by Watanabe *et al.* (1989) [19] in dogs and Jagapathi *et al.* (2012) [12] in cats. The presence of δ cells within central parts of some islets in sheep and goat is comparable to the findings of Prakash *et al.* (2014) [16] in Madras Red sheep, indicating that somatostatin cells modulate insulin and glucagon secretion through local interactions.

The pancreatic polypeptide (PP) cells were the least numerous, found singly or in small clusters at the periphery of the islets, forming 5.07 to 7.10 per cent in buffalo, 4.15 to 6.09 per cent in sheep and 3.01 to 7.57 per cent in goat. Their variable occurrence and inconsistent distribution across species support the observations of Delmann and Eurell (1998) [5] and Furuzawa *et al.* (1992) [7], who reported similar findings in domestic animals. The nuclear diameter of endocrine cells also varied slightly among species; β cells exhibited the largest nuclei (4.98-6.28 µm in buffalo, 4.96-7.51 µm in sheep, and 5.17-7.44 µm in goat), followed by δ, α and PP cells. Occasional giant nuclei in β cells of sheep indicate heightened secretory activity, similar to the report of Prakash *et al.* (2014) [16].

The vascular network within the islets was formed by dense sinusoidal capillaries surrounding the endocrine cords, consistent with the glomerular-type microvasculature described by Weir and Orci (1982) [20] in rat pancreas. Periinsular nerve plexuses were well developed in buffalo and sheep, and fine nerve fibres were observed entering the islets in goat, findings that align with the neuro-insular association reported by Watanabe *et al.* (1989) [19] in dogs and Ahmed *et al.* (2017) [2] in rats. These neural elements likely play a significant role in regulating endocrine secretions, as proposed by Sreeranjini *et al.* (2015) [18].

Comparatively, the buffalo exhibited larger but fewer islets with extensive β-cell clustering and distinct periinsular nerve supply; sheep showed moderately sized islets with relatively balanced α and β cell proportions; and goats had smaller, more numerous islets with a higher β cell percentage and richer vascularization. These species differences may represent physiological adaptations linked to their metabolic requirements and feeding behaviour. The larger islets in buffalo could be associated with greater insulin secretion per islet and a slower metabolic rate, whereas the increased number and density of β cells in goats may support higher insulin turnover and glucose utilization.

Conclusion

The present findings establish that the general histoarchitecture of the pancreatic islets in buffalo, sheep and goat is fundamentally similar, but species-specific variations exist in islet size, cell proportions, and vascular and neural associations. These differences reflect metabolic adaptations among ruminants and provide a morphological baseline for further studies on endocrine regulation and comparative pancreatic physiology.

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