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EARLY VIEW

REVİEW

Blue-Breasted Quail (*Synoicus chinensis*): Characteristics, Breeding Techniques and Research

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Abstract

The blue-breasted quail is a socially monogamous, sexually dimorphic and precocial species pan-Asian, classified in the order Galliformes and family Phasianidae. There are different names for the blue-breasted quail in the scientific literature, so it is easily be confused that these names refer to the same species, and recently the scientific name *Synoicus chinensis* has been used. The main advantages include easy rearing in small areas, small body size, hardiness, high egg-laying performance, short generation interval and sex determination after the fourth week of life. In addition, blue-breasted quail are smaller than Japanese quail and still retain species-specific behavioural traits even after domestication. The blue-breasted quail was proposed as a model animal nearly three decades ago and has been used for more than two decades, mainly in zoology, animal genetics, heredity and immunology research. It is also worth noting that the blue-breasted quail is a widespread used parthenogenesis model. This study compiles scientific research on the blue-breasted quail and presents this information under physiological, morphological and behavioural characteristics, including information on the breeding techniques of the species. The studies show that there is growing recognition of the significance of blue-breasted quail in research laboratories and that their position is likely to be strengthened in the future.

Introduction

Quails are divided phylogenetically into two groups, The Old-World quail belongs to the Phasianidae (including several genera representing Old World species) and distributes in the Palaearctic region (Europe, North Africa and Asia), while the New World quail classified as the Odontophoridae is restricted to North and South America (Shibusawa *et al.* 2004; Lukanov, 2019). Among Galliformes, 38 species are named "quails"; 14 species are classified as Phasianidae, comprising 5 genera, and 24 as Odontophoridae, comprising 7 genera (Nishibori *et al.*, 2002). Synoicus chinensis (blue-breasted quail) is classically classified in the order Galliformes and family Phasianidae on the basis of morphological characteristics and cytogenetic data and biochemical evidence, as are chicken and Japanese quail (Shibusawa *et al*. 2004; Nishibori *et al.,* 2002). The blue-breasted quail is the smallest species of the order Galliformes (Tsudzuki, 1994) and has even been described as dwarf (Prinzinger *et al*., 1993) and miniature (Landry, 2015).

The blue-breasted quail is a geographic specie of pan-Asian (Roberts and Baudinette, 1984), originating from India, Southeast Asia and the southeastern region of China (Pis and Luśnia, 2005; Nakamura *et al.,* 2019'a). Despite the fact that this quail is thought to have always been widespread in Asia, it has not been recorded in Sumatra in recent times, and there are 40 % fewer areas recorded in the sub-region than before 1970 (Mcgowan

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and Gillman, 1997). On the Australian mainland, the species is restricted to the mesic coastal belt around eastern Australia and the coastal Northern Territory (Pearson, 1994). Blue-breasted quail is among the non-migratory species living in these regions (Saini *et al*, 2019). With the exception of the Japanese quail (*Coturnix coturnix japonica*), it is the most widely raised quail species and is relatively easy to obtain from commercial suppliers in Europe (Pis and Luśnia, 2005).

The blue-breasted quail is also called "button quail" in the USA, "King quail" in Australia and "Chinese painted quail" in Europe. Other common names are Indian blue quail, Asian blue-breasted quail and blue quail (Ono *et al*., 2005). The three Latin binominal names of this species are chronologically *Excalfactoria chinensis* (Tsudzuki, 1995'a), *Coturnix chinensis* (Shibusawa *et al*. 2004) and *Synoicus chinensis* (Adkins-Regan, 2016; Zi *et al*., 2023).

Its major advantages include easy rearing in small areas, small body size, durability, high spawning performance, short generation interval and sex discrimination after the fourth week (Wei *et al.,* 2011a; Nishibori *et al*., 2002; Tsudzuki, 1994; Kageyama *et al*., 2018; Nakamura *et al*., 2019b). In addition, blue-breasted quail are smaller than Japanese quail (Sarkadi *et al*., 2013) and have retained species-specific behavioural traits even after domestication (Hickman, 1984), but have not been selected for any traits (Pearson et al., 1998). Hence, the benefits of using blue-breasted quail as an avian model for research are the reduction of costs, area and labour required for their care (Nakamura *et al.,* 2019a), as well as their suitability for improvement due to the variation of their biological traits. Monogamous housing leads to more systematic searching and less aggressive behaviour (MacDonald, 2010). Due to these advantages, blue-breasted quail have been used for over 20 years in numerous disciplines including developmental biology, genetics, reproduction, behaviour and immunology (Nakamura et al., 2019b). Besides, because of its small size and variety of feather colours, the blue-breasted quail is occasionally bred as a pet (Kageyama *et al*., 2018).

Although the Japanese quail is the most studied domestic quail in scientific research, the blue-breasted quail was proposed as a potential model animal about three decades ago (Tsudzuki, 1994). Subsequently, the complete mitochondrial (mt) genome of the blue-breasted quail was sequenced for phylogenetic analysis, confirming its close relation to the Japanese quail (Nishibori *et al*., 2002). A phylogenetic analysis of avian and some mammalian β-defensin-9 (BDF9) sequences showed that blue-breasted quail AvBD9 clusters with chicken and duck AvBD9s (97% homology) (Wang *et al.,* 2010). Another study found that blue-breasted quail and chicken share highly repetitive microchromosome-specific sequences from a common ancestor, forming key components of chromosomal heterochromatin in Galliformes (Yamada *et al*., 2002).

The aim of this review is to compile information on the characteristics and breeding techniques of blue-breasted quail and to analyze the status of blue-breasted quail in scientific research.

Morphological and physiological characters

The morphological characteristics of birds offer valuable insights into their physiology and behaviour(Vatsalya and Arora, 2011).The blue-breasted quail is a sexually dichromatic bird (Hickman, 1984) and with the exception of monochromatic white and some tuxedo plumage mutations, sex can be determined at 4 (Wei *et al*., 2011a; Parker *et al*., 2014; Parker *et al.,* 2017) and/or 5 weeks of age by the presence or absence of male secondary sexual characteristics in feather pattern and colour (Andersson *et al*., 2004; Landry, 2015).

As shown in Figure 1, the wild-type plumage of the male, from which the species takes one of its names, is quite striking and has a slate blue-grey breast, a dark rust to chestnut-red abdomen with a slate blue-grey throat marking bordered by a black and white throat marking bordered by a black stripe called a badge (Uller *et al*., 2005), while the wild female has dulled and rusty brown plumage. The whole pattern is in an anti-predatory plumage structure designed to be least noticeable when viewed from above, and is surprisingly effective at concealing the bird. Black beak, yellow to orange leg and short dark brown tail are common to both males and females (Harrison, 1965). Nevertheless, the colour of the leg and toe are rubbery yellow in egg-laying females and more orange in males.

The blue-breasted quail is characterized by social monogamy and strong pair bonds, with ongoing research examining the role of male coloration in pair behaviour (Adkins-Regan, 2016). While no paternal care has been documented, badge size -a secondary sexual trait- has been positively correlated with male mating success, either due to female mate preference or male coercion. Additionally, females mating with males possessing larger badges produced significantly larger eggs, suggesting badge size may serve as an indicator of genetic quality or confer material benefits such as courtship feeding (tidbitting) or protection (Uller *et al*., 2005). Furthermore, an investigation into the relationship between adult sexual characteristics and juvenile immune function found no association between badge size and testis traits. However, a significant negative correlation was observed between juvenile immune response and adult badge size ($r=-0.54$, $P=0.0014$), indicating potential trade-offs between ornamentation and immune function (Uller et al., 2006). Linear growth in blue-breasted quail to adulthood occurs between 4 and 5 weeks of age, with the growth period divided into two stages: weeks 1-4 and weeks 5-8 (Wei *et al*., 2011a). At 8 weeks, the increase in body weight in females was described to be due to the rapid development of the ovaries and oviducts in preparation for the onset of ovulation (Wei *et al.,* 2011a). Adult blue-breasted quail, on the other hand, show a marked reversed sexual dimorphism in body size (females are slightly larger than males) (Zi *et al.,* 2023). The gonadal development of blue-breasted quail at 7-8 days does not allow for 100% accurate sex determination (Bautista *et al.*, 2021). However, the melting curve analysis-based real-time PCR method, applied to feather samples for the first time, proved reliable for sex determination (Chen *et al*., 2012). The morphological and developmental traits of the blue-breasted quail are summarized in Table 1.

The thermal neutral zone for adult blue-breasted quail (47.2±1.2 g) is between 28-35°C, with an average body temperature of 41.7°C. Body temperature increases slightly above 20°C, with variability at lower temperatures (Roberts and Baudinette, 1986). At temperatures up to 40°C, quails can dissipate 75% of heat via evaporation, compared to 20% at thermal neutrality (Roberts and Baudinette, 1986). Breathing frequency in the thermal neutral zone is 50-60/min, with no sex differences in metabolic or respiratory rates (Prinzinger *et al*., 1993). No mortality occurred in quails exposed to 20-50°C, with a maximum body temperature of 46°C at 40.9°C (Roberts and Baudinette, 1988). Skin evaporation surpassed respiratory evaporation in 0-3-day-old, 24-28-day-old, and adult quail at 25-35°C, with higher rates in young quail (Roberts and Baudinette, 1988). Despite males having lower body mass (44.5-45.8 g) compared to females (58.7-63.8 g), no significant difference was found in body temperature (40.7±0.18°C) (Bautista *et al.,* 2021).

Blue-breasted quail chicks were partially endothermic between days 2-10, maintaining high body temperature at ~13 g body mass, and exhibited shallow nocturnal torpor with >40% decrease in metabolism for 4-5 hours on days 14 and 17 (Aharon-Rotman *et al*., 2020). Poikilothermia in 3 g chicks transitioned to homeothermia by 25 g at 28 days (Bernstein, 1973), with a key development period between days 10-16 (Pis and Luśnia, 2005). Hatchling oxygen consumption was 214.8 ± 36.0 mL O_2 day^{-1} (4.03 g) (Pearson, 1999), with brooded chicks maintaining constant consumption at 10-35°C, while un-brooded chicks consumed twice as much oxygen at temperatures below 30°C (Pearson, 1994). Weight-specific oxygen consumption was higher in 24–28-day-old quail than in younger or older birds at 25°C, with increased consumption at 35°C during puberty (Bernstein, 1971).

The metabolic and respiratory physiology of blue-breasted quail exposed to low (800 PAH ng/g food) and high (2,400 PAH ng/g food) crude oil doses was evaluated. Results indicated that neither sex nor exposure levels influenced resting O_2 consumption or CO_2 production, which were both significantly correlated with body mass, but not body temperature. Resting O_2 consumption ranged from 50–60 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$, while CO_2 production varied between 28.9 and 41.5 mL/kg/min (Bautista *et al*., 2021). Moreover, minute ventilation and breathing frequency showed no significant differences between the experimental groups or sexes (Bautista *et al*., 2021).

Following the first week post-hatching, the heart rate (fH) of blue-breasted quail was maintained at elevated levels (550–650 beats per minute), subsequently decreasing with age and increased body mass. Notably, the maximum heart rate observed in quail chicks exhibited a more pronounced post-hatching increase in fH compared to larger precocial species, such as chickens. This observed difference can be attributed to the heightened thermoregulatory demands associated with the relatively smaller body mass of quails (Pearson *et al*., 1998).

The study on the water requirements of blue-breasted quails indicated that they need at least 2.3 ml of water per day, which corresponds to 5.8±1.0% of their body weight, with an ad-libitum water consumption rate of 9.8 (BW day^{-1} %) (Roberts and Baudinette, 1984).

The study examining the effects of leptin on risk-taking and feeding behavior in blue-breasted quail found that risk-taking behavior, measured by the time to start feeding, was influenced by social factors and the bird's weight, but not leptin treatment. Focal birds with leptin-treated mates took longer to begin feeding than those with control mates Additionally, leptin-treated focal birds spent less time feeding than controls (Lõhmus and Sundström, 2004). In another study, leptin-treated birds showed decreased body weight and feeding activity, while males became more active and molted more. Leptin treatment also reduced plasma cholesterol, maintained low plasma triglycerides, and had no effect on glucose levels. Furthermore, leptin-treated males stayed closer to females, and females mated with leptin-treated males took longer to lay their first eggs (Lõhmus *et al*., 2006)

Both photoperiod and social interaction can influence maternal hormone levels, impacting steroid allocation to offspring and their growth and behavior. Testosterone injection had no effect on offspring size or immune response, but testosterone-treated offspring exhibited impaired immune function compared to controls, suggesting an immunological cost of steroid allocation that may outweigh post-hatching benefits (Andersson *et al*., 2004).

Blue-breasted quail are precocial birds, where brood patches are not necessary for incubation or brooding. Brooding behavior in adults is triggered by chicks seeking warmth, prompting adults to squat and fluff their feathers (Pearson, 1994). Additionally, the precocial nature of quails, unlike large mammals, eliminates potential indirect effects of parental behavior on offspring immunity (Saini *et al*., 2019). In blue-breasted quail, the fertility period following male removal was found to be 9 days, with approximately 75 sperm-egg penetrations required to achieve over 95% fertility. This species exhibits a shorter fertility period compared to other galliforms and demands a higher number of sperm-egg interactions for optimal fertility. Such a requirement may lead to an excessive release of spermatozoa from the sperm-storage tubules at each ovulation, ultimately resulting in inefficient sperm storage and potentially diminishing the long-term effectiveness of sperm reserves (Ramachandran *et al.,* 2019a).

The diploid chromosome number of the blue-breasted quail is 2n = 78-80. Its G-banded karyotype closely resembles that of the Japanese quail, with notable differences in the centromere position on chromosome 1 and the banding pattern of chromosome 2. The C-banded chromosomes of the blue-breasted quail are also similar to those of the Japanese quail (Shibusawa *et al.,* 2004).

Kálmán and Sebők (2023) found that entopallial astrocytes in blue-breasted quail, chicken, Japanese quail, pigeon, and duck exhibited high levels of GFAP (glial fibrillary acidic protein) immunoreactivity, whereas the telencephalon, nidopallium, and lateral striatum displayed comparatively low levels.

Plumage color variations

Blue-breasted quail are primarily bred for their feather color, a key economic factor for breeders (Van der Zwan *et al.,* 2019), and are also used in research due to their genetic mutations (Kageyama *et al*., 2018). In addition to the wild feather form, various color mutations are bred in captivity, with the most common being the silver mutation. Other color variations include shades of white (non-albino), brown, extended brown and red-breasted, and mottled colours: silver-red-breasted, cinnamon-red-breasted, blue-face-cinnamon, golden-pearl, silver-pearl, cinnamon-pearl, fallow, ivory, ivory-pearl, slate, smoky, splash and tuxedo (Landry, 2015).

The first feather color mutation identified in blue-breasted quail is a light grey (silver) plumage, controlled by an autosomal recessive gene (*lg*), resulting in a diluted grey color instead of the wild-type dark plumage (Tsudzuki, 1995a). The second mutation, brown, is also autosomal recessive (*br*) and does not allelically relate to the light grey (*lg*) gene, with brown plumage lacking the wild-type black pigmentation (Tsudzuki, 1995b). A third mutation, extended brown (EB), is controlled by a non-dominant autosomal allele (Eb), and EB feathers are dark brown, with homozygotes exhibiting darker pigmentation than heterozygotes (Kageyama *et al.,* 2018). DNA analyses of EB mutants, also known as Blue Face (Landry, 2015; Araguas *et al*., 2018), revealed a strong association with a G-A nucleotide substitution at position 274 in the Melanocortin 1 receptor (MC1R) gene, identifying MC1R as a candidate gene for EB plumage (Kageyama *et al*., 2018). Additionally, Blue Face, a melanic phenotype similar to the Extended Brown of Japanese quail, shares the p. Glu92Lys mutation (Araguas et al., 2018), causing dark brown to near-black feathers, possibly identical to the 'black' feather color (Saini *et al.*, 2019). The red-breasted mutation, identified in 1987, is recessive to the wild type, crossable with silver and fawn (cinnamon) (Landry, 2015), and contains the p. Pro292Leu mutation, likely affecting feather pattern and color distribution (Araguas *et al*., 2018). Newly hatched chicks with light grey plumage exhibit a greyish-creamy yellow base color with the same stripe pattern as the wild type, though the surface is significantly diluted (Tsudzuki, 1995a). In brown-feathered chicks, the base color is a greenish creamy yellow with a bright brown tint, and the stripes are lighter brown compared to the wild type (Tsudzuki, 1995b). Red-breasted chicks, identifiable by their yellow striped dorsal markings and light yellow abdomen, differ from others after hatching (Landry, 2015). Upon reaching maturity, female red-breasted quails are lighter brown, while males develop a completely blackened face and an elongated red patch on the ventral side (Araguas *et al*., 2018).

Egg and hatchling characters

Precocial species, such as blue-breasted quail, which are feathered, mobile, and capable of thermoregulation immediately after hatching (Aharon-Rotman *et al*., 2020), tend to lay larger eggs relative to the female's body mass. This is to support a higher degree of physiological maturity at hatching compared to less active, altricial species. Furthermore, these species invest more energy into their eggs, with a greater proportion of yolk (the primary energy source) and less water (Pearson, 1999). The ratio of egg mass to female body mass varies, ranging from approximately 8.7% (5.33 g per 61.51 g) (Pis and Luśnia, 2005) to around 10% (5.96 g per 55.89 g) (Tsudzuki, 1994). It has also been observed that the primary components of albumin are similar across chicken, Japanese quail, and blue-breasted quail (Ono *et al*., 2005). Additionally, energy values for the egg, yolk-free hatchling, spare yolk, yolk-free hatchling yield, spare yolk ratio, and the cost of development from egg to hatchling were reported as 35.75, 16.74, 6, 49.5, 16.6, and 13.86 kJ, respectively (Pearson, 1999). As shown in Table 2, the egg and hatchling characteristics of the blue-breasted quail are detailed.

Behaviour

Over four decades ago, the blue-breasted quail was identified as a promising candidate for use as a standard animal model in various behavioral observations and experiments, particularly in ethology laboratories (Schleidt *et al*., 1984). Subsequently, it was recognized as a valuable species for studying avian mating behaviors, owing to its distinctive and easily measurable actions (Adkins-Regan, 2016). An ethogram was published that documented and illustrated the sixty most frequently observed and visually distinguishable behaviors in blue-breasted quail. These behaviors were categorized into six behavioral complexes: individual maintenance (36 behaviors), interindividual mating and courtship (8 behaviors), interindividual incubation (5 behaviors), interindividual parental (1 behavior), interindividual agonistic (7 behaviors), and interindividual miscellaneous (3 behaviors) (Schleidt *et al.,* 1984).

Blue-breasted quail are highly social, often engaging in group activities such as eating, hiding, preening, and sleeping simultaneously. Despite their small size, they can exhibit aggression, particularly among males. As a result, males are typically housed separately or with one or more females to minimize conflict (Lõhmus and Sundström, 2004). Pairs that had to be separated due to intra-pair antagonism were excluded from analyses before the experiment's completion (Uller *et al*., 2005). While previously unmated males and females were initially avoidant or aggressive, they quickly displayed allopreening and huddling behaviors. Males that had previously mated showed aggression toward females other than their mates, while unmated males exhibited mating behavior towards familiar females. Notably, pairs were able to recognize and remember their former cohabitation partners for at least ten weeks post-separation (Adkins-Regan, 2016). Furthermore, both sexes of blue-breasted quail demonstrate clear pecking orders when introduced to a new environment, with the pecking order correlating strongly with their arrival order. When multiple quail are transferred together, they typically do not exhibit mutual hostility and share the environment peacefully. Residents tend to show negative behaviors, such as pecking, towards outsiders. However, outsiders were more likely to join a new group when fewer females were present in the resident cohort, when they were younger than the residents, or when they engaged in pecking towards the residents with less intensity (Zi *et al.,* 2023).

The maximum instantaneous and cycle-averaged skeletal muscle powers measured in the pectoralis muscle of blue-breasted quail, operating at a midcycle frequency of 23 Hz, were reported to be approximately 1200 W kg^{-1} and 400 W kg^{-1}, respectively (Askew and Marsh, 2001; Askew and Marsh, 2002). Quail exhibit typical flight behavior characterized by a rapid take-off followed by brief, intermittent flapping flights. After several flights, the birds quickly become exhausted and flightless, landing and seeking escape (Askew and Marsh, 2002). This adaptation, which facilitates high power production, may lead to muscles that are unable to sustain power due to rapid fatigue. Thus, explosive flight in blue-breasted quail is an initial, rapid anti-predatory response (Askew *et al*., 2023).

It was reported that only half of the blue-breasted quail subjected to the learning experiment successfully adapted to social isolation in the experimental cage and acquired the ability to open the feeder lid required for the tests, maintaining high response accuracy for 15 days. However, the quail forgot how to perform the task 45 days after the learning exercise. In contrast, stereotypic pacing and frequent calling were observed in quail that did not adapt to social isolation (Ueno and Suzuki, 2014).

It was noted that when quails fed a low-fibre diet were given a high-fibre diet, they exhibited feed sorting behaviors, which were believed to be triggered by a physiological challenge. This behavior enabled them to maintain their body condition (mass, abdominal fat mass) without any changes in the sizes of intestinal organs or gastrolith mass (Stewart and Munn, 2014).

Parthenogenesis research

The incidence of parthenogenesis (embryonic development of an unfertilized egg) in blue-breasted quail was first shown to decrease as egg production and clutch size increased, with the highest occurrence in the first egg of a clutch, which dropped by approximately half by the second egg (Parker and McDaniel, 2009). The average parthenogenesis incidence was reported to be 4.8%, with a parthenogenetic germinal disc size of 3.7 mm (Parker and McDaniel, 2009). In a subsequent study on genetic selection for parthenogenesis across five generations, it was found that selection for parthenogenesis increased both the incidence of parthenogenesis and embryonic size, but reduced egg production and the position of eggs within the clutch as the selection generations advanced (Parker *et al.,* 2010). Notably, parthenogenesis incidence nearly tripled in the fourth generation (from 4.6% to 12.5%) compared to the base generation, with hens exhibiting parthenogenesis showing a fourfold increase in the proportion of eggs with embryonic development (Parker *et al*., 2010). Additionally, a study investigating the relationship between incubational egg weight loss, eggshell quality, and parthenogenesis revealed that egg weight loss was negatively correlated with the incidence of parthenogenesis, parthenogen size, and egg storage length ($r = -0.56$, -0.56, and -0.24, respectively), while it was positively correlated with clutch sequence position ($r = 0.32$), suggesting that eggshell quality significantly affects parthenogenesis incidence in blue-breasted quail eggs (Wells *et al*., 2012). A study examining the relationship between pre-mating parthenogenesis and post-mating embryonic development and hatchability in blue-breasted quail divided females into seven groups based on their parthenogenesis incidence (0%, 10%, 20%, 30%, 40%, 50%, and more than 50%). It was found that as the incidence of parthenogenesis increased, hatchability of set eggs, hatchability of fertile eggs, and late embryonic mortality significantly decreased, while early embryonic mortality increased (Parker *et al*., 2012). Additionally, a study investigating the effects of parental and seven generations of selection on hatching outcomes, based on parthenogenesis incidence in both maternal and paternal lineages, reported that Generation 1 had the highest percentage of eggs hatched for both set eggs and fertile eggs. In contrast, the percentage of eggs hatched decreased linearly as the selection generation increased (Parker *et al.,* 2014). The same study found a linear increase in both the percentage of eggs showing possible parthenogenesis and early embryonic mortality as the selection generation advanced, while Generation 2 had the highest percentage of infertile eggs.

Furthermore, unlike early embryonic mortality, the parental generation exhibited the highest percentage of embryo mortality at both the middle and late stages of hatching (Parker *et al.,* 2014). Another study revealed that albumin from parthenogenetically developing unfertilized eggs during a 12-day incubation period had lower pH, O_2, and Cl^- concentrations, as well as a lower egg weight loss rate. In contrast, it had higher Ca^{+2}, Na^+, and CO_2 concentrations compared to albumin from non-developing unfertilized eggs (Santa Rosa *et al*., 2016a). The authors also reported that as parthenogenetic size increased, albumin pH, O_2, and Cl^- concentrations decreased, while CO_2 and Ca^{+2} concentrations increased (Santa Rosa *et al*., 2016a). In a subsequent study, it was found that in eggs from quails selected for parthenogenesis and mated after selection, parthenogenesis decreased albumin pH, O_2, and protein concentrations, while increasing Ca^{2+} and CO_2 levels compared to non-developing eggs (Santa Rosa *et al.,* 2016b). For eggs from quail mated after selection for parthenogenesis, albumin pH and O_2 were lower, while CO_2 was higher in eggs containing parthenogenetic or early-dead embryos compared to unfertilized eggs. Additionally, in terms of sperm-egg penetration, eggs classified as infertile or parthenogenetic from quail mated after selection for parthenogenesis had similar sperm-egg penetration holes as those from quail not selected for parthenogenesis, whereas fertilized eggs had only one-sixth the number of sperm-egg penetration holes (Santa Rosa *et al*., 2016b). Eggs from mated quail not selected for parthenogenesis showed 3.5 times more sperm-egg penetration holes compared to eggs from parthenogenesis-selected quail that were then mated. Thus, parthenogenesis in mated quail eggs, similar to parthenogenesis in unfertilized eggs and early embryonic death in fertilized eggs, inhibits fertility and alters albumin properties, although the parental sex responsible remains unclear (Santa Rosa *et al*., 2016b).

The investigation examined the influence of sex on egg weight, albumin pH, hatchability, and sperm-egg penetration in parthenogenetic birds by mating quail lines selected for parthenogenesis with a control line, using a factorial design with four breeding combinations. The results indicated a significant effect of dam on egg set weight, with parthenogenetic dams laying heavier eggs than control dams. Parthenogenetic dams and sires also exhibited lower albumin pH, shorter incubation times, and higher incidences of parthenogenesis compared to the control group. On the other hand, only sire had a significant effect on fertility and sperm-egg penetration. Parthenogenetic sires showed the highest infertility, linked to reduced sperm-egg penetration. The study concluded that both parthenogenetic dams and sires contributed to reduced reproductive performance, with low fertility attributed to the low sperm-egg penetration caused by the parthenogenetic sires (Parker *et al*., 2017). A study examining the contribution of the parthenogenetic trait to changes in egg components such as yolk, albumen, and shell weights in dams, sires, or both, used identical treatment groups and found a significant dam effect. Parthenogenetic line dams exhibited heavier total egg weight, yolk, albumen, and shell weight, a greater albumin percentage, and a higher albumin/yolk ratio compared to control line dams, while yolk percentage was higher in control line dams. This increase in egg and egg component weights due to the parthenogenetic trait was interpreted to result from altered egg passage through the oviduct, with prolonged passage through the magnum and uterus potentially leading to increased albumin and shell weights (Ramachandran *et al*., 2018a). In a separate study investigating the impact of parthenogenesis selection on offspring performance, it was found that parthenogenetic line dams produced heavier offspring at hatch and at four weeks, but also had higher first-week chick mortality compared to control line dams (Ramachandran *et al.,* 2018b). Additionally, in the parental interaction, eggs from parthenogenetic parental matings had the highest number of eggs and the highest proportion of female progeny exhibiting parthenogenesis, while control matings produced the lowest egg weights for the first twenty eggs. The study concluded that both dams and sires selected for parthenogenesis influence progeny performance by contributing to the degree of parthenogenesis exhibited by virgin female progeny. The study also highlighted two key points: accidental selection for the parthenogenetic trait in poultry could negatively impact chick production and performance, and parthenogenesis in blue-breasted quail, like in other birds, is likely an autosomal recessive trait, though further research is needed to confirm this (Ramachandran *et al*., 2018b). The first study exploring the effects of existing virus vaccine strains, pigeon pox and Newcastle disease, on parthenogenesis and their mechanisms of action using the blue-breasted quail as a model, demonstrated that vaccination of virgin chickens with live pigeon pox virus could potentially increase parthenogenesis and parthenogenetic size through direct effects on the embryo. Additionally, live Newcastle disease virus was found to have similar effects to live pigeon pox virus under in vitro conditions (Ramachandran *et al*., 2019).

Veterinary research

Isolates from a blue-breasted quail infected with avian tuberculosis, which showed multiple lesions in the liver, oviduct, and intestine, were inoculated into chickens, resulting in the development of clinical symptoms of avian tuberculosis (Morita *et al.,* 1999). In contrast, reovirus infection observed in budgerigars (*Melopsittacus undulatus*) did not affect blue-breasted quail housed in the same aviary (Perpiñán *et al*., 2010). A persistent ectoparasitic mite (Acariformes: Prostigmata) living inside hollow feathers, piercing the feather wall with its long chelicerae and feeding on the living tissue of the feather follicles (Grossi and Proctor, 2020), was noted in blue-breasted quail (Skoracki and Sikora, 2011). A newly identified avian beta-defensin (AvBD) orthologue was isolated from lung and bone marrow tissues (Wang *et al.*, 2010), and a novel avian beta-defensin (AvBD10) was discovered in the liver and bone marrow of blue-breasted quail (Ma *et al.*, 2011). Blue-breasted quail were shown to be suitable for testing vaccine-induced protection against avian H5N1 viruses. A single dose of NIBRG-14 vaccine induced low titres of antibodies against the homologous strain, with only partial seroconversion to the heterologous strain. A high dose of the A/Swan/Nagybaracska/01/06 (H5N1) strain provided 100% protection (Sarkadi *et al*., 2013).

A study examining the effects of inactivated Newcastle Disease virus vaccine (Nobilis Paramyxo P201) and bacterial vaccine against Salmonella (Nobilis SalenvacT) administered to blue-breasted quail females at the onset of spawning found significant variations in the maternal antibody transfer to offspring over 42 days. Notably, these variations were independent of the females' overall immune response (Coakley *et al*., 2014).

Breeding techniques

Incubation and egg storage

The eggs are laid in afternoon hours at between 15.30-16.00 (Harrison, 1968). Only the female blue breasted quail incubate the eggs and lay around 10-13 eggs per clutch (Harrison, 1968). The average clutch size was 3.3 (ranging from 1-20) in the study using unfertilised eggs (Parker and McDaniel, 2009). Andersson *et al.* (2004) reported that the average clutch size of fertilised eggs laid for two weeks was 12.

As shown in Table 3, various parameters, including temperature, humidity, and turning frequency, are applied at different settings.

The classification system developed for Japanese quails (Petek and Dikmen, 2004) was adapted for blue-breasted quails. At the end of 18 days of incubation, unhatched eggs were opened and macroscopically classified into several categories: infertile, early embryonic death (1–6 days of incubation), mid embryonic death (6–12 days of incubation), late embryonic death (13–18 days of incubation), pipped, cracked, or contaminated eggs (Parker *et al.,* 2012). In this study, early embryonic deaths occurring within the first six days were further classified based on the size of the germinal disc: small early possible parthenogenic deaths (≤7 mm) and large fertilized early deaths (>7 mm) (Parker *et al*., 2012). Another study similarly evaluated hatching outcomes based on this classification (Parker *et al*., 2014). It identified hatching failures as follows: undeveloped unfertilized eggs, unfertilized eggs with parthenogens (≤7 mm), early deaths (1–6 days), mid deaths (6–12 days), and late deaths (12–18 days) (Parker *et al*., 2017). In contrast, a simpler approach was used in another study, where all unhatched eggs were opened after 20 days of incubation, and embryos were classified into early or late stages based on feather visibility (Cai *et al.*, 2019).

It has been demonstrated that blue-breasted quails can be successfully reared under laboratory conditions, exhibiting egg production rates ranging from 60% to 80% (Tsudzuki, 1994). Additionally, it has been reported that these quails can produce approximately 250 eggs annually (Cai *et al.*, 2019). Furthermore, fertility, hatchability, and survival rates to maturity were reported as 91%, 84%, and 78%, respectively (Tsudzuki, 1994). However, a more recent study indicated a lower fertility rate of 42.8% (247 out of 577 eggs) and hatchability of 19.1% (110 out of 577 eggs) (Zi *et al.,* 2023). Moreover, the hatching outcomes were categorized with the following ratios: 83.9% for fertile eggs, 18.6% for early dead embryos, 1.7% for possible parthenogenetic embryos, 1.3% for mid-dead embryos, 9.0% for late dead embryos, 1.3% for pipped embryos, 12.6% for cracked eggs, 0.7% for contaminated eggs, 38.6% for hatch of set eggs, and 46.0% for hatch of fertile eggs (Parker *et al.,* 2014).

As with other galliform species, the embryonic development stages initially identified in blue-breasted quail were based on those described for chicken embryos by Hamburger and Hamilton (1951) and adapted by Perry *et al.* (2022). In incubators set at 37.5°C, no significant morphological changes were observed until the 5-hour mark. At this stage, a belt-like structure, similar to Koller's sickle, became visible, along with a transparent belt. By 6 hours of incubation, the primitive streak began to form, marking the transition to Hamburger-Hamilton (HH) stage 2. After 9.5 hours, a complete primitive groove appeared, indicating HH stage 4. At 24 hours, the embryos showed a closed neural tube and 6 somites, corresponding to stages HH8 and HH9 (Cai *et al.,* 2019). In contrast, Nakamura *et al*. (2019a) established a normal staging table for blue-breasted quail embryos at 37.7°C with 39 incubation stages, with stages 1-16 very similar to those of chicken and Japanese quail. According to this study, the primitive streak was not visible until 9 hours of incubation (stage 1). It became visible between 6 and 11 hours (stage 2), with Hensen's node appearing within the same period (stage 3). Additionally, during stages 7 to 16 (22–55 hours of incubation), somitogenesis occurred, with somite numbers increasing from 1 to 26-27. Key morphological developments, including limb bud formation, were observed during stages 17-24 (57 hours to 5.5 days of incubation). Feather germ formation and pigmentation occurred during stages 25-33 (6–11 days), while embryo weight and third toe length were used as indicators during stages 34-39 (12–17 days of incubation) (Nakamura *et al.,* 2019a).

Furthermore, according to the NNT (Nakamura, Nakane, and Tsudzuki) developmental stages, most membranous skull bones began ossifying between days 7 and 11 of incubation (NNT stages 27-33). All skull bones became visible by day 11 (NNT stage 33), while ossification continued in the later stages (11–17 days of incubation; NNT stages 33–39). Notably, bones underwent chondrification between days 3 and 5 (NNT stages 19-23) (Nakamura *et al*., 2019b). Additionally, the yolk-free embryo mass increased sigmoidally, and the embryos' oxygen consumption rate rose exponentially during incubation (Pearson, 1999).

In blue-breasted quail, embryonic diapause was induced at 21°C, while hatchability was significantly higher at 16°C. Prolonged egg storage resulted in reduced hatchability and increased embryonic mortality. In contrast, pre-incubation had no significant effect on hatchability (Cai *et al*., 2019). The egg storage conditions in blue-breasted quail are outlined in Table 4.

Lighting and heating

After hatching, the chicks were kept in a brooder for 12 hours before being transferred to cages with a 40 W red spotlight, which created a thermal gradient of 33–42°C under continuous illumination (Andersson et al., 2004). Additionally, chicks were dried in an incubator set to 37.8°C for 12 hours, maintaining this temperature for the first week. Subsequently, the temperature was reduced by approximately 5°C each week, reaching a final ambient temperature of 23.9°C by week 3 (Saini et al., 2019; Sepp et al., 2021). The brooder temperature was maintained at 40±1°C for the first two weeks, then decreased by 2°C every two days until reaching 30°C, which was sustained until the chicks reached 8 weeks of age (Wei *et al*., 2011a; Wei *et al.,* 2011b).

It has been reported that the majority of blue-breasted quail hens lay their eggs under a light exposure of 12 to 14 hours (Tsudzuki, 1994). In contrast, pair-housed quail were initially subjected to a 10:14 h light/dark photoperiod for one week to ensure the birds remained in a non-reproductive state. Subsequently, the photoperiod was increased by 1 minute every 2 days for one week, followed by an increase of 2 minutes every 2 days until reproduction commenced, with a maximum photoperiod of 10.25 hours of light and 13.75 hours of darkness (Parker et al., 2008). However, both chicks and adult quail were exposed to 17 hours of light (Parker and McDaniel, 2009; Parker *et al*., 2010; Parker et al., 2012; Parker *et al.,* 2014; Santa Rosa et al., 2016b; Parker et al., 2017). The temperature of the rearing room was maintained at 25±3°C after 30 days of age (Zi *et al*., 2023). In another study, a 12-hour light:12-hour dark photoperiod was used, with lights on from 06:00 to 18:00 following hatching (Aharon-Rotman *et al.,* 2020). As shown in Table 5, the environmental temperature and photoperiod for blue-breasted quail are presented. In the blue-breasted quail, a diurnal species (Aharon-Rotman *et al*., 2020), it has been reported that after 3 weeks of age, exposure to weak artificial blue night light (approximately 0.3 lx; 18 hours light:6 hours dark) for 6 weeks significantly enhanced bactericidal activity, as evidenced by the weekly assessment of plasma bactericidal activity against *Escherichia coli*—a common marker of innate immunity. This effect was observed across quails of various plumage colors, including wild type, silver (light gray), white, black (extended brown), and fawn (cinnamon), with immune responses differing between males and females at distinct developmental stages (Saini *et al.,* 2019). Additionally, the same artificial light exposure led to a reduction in digestive efficiency at two specific time points between weeks 4 and 9 post-hatching, as indicated by steatocrit values from weekly faecal samples. This decline in digestive function coincided with a period of rapid skeletal growth, suggesting that increased energetic demands during growth may compromise digestion. However, it was also noted that growth rate remained unaffected by the artificial light manipulation. It was suggested that ad libitum feeding may mask the adverse physiological effects, as the changes in digestive efficiency were too minor to influence growth or overall condition, and that energy expenditure in the exposed birds was reduced (Sepp *et al*., 2021).

Feeding

In the breeding of blue-breasted quails, feed and fresh water were provided ad libitum, with varying types and compositions of feed used. For example, both chicks and juvenile quails were given commercial Japanese quail diets containing 24% protein (Tsudzuki, 1994), whereas adult quails were fed exclusively commercial poultry feed (Ueno and Suzuki, 2014). Alternatively, quails were also fed a mixture of finch seed (Roberts and Baudinette, 1984), supplemented weekly with greens (Roberts and Baudinette, 1986). Additionally, adult quails were provided a diet containing 2900 kcal/kg of metabolizable energy, 23% protein, and 3.5% calcium supplementation (Cai *et al.,* 2019). The quails were initially fed commercial game bird feed (28% protein, 3% fat) immediately after hatching (Aharon-Rotman *et al*., 2020). Additionally, they were provided Bell turkey and game bird feed, supplemented with vitamins and water, while their diet was further enriched weekly with Tenebrio larvae and lettuce leaves (Bernstein, 1971). In another study, chicks were initially fed a commercial quail starter diet until 4 weeks of age, after which they transitioned to a commercial quail breeder diet (Parker and McDaniel, 2009; Parker *et al*., 2010; Parker *et al*., 2012; Parker *et al*., 2014; Parker *et al*., 2017). In contrast, chicks were initially provided animal feed, including chopped tuber weevil and mealworm larvae, as well as standard chicken feed (26.5% protein content) for approximately the first week. Following this, they were switched to a commercial budgerigar diet (composed of Laplata millet, white millet, Japanese millet, sorghum, canary seed, hemp, and oats), supplemented with poppy seeds, apples, chopped alfalfa, yarrow, cottage cheese, and boiled egg whites (Pis and Luśnia, 2005). In other studies, quails were also fed a mixture of finch seed, egg feed, protein-rich feed, and vitamins and minerals (Lõhmus and Sundström, 2004; Lõhmus *et al.,* 2006). Insect feed was added to their diet using a similar mixture (Andersson *et al.,* 2004). Furthermore, quails were given a mixture of small carrot seed ad libitum, supplemented with mineral cuttlebone, lettuce, fruit, and mealworm larvae (Tenebrio sp.) (Pearson, 1999). Alfalfa sprouts and game bird feed were also included in their diet (Askew and Marsh, 2001).

It was reported that there were no significant differences in feed intake, gut morphology, or gastrolith mass between quail fed low-fiber diets (comprised of a commercial pullet starter crumble with 13% neutral detergent fibre and 4% acid detergent fibre) and high-fiber diets (achieved by diluting the low-fiber control diet with 20% dry wood shavings, resulting in 23% neutral detergent fibre and 14% acid detergent fibre) (Stewart and Munn, 2014). On the other hand, a study comparing quail fed low-fiber (8.5% neutral detergent fibre, i.e., high-quality) and high-fiber (16% neutral detergent fibre, i.e., low-quality) diets, both at identical energy levels, indicated that the available energy in the diet may have a more pronounced effect on inducing phenotypic changes in the gut than the physical impact of dietary fibre on feed intake or muscle compensation for fibrous nutrients (Williamson *et al*., 2014).

In addition to the various diets, the dietary crude protein requirements and the effect of dietary metabolisable energy concentration on these requirements for growing blue-breasted quail were investigated. The study reported that it is not necessary to provide extremely high crude protein diets, such as turkey starter feed containing around 30% crude protein. Instead, good performance can be achieved with diets containing more than 20.4% crude protein and 2,750 kcal/kg metabolisable energy during weeks 1 to 4 (Wei *et al*., 2011a).

It was indicated that blue-breasted quails, with similar initial weights (mean 10.4 g) at seven days of age, were fed diets with varying crude protein levels of 12.5%, 15%, 17.5%, 20%, 22.5%, and 25% at 2,900 kcal/kg metabolisable energy. At 21 days of age, their weights were 9.3, 13.1, 20.3, 25.8, 27.5, and 29.2 g, respectively (Wei *et al.,* 2011b). Moreover, it was determined that, after meeting maintenance requirements, quails in this period required an extra 0.47 g of protein to gain 1 g of weight and 13 g of protein to accumulate 1 g of body nitrogen. The dietary crude protein level was calculated to be 20.6% or 19.6%, based on estimated daily feed intake, as an additional 412 mg of protein per day was needed for average daily maintenance and 456 mg per day for average daily growth (Wei *et al*., 2011b).

Housing

The relatively small size of blue-breasted quails facilitates their handling and maintenance in cage environments (Lõhmus and Sundström, 2004). Adult quails were individually housed in metal cages (0.3 m²) (Roberts and Baudinette, 1984; Roberts and Baudinette, 1986; Roberts and Baudinette, 1988). Additionally, quails were maintained in pairs or larger groups within terrariums (62x31x31 cm) or cages of varying sizes (335x315x240 cm) (Schleidt *et al*., 1984), as well as in pairs in cages measuring 80x60x50 cm (Andersson *et al.,* 2004; Uller *et al*., 2005; Uller *et al*., 2006). Pairs of one male and one female were housed together in plastic cages (60x48x35 cm) equipped with ventilation and lined with wood shavings to mitigate foot injuries and absorb moisture (Bautista et al., 2021), as well as in smaller cages (37x13x19 cm) (Cai *et al*., 2019). In another study, quails were housed in groups of three (one male with two females) in large plastic boxes (80x60x50 cm) lined with a mixture of fine bird sand, crushed shells, and very fine gravel (Lõhmus and Sundström, 2004; Lõhmus *et al*., 2006). Furthermore, wood chips were utilized as bedding material, and a sand bowl was provided in the cages (Andersson *et al.,* 2004; Uller *et al*., 2005; Uller *et al*., 2006). Pairs were housed in relatively small commercial aviaries (75x28x28 cm, two individuals per cage) (Parker *et al*., 2008), while randomly sexed pairs were housed in cages measuring 38x46x46 cm, with rubber matting on the cage floors to prevent slipping and leg splay (Saini et al., 2019; Sepp *et al.,* 2021). Additionally, quails were housed in pairs and trios in cages (Bernstein, 1971).

One-day-old quails were reared in cages (48x33 cm²) with a stocking density of 10 birds until they reached eight weeks of age (Wei *et al*., 2011a). In a separate study, quails were housed in cages of the same dimensions, with five birds per cage, from one to three weeks of age (Wei *et al.,* 2011b). Additionally, chicks were housed individually in wire cages (57 cm long x 32 cm deep x 40 cm high) after reaching four weeks of age (Adkins-Regan, 2016). In contrast, some chicks were raised in larger mixed-sex cages (240x50x37.5 cm) with wood shavings, multiple feeding stations, enclosures, and sand baths, which allowed the birds to engage in their full natural behavioural repertoire, with 14 birds per cage, until sexual maturity (Coakley *et al.,* 2014). Similarly, four or five quails were housed in plastic cages (43.3x80x51 cm), bedded with pine shavings (Aharon-Rotman *et al*., 2020). Although quails were housed individually in smaller cages (21x29x40 cm) during learning experiments (Ueno and Suzuki, 2014), they were kept in steel cages (41x28x38 cm) for a study on physiological and behavioural flexibility in response to dietary changes (Stewart and Munn, 2014). Chicks were initially housed in sibling pairs in cages until sexual maturity, which occurred at approximately five weeks of age. Afterward, they were assigned to pairs of unrelated individuals (one male and one female) (Uller et al., 2006). Similarly, quails were mated in wire cages, ensuring that sibling matings were avoided (Tsudzuki, 1994).

Blue-breasted quail research

This study utilized the Web of Science database (2024), a comprehensive commercial product developed by the Institute for Scientific Information, to assess the global volume and scope of blue-breasted quail research. The database was queried using the three scientific names of the blue-breasted quail, and all studies published from 1982 to the present were analyzed. Since 1982, a total of 73 publications have been produced on the blue-breasted quail, with each publication potentially spanning one to four Web of Science categories. Figure 2 aggregates these publications into 10-year periods, excluding the three articles published in 1982 and 1983, which are not included in the figure. Additionally, three publications—two in forestry and one in ornithology—investigating predation rates in experimental nests using blue-breasted quail eggs were not considered. Furthermore, a publication from the Multidisciplinary Sciences category, which used the blue-breasted quail to compare thermoregulatory behavior in reptiles, was not included due to the unavailability of the full text.

Figure 2 illustrates that there were 7 publications during the 1984-1993 period. In the subsequent decade (1994-2002), the number of publications nearly doubled to 15. Surprisingly, the number of publications increased further to 25 in the 2004-2013 period, representing a significant rise compared to previous periods. However, in the most recent decade (2014-2023), the number of studies on the blue-breasted quail slightly decreased compared to the previous period.

Figure 3 presents a pie chart showing the distribution of publications by research field across twenty-two categories. As depicted in the chart, the blue-breasted quail was most frequently studied in the field of zoology (29 publications), followed by agriculture, dairy and animal science (14), genetics and heredity (11), veterinary sciences (10), and physiology (9).

Conclusion

The morphological, physiological and behavioral characteristics of blue-breasted quail have attracted attention and have been studied for various purposes. The study of quail reared under specific conditions has greatly improved our understanding of numerous physiological systems, their behavior and performance. The use of the blue-breasted quail, ranging from being a pet animal to being studied in complex experimental analyses, makes it valuable in both hobby breeding and scientific studies. The quail's average embryonic developmental period of 17 days, coupled with an 8-week sexual maturation period, results in significantly shorter generation times than other poultry, with the exception of Japanese quail. Furthermore, the body size of the adult quail, which is even smaller than the Japanese quail, greatly reduces the area and cost of rearing. Over the last four decades, the blue-breasted quail has proven to be a truly diverse and productive animal model, but it also has many potential subjects for study in terms of genetic variation, as it has not yet been the subject of intensive selection breeding. It should also be pointed that the blue-breasted quail is a suitable experimental animal for parthenogenesis studies. Studies so far suggest that blue-breasted quail will continue to occupy a small but important place in research laboratories around the world in the future.

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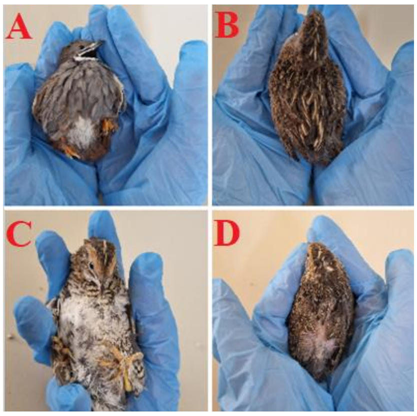

Figure 1. Wild feather color of male and female blue-breasted quails (A and B: top and bottom views of male; C and D: top and bottom views of female)

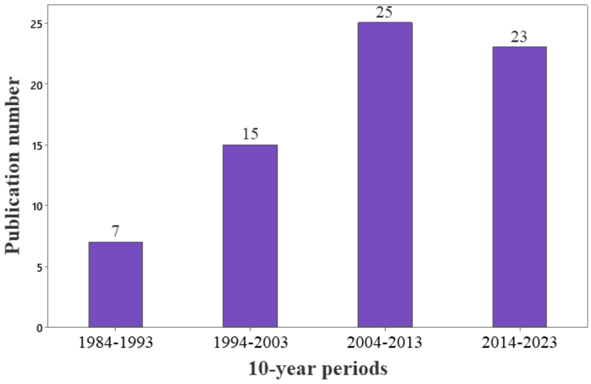

Figure 2. Number of publications on the blue-breasted quail over 10-year periods, as retrieved from the Web of Science database

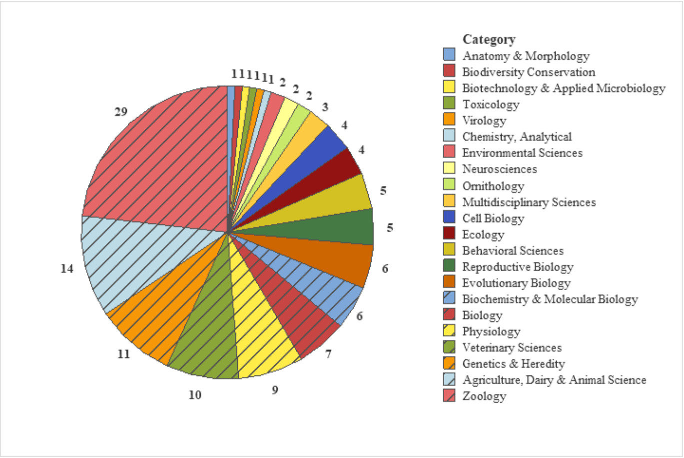

Figure 3. Pie chart of number of Web of Science categories, the number is rising downwards

Table 1: Morphological and developmental traits of blue-breasted quail

Attribute	Age/Day and sex	Value (unit)/Situation	References
Chick weight	1-3 days M, F	3,48±0,343 g	Pis and Luśnia (2005)
	7-8 days M, F	8.1g	Bautista *et al.* (2021)
	7-10 days M, F	8,51±1,011 g	Pis and Luśnia (2005)
	16-19 days M, F	21,14±1,438 g	
	22 days M	27,58 g	
	22 days F	30,34 g	
Organ mass ratios	7-8 days M, F	Ratio of organ weight to body weight	Bautista *et al.* (2021)
Heart		1.2±0.04%	
Liver		4.3±0.4%	
Lungs		0.7±0.04%	
Gut		5.7±0.9%	
Eyes		2.5±0.2%	
Brain		3.3±0.2%	
Ceca		1.0±0.04%	
Kidneys		1.3±0.2%	
Sex determination	22 days	Body mass differences	Pis and Luśnia (2005)
	25 days	Exhibition the initial secondary sexual plumage	Zi *et al.* (2023)
	28-35 days	Presence or absence of male secondary sexual characteristics	Andersson *et al.* (2004)
	28 days		Tsudzuki (1994)
Adult age	65 days, M, F		Zi *et al*. (2023)
Adult weight	56-63 days	50 g	Ono *et al*. (2005)
	59 days, M	46.99 g	Pis and Luśnia (2005)
	59 days F	61.51 g	
	M, F	49.7±0.09 g	Roberts and Baudinette (1984)
	M, F	44.9±2.1 g	Roberts and Baudinette (1986)
	M, F	49.6±1.7 g	Roberts and Baudinette (1988)
	M	45–50 g	Andersson *et al.,* (2004)
	F	50–60 g	
	63 days, M, F	45.7±1.4 g	Askew and Marsh, (2001)
First laying time	Mostly 56-63, but also at 47 days, F	Age at first lay an egg	Tsudzuki, (1994)
	80 days, F		Zi *et al.*, (2023)
Body weight	112 days, M	47.66±0.52	Tsudzuki, (1994)
	112 days, F	55.89±0.75 g (without egg in uterus) 61.89±0.77 g (with egg in uterus)	Tsudzuki, (1994)
Organ mass ratios	Adult	Ratio of organ weight to body weight	Bautista *et al.*, (2021)
Liver	M and F, respectively	1.84±0.10 and 3.05±0.42%	
Gut		1.77±0.09 and 2.38±0.16%	
Ceca		0.40±0.03 and 0.43±0.02%	
Kidneys		0.67±0.04 and 0.90±0.08%	
Brain		1.11±0.04 and 0.84±0.11%	
Heart		0.74±0.05 and 0.9±0.05%	
Lungs		0.87±0.11 and 0.8±0.07%	
Eyes		0.53±0.05 and 0.97±0.12%	
Kidney weight	Adult M, F	0.42±0.03 g	Roberts and Baudinette (1984)
Wing Length	Adult M, F	9.6±0.1 cm	Askew *et al.*, (2001)
Wing Span		22.0±0.3 cm	
Wing Area		97.7±1.5 cm²	
Pectoralis mass ratio		15.0±0.6 %	
Testicular mass	Adult M	1.11±0.05 g	Uller *et al.,* (2005)
Testicular length		14±0.30 mm	

M: male and F: female

Table 2. Egg and hatchling characteristics of blue-breasted quail

Characteristic	Value(unit)/attribute	Reference
Fresh egg mass	5.7±0.5 g (n=577, range:4.0–7.5 g)	Zi *et al*., (2023)
Egg weight	5.96±0.04 g	Tsudzuki, (1994)
	5-6 g	Pearson *et al*., (1998)
	4.86 g	Pearson, (1999)
	5.33±0.458 g	Pis and Luśnia, (2005)
Egg length (major axis)	25.6±0.01 mm	Tsudzuki, (1994)
	25.0±0.012 mm	Bautista *et al*., (2021)
Egg width (minor axis)	20.5±0.01 mm	Tsudzuki, (1994)
	19.0±0.011 mm	Bautista *et al*., (2021)
Egg volume	5.2±0.6 cm³	Zi *et al*., (2023)
	5.09±0.5 mL	Lewis and Montevecchi, (1999)
Eggshell color variations	Greyish beige, reddish beige, greenish beige, bluish beige	Tsudzuki, (1994)
Albumen mass	2.54 g (58.2% of unshell eggs)	Pearson, (1999)
Yolk mass	1.79 g (41.8% of unshell eggs)	
Eggshell mass	0.51 g	
Water content in eggshell	37.3%	
Water content in albumen	88.9%	
Water content in yolk	49.5%	
Water content in whole egg	72.6%	
Dry matter in eggshell	0.31 g	
Dry matter in albumen	0.28 g	
Dry matter in yolk	0.90 g	
Energy content in egg	35.75 kJ (8.54 kcal; 5.46 g egg)	
Hatchling weight	3.5–5 g	Pearson *et al*., (1998)
	3.84 g	Pearson, (1999)
	3.59±0.11 g	Andersson *et al*., (2004)
	3.48 g	Pis and Luśnia, (2005)
	4.19±0.15 g	Nakamura *et al*., (2019a)
Hatchling yield	72.6%	Pearson, (1999)
Hatchling tarsus length	10.30±0.11 mm	Andersson *et al*., (2004)
Hatchling beak length	2.57±0.21 mm	Nakamura *et al*., (2019a)
Hatchling third toe length	10.73±0.45 mm	
One day-old hatchling weight	3.80 ± 0.40 g	Wei *et al*., (2011a)
Yolk-free hatchling weight	2.83 g	Pearson, (1999)
Spare yolk weight	0.42 g	
Yolk-free hatchling yield	58.6%	
Spare yolk ratio	8.5%	

Table 3. Incubation process of blue-breasted quails

Parameter	Value (unit)/Process	Reference
Incubation period	16 days	Pearson (1999); Cai *et al*. (2019)
	17 days	Ono *et al*. (2005); Nakamura *et al*. (2019a); Cai *et al*. (2019)
	18 days	Pis and Luśnia (2005); Parker *et al*. (2014); Aharon-Rotman *et al*. (2020)
	Up to 21 days	Harrison (1968); Zi *et al*. (2023)
Externally pipped	Hatches within 12 hours	Pearson (1999)
Temperature and humidity	37.5°C; ~30% RH	Adkins-Regan (2016)
	37.5°C; 50% RH	Parker *et al*. (2012)
	37.5°C; 60% RH	Parker et al. (2017); Ramachandran *et al*. (2019); Bautista *et al*. (2021)
	37.7±0.2°C; 70% RH	Tsudzuki (1994); Nakamura *et al*. (2019a); Nakamura *et al*. (2019b)
	37.7°C; 50% RH	Aharon-Rotman *et al*. (2020)
	38°C; 50–80% RH	Zi *et al*. (2023)
	38±0.5°C; 55% RH	Pearson *et al*. (1998)
	38.5±0.5°C; 58–59% RH	Pearson (1999)
	37–38°C; 40–50% RH (rising to 70% prior to hatching)	Coakley *et al*. (2014)
	40°C with 95% RH	Bernstein (1973, 1971)
	37.5°C; 55–65% RH	Cai *et al*. (2019)
	37.8°C; 45–65% RH for 13 days; >65% RH for next 11 days	Saini *et al*. (2019)
	38.5°C; increased RH 2 days before hatching	Andersson *et al*. (2004)
Egg Rotation	Stopped on day 13	Bautista *et al*. (2021)
	Stopped on day 15	Saini *et al*. (2019)
	Every hour for the first 14 days at a 45° angle	Cai *et al*. (2019)
	Twice daily (180° manual rotation)	Pearson (1999)
	Twice daily	Andersson *et al*. (2004)
	Several times per day	Bernstein (1973)
	Every 1.5 hours	Zi *et al*. (2023)
	Every hour at a 90° angle	Nakamura *et al*. (2019a)

RH: relative humidity

Table 4. Egg storage conditions in blue-breasted quail

Purpose	Storage Condition	Storage Duration	Reference
Embryo culture study	12-14 °C	Maximum 7 days	Ono *et al*. (2005)
Embryonic development study	15 °C	Maximum 5 days	Nakamura *et al*. (2019a)
Embryonic heart rate study	15 °C	Maximum 5 days	Pearson *et al*. (1998)
Parthenogenesis study	20 °C	Maximum 3 days	Parker and McDaniel (2009); Parker *et al*. (2010); Parker *et al.* (2012); Wells *et al*. (2012); Parker *et al.* (2014)
Fertilized egg and parthenogenesis study	20 °C	Maximum 7 days	Parker *et al*. (2012), Parker *et al*. (2014)
Testosterone manipulation effects on offspring	Room temperature	Maximum 14 days (last 8 eggs)	Andersson *et al.* (2004)
Effect of storage temperature on hatchability and embryonic diapause	16°C or 21°C and 65-75% RH	3, 7, or 14 days	Cai *et al.* (2019)
Effect of pre-incubation	45◦ rotation at 37.5◦C for 6 h and 55-65% RH		

RH: relative humidity, h: hour

Table 5. Environmental temperature and photoperiod for blue-breasted quail

Age (Weeks)	Photoperiod light/dark	Temperature and Humidity (unit)	Reference
0-2	24h	36±2°C	Tsudzuki, (1994)
2-4	24h	33±2°C	
2+	16 h/8 h	25-27°C, 65-70% RH	Pis and Luśnia, (2005)
4	14 h/10h		Adkins-Regan, (2016)
4-6	24h	28±2°C	Tsudzuki, (1994)
6-8	24h	25±2°C	
8+	14 h/10h	23±2°C	
Adult	16 h/8 h	28°C, 45% RH	Bernstein, (1971)
Adult	16 h/8 h	25-30°C,30-60% RH	Bernstein, (1973)
Adult	12 h/12h	23±1°C	Stewart and Munn, (2014)
Adult	14 h/10h		Schleidt *et al*., (1984)
Adult	14 h/10h	23°C	Lõhmus and Sundström (2004); Lõhmus *et al*. (2006)
Adult	14 h/10h	28°C (day), 22°C (night)	Andersson *et al.,* (2004); Uller *at al*., (2005); Uller *et al.,* (2006)
Adult	14 h/10h	23-25◦C, 40-60% RH	Cai *et al*. (2019)
Adult	14 h/10h	∼24◦C,∼60% RH	Bautista *et al*. (2021)
Adult	12 h/12h	∼25°C	Roberts and Baudinette (1986); Roberts and Baudinette (1988)
Adult	12 h/12h	25°C, 45- 62% RH	Roberts and Baudinette (1984)
3-9	12 h/12h	24°C	Askew and Marsh, (2001)

h: hour, RH: relative humidity