Animal personality in *Betta splendens*: boldness, aggressiveness, syndromes and domestication

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Abstract. This review synthesizes current knowledge on animal personality in *Betta splendens*, with particular emphasis on aggressiveness, boldness, and their integration into broader behavioural syndromes. Drawing on comparative frameworks from behavioural ecology and ichthyology, the paper situates Betta splendens within the wider context of model fish species used to investigate consistent individual differences in behaviour. Empirical evidence demonstrates that aggression in this species is highly variable among individuals yet temporally repeatable, fulfilling key criteria for personality traits. Moreover, aggression is shown to be both plastic and modulated by environmental conditions, including social experience and developmental history. The review further explores the extent to which aggression correlates with other behavioural axes such as exploration and boldness, highlighting the context-dependent nature of behavioural syndromes in fishes. Particular attention is given to the effects of artificial selection and domestication, which have profoundly reshaped aggressive phenotypes and associated physiological traits in *B. splendens*. Genomic insights reveal a polygenic architecture underlying aggression, suggesting complex interactions between neural, hormonal, and environmental factors. Overall, *B. splendens* emerges as a powerful model for understanding the evolution of personality traits, the mechanisms underlying behavioural consistency and plasticity, and the consequences of domestication on behavioural phenotypes.

Key Words: *Betta splendens*, aggression, boldness, behavioural syndromes, artificial selection, fish models, behavioural ecology, individual variation.

Introduction. Model fish species occupy a central position in behavioural ecology, cognition, and evolutionary ecology due to their tractability, ecological diversity, and the relative ease with which both laboratory and semi-natural experiments can be conducted (Bshary & Triki 2022; Petrescu-Mag 2023ab, 2025c; Boaru & Petrescu-Mag 2024abc). Among these, the three-spined stickleback (*Gasterosteus aculeatus*) represents one of the most intensively studied vertebrate models, offering exceptional insights into the interplay between ecological pressures and behavioural diversification (McInnes et al 2025). Its wide geographic distribution across marine and freshwater environments, coupled with repeated independent colonization events, has enabled researchers to investigate rapid adaptive divergence, particularly in traits such as antipredator behaviour, mating displays, parental care, and foraging strategies (Nowak & Păpuc 2026; Bell 2004; Bell & Sih 2007). Sticklebacks have been instrumental in linking behavioural phenotypes to underlying genetic architectures and environmental variability, thereby contributing substantially to our understanding of microevolutionary processes (Bakker 1986; Bolyard & Rowland 1996).

Equally important are members of the family Poeciliidae, a diverse clade of livebearing fishes that includes well-established model organisms such as *Poecilia spp*., *Poeciliopsis spp*., and *Xiphophorus spp*. (Oroian & Daescu 2024; Triki et al 2024, 2025; Gavriloaie et al 2025). Poeciliids have proven particularly valuable for studying sexual selection, life-history evolution, and social behaviour (Bourne & Sammons 2008; Bourne & Watson 2009; Gavriloaie 2023; Păpuc 2023). The guppy (*Poecilia reticulata*), in particular, has become a canonical system for examining predator-driven selection and its consequences on behaviour, morphology, and coloration (Petrescu-Mag & Păsărin 2025; Popescu & Păpuc 2025). Natural populations exposed to different predation regimes exhibit consistent differences in risk-taking behaviour, shoaling tendencies, and reproductive strategies, making them ideal for testing theoretical predictions in evolutionary ecology (Petrescu-Mag 2008). Moreover, poeciliids display sophisticated social interactions, including mate choice copying, kin recognition, and social learning, thus providing a bridge between behavioural ecology and cognitive research (Gavriloaie 2023; Inman et al 2025ab).

In the domain of cognition, fish models have increasingly challenged traditional assumptions about the limits of vertebrate intelligence. Species such as zebrafish (*Danio rerio*), cichlids, and poeciliids demonstrate capabilities in spatial learning, numerical discrimination, and problem-solving, often within ecologically relevant contexts (Gerlai 2025ab). These findings have broadened the comparative framework of cognition and highlighted the adaptive significance of cognitive traits in variable environments. Experimental paradigms in fishes benefit from high replicability and the possibility of manipulating both ecological and social variables, allowing for integrative approaches that link neural, behavioural, and evolutionary perspectives.

Animal personality research focuses on consistent individual differences in behaviour across time and contexts, typically along axes such as boldness, aggressiveness, exploration, activity and sociability. This framework has been extensively developed in fishes and provides the main theoretical background for studying *Betta splendens*. Personality traits are defined by three criteria: individual differences, temporal stability, and contextual consistency (Kaiser & Müller 2021). Within ichthyological models, personality variation has been documented in species such as *Gasterosteus aculeatus* and *Poecilia reticulata*, where individuals differ consistently in their response to predation risk, foraging behaviour, and social interactions. These behavioural syndromes are not only repeatable but often correlated across contexts, suggesting underlying physiological or genetic constraints. Importantly, personality traits can have direct fitness consequences, influencing survival, reproductive success, and dispersal tendencies.

The integration of behavioural ecology with evolutionary frameworks has been particularly fruitful in fish systems because of their ecological heterogeneity and rapid generation times. For instance, comparative studies across stickleback ecotypes or guppy populations have revealed how environmental gradients shape behavioural repertoires and cognitive abilities (Yang et al 2025; Reyes et al 2022; Reddon et al 2018; Odling-Smee et al 2008; Keagy et al 2017; Huizinga et al 2009; Fox et al 2024; Dingemanse et al 2007; Di-Poi et al 2014; Burns et al 2016). At the same time, experimental evolution approaches in controlled settings allow researchers to test causal relationships between ecological variables and behavioural outcomes. This dual capacity—combining field realism with laboratory precision—positions fish as uniquely powerful models for addressing fundamental questions about the evolution of behaviour and cognition (Table 1).

Table 1

Representative model fish species used in behavioural ecology, cognition, and evolutionary ecology, with associated research domains and key behavioural traits studied

Model species/group	*Key research domains*	*Notable traits studied*
Gasterosteus aculeatus	Behavioural ecology, evolutionary ecology	Antipredator behaviour, parental care, local adaptation (Nowak & Păpuc 2026; Schnider et al 2026)

Model species/group	*Key research domains*	*Notable traits studied*
Poeciliidae (*Poecilia* spp.)	Sexual selection, social behaviour, cognition	Mate choice, shoaling, predator response, learning (Păpuc 2023; Dăescu & Petrescu-Mag 2024; Petrescu-Mag & Păsărin 2025; Petrescu-Mag et al 2025; Popescu et al 2025; Păpuc et al 2025; Bora et al 2025)
Danio rerio	Neurobiology, cognition	Learning, memory, genetic basis of behaviour (Firdous et al 2024; Gerlai 2025ab; Gazzano et al 2025)
Cichlidae	Social evolution, cognition	Dominance hierarchies, cooperative behaviour (Wallace et al 2022; Guadagno & Triki 2024)
Betta splendens	Personality, aggression	Aggressiveness, territoriality, behavioural syndromes (Pop & Mag-Mureșan 2004ab; Polgardani et al 2017; Agues-Barbosa et al 2022; Petrescu-Mag 2025ab; daSilva et al 2025).

Aim of the Review. The primary aim of this review is to provide a comprehensive and integrative analysis of animal personality in *Betta splendens*, with a focus on aggressiveness as a central behavioural trait. Specifically, the review seeks to: (i) contextualize *B. splendens* within the broader framework of model organisms used in behavioural ecology and evolutionary research; (ii) evaluate empirical evidence for consistent individual differences in aggression and their temporal stability; (iii) examine the existence and structure of behavioural syndromes involving aggression, boldness, and exploration; and (iv) assess the impact of artificial selection and domestication on the expression, variability, and genetic architecture of aggressive behaviour. By synthesizing findings from experimental, comparative, and genomic studies, this review aims to clarify the role of *B. splendens* as a model system for investigating the ecological and evolutionary significance of animal personality.

The *Betta* Genus: An Overview

Genus Betta. The genus *Betta* (family Osphronemidae) comprises more than 70–80 small freshwater species, many endemic to Southeast Asia and increasingly threatened by habitat loss and overcollection for the ornamental trade (Putri et al 2021; Helmizuryani et al 2026; Nur et al 2022; Fahmi et al 2020). *Betta* species are popular as ornamental fishes, with *Betta splendens* (Siamese fighting fish) being globally important in aquaculture and a rising genetic model organism (Sriwattanarothai et al 2010; Yue et al 2022; Lichak et al 2022).

Morphological and biological characteristics. *Betta* are small-bodied fishes, often under 5 cm in total length in wild forms, with elongated bodies and well developed unpaired fins; wild *B. splendens* in Aceh, for example, reach ~21–40 mm total length (Nur et al 2022). Larval morphology is relatively conserved among bubble nesting species (*B. splendens, B. imbellis, B. smaragdina, B. mahachaiensis, B. siamorientalis*), with oblong, laterally compressed bodies, small rounded heads, terminal mouths, and characteristic developmental changes in fin rays and pigmentation patterns (Poungcharean & Limpivadhana 2022). Many *Betta* possess vivid coloration and sexually dimorphic fins, particularly in domesticated *B. splendens*, which has been intensively selected for body size, fin shape, and diverse color patterns (Yue et al 2022). All *Betta* are anabantoid fishes with a suprabranchial breathing organ (labyrinth), enabling survival in warm, hypoxic, shallow waters (Yue et al 2022; Jaroensutasinee & Jaroensutansinee 2001; Lichak et al 2022). Reproductive strategies differ: some species are bubble nest builders (e.g. *B. splendens* group), others mouthbrooders, and these parental care modes are phylogenetically informative (Fahmi et al 2020; Putri et al 2025; Poungcharean & Limpivadhana 2022).

Geographic distribution and habitat. *Betta* are restricted to freshwaters of Southeast Asia, especially Thailand, Peninsular Malaysia, Sumatra, Borneo, and surrounding islands (Panijpan et al 2020; Putri et al 2021; Helmizuryani et al 2026; Fahmi et al 2020; Putri et al 2025). They typically occupy shallow, slow flowing or stagnant habitats such as peat swamps, forest streams, rice paddies, and floodplain ditches, often with dense marginal vegetation and low dissolved oxygen (Nur et al 2022; Panijpan et al 2020; Jaroensutasinee & Jaroensutansinee 2001). In Aceh (Sumatra), four species (*B. dennisyongi, B. rubra, B. splendens, B. imbellis*) occur across blackwater and clearwater sites with temperatures ~23.7–31.9 °C and pH 5.24–8.51 (Nur et al 2022). Other species inhabit highly acidic peatland waters, as on Bangka Island (*B. burdigala, B. chloropharynx, B. schalleri*), or island blackwater streams (e.g. *B. foerschi* in Borneo and Belitung) (Helmizuryani et al 2026; Syarif et al 2023).

Taxonomic representatives and intrageneric grouping. Molecular and morphological studies reveal that *Betta* is taxonomically rich and structured into several species complexes reflecting reproductive mode and morphology. Using COI and other mitochondrial markers, wild bubble nesting *Betta* in Thailand are resolved into at least the splendens group (*B. splendens, B. imbellis, B. mahachaiensis, B. smaragdina, B. siamorientalis, B. stiktos*), with cryptic diversity documented within *B. smaragdina* (Sriwattanarothai et al 2010; Kowasupat et al 2014; Kowasupat 2012; Putri et al 2025; Poungcharean & Limpivadhana 2022). Mouthbrooding taxa are arranged in complexes such as Pugnax, Unimaculata, and other lineages, with species like *B. pugnax, B. picta*, *B. ferox, B. apollon, B. stigmosa* and related forms (Putri et al 2021; Fahmi et al 2020; Putri et al 2025). Additional complexes include the coccina complex, containing small, red patterned peat swamp species (e.g. *B. coccina, B. persephone, B. brownorum, B. rutilans*, and newly described *B. iaspis* and *B. mulyadii*) (Ding et al 2025; Putri et al 2021; Helmizuryani et al 2026). DNA barcoding and cyt b/COI phylogenies consistently show *Betta* as a monophyletic genus, with interspecific distances commonly >0.13 and multiple undescribed or previously overlooked species (Putri et al 2021; Sriwattanarothai et al 2010; Kowasupat et al 2014; Fahmi et al 2020; Putri et al 2025).

Related genera within Osphronemidae. Within Osphronemidae, *Betta* is closely related to other labyrinth fish genera such as *Macropodus* and *Parosphromenus* (Adelina et al 2024; Munzir et al 2024; Heptarina et al 2025; Wijayanto 2025; Ding et al 2025). Mitogenomic analyses place *B. splendens* near *Macropodus* in phylogenetic trees based on complete mitochondrial genomes (Song et al 2016), while several *Betta* phylogenies use *Parosphromenus deissneri* as an outgroup, emphasizing its close but distinct position within the same family (Ding et al 2025). More broadly, the family includes additional genera such as *Trichogaster* and others, which share labyrinth organs and similar ecological adaptations but differ in morphology and reproductive behaviors (Almaaty et al 2020; Song et al 2016).

Conservation and broader importance. Many wild *Betta* are of conservation concern due to specialized habitats, narrow distributions, and collection pressure for the ornamental trade. In Aceh, *B. rubra* is listed as Critically Endangered and *B. dennisyongi* and wild *B. splendens* as Vulnerable on the IUCN Red List (Nur et al 2022). Endemic taxa from peatlands and islands (e.g. Bangka, Belitung, Harau Valley) are similarly threatened by habitat degradation, making accurate taxonomy and phylogeny essential for conservation planning (Putri et al 2021; Helmizuryani et al 2026; Syarif et al 2023; Fahmi et al 2020; Putri et al 2025). At the same time, the genus is economically important as a source of high value ornamental fishes, particularly wild type forms and newly recognized species, and scientifically important as a model for evolutionary diversification, speciation, and genome phenotype relationships (Panijpan et al 2020;

Sriwattanarothai et al 2010; Yue et al 2022; Fahmi et al 2020; Lichak et al 2022) (Table 2).

Table 2

Examples of geographic distribution and taxonomic placement of selected *Betta* species

Species (Genus Betta)	*Complex / Group (if stated)*	*Country / Region of occurrence*	*References*
B. splendens	Splendens group, bubble-nester	Thailand; Aceh (Indonesia); domesticated worldwide	(Nur et al 2022; Panijpan et al 2020; Sriwattanarothai et al 2010; Kowasupat et al 2014; Kowasupat 2012; Jaroensutasinee & Jaroensutansinee 2001; Lichak et al 2022; Valen et al 2023; Matielo et al 2019; Kattakdad et al 2021; Khairul et al 2024; Pertiwi et al 2025)
B. imbellis	Splendens group, bubble-nester	Thailand; Aceh (Indonesia)	(Nur et al 2022; Sriwattanarothai et al 2010; Kowasupat et al 2014; Kowasupat 2012; Poungcharean & Limpivadhana 2022)
B. smaragdina (+ cryptic lineages)	Splendens group, bubble-nester	Northeastern and other parts of Thailand	(Sriwattanarothai et al 2010; Kowasupat et al 2014; Poungcharean & Limpivadhana 2022)
B. mahachaiensis	Splendens group, bubble-nester	Central Thailand (brackish and freshwater)	(Sriwattanarothai et al 2010; Kowasupat et al 2014; Poungcharean & Limpivadhana 2022)
B. siamorientalis	Splendens group, bubble-nester	Eastern Thailand	(Kowasupat et al 2014; Kowasupat 2012; Poungcharean & Limpivadhana 2022)
B. rubra	Coccina complex (red peat-swamp bettas)	Sumatra (including Aceh), Indonesia	(Nur et al 2022; Fahmi et al 2020)
B. dennisyongi	Mouthbrooder; peat/swamp habitats	Aceh (Indonesia)	(Nur et al 2022; Saputra et al 2024)
B. burdigala, *B. chloropharynx*, *B. schalleri*	Coccina / waseri / pugnax-related groups	Bangka Island peatlands, Indonesia	(Helmizuryani et al 2026)
B. coccina, *B. brownorum*, *B. rutilans* and related species	Coccina complex, peat-swamp species	Borneo, Bangka, Peninsular Malaysia	(Putri et al 2021; Fahmi et al 2020)
B. picta, *B. pugnax*, *B. fusca*, *B. simplex*	Pugnax / Unimaculata mouthbrooder complexes	Sumatra, Peninsular Malaysia, Singapore, Thailand	(Putri et al 2021; Fahmi et al 2020; Putri et al 2025)
B. foerschi	Mouthbrooder, Osphronemidae	Borneo and Belitung Island, Indonesia	(Syarif et al 2023).

Conceptual and Comparative Framework: Animal Personality and Fish. An influential conceptual account defines personality traits as behavioural dispositions identified via: stable individual differences, consistency over time, and across contexts (Kaiser & Müller 2021). Methodologically, traits such as boldness and aggressiveness are operationalised through specific assays (e.g. emergence from shelter, mirror tests) rather than by global "personality" labels (Kaiser & Müller 2021).

Fish research has been central in mapping the main personality axes (shyness–boldness, exploration–avoidance, activity, aggressiveness, sociability) and in demonstrating behavioural syndromes, i.e. correlations among traits such as boldness, exploration and aggression (Conrad et al 2011; Martorell-Barceló et al 2023; Mazué et al 2015). Boldness is usually assayed as risk-taking in a novel or risky situation, exploration as activity in a novel environment, and aggressiveness via conspecific or mirror challenges (Pathirana et al 2024; Conrad et al 2011; Mazué et al 2015; Martorell-Barceló et al 2023).

Across fish species, many behavioural measures show significant repeatability, indicating stable among-individual differences in boldness, exploration and aggression over days to months (Pathirana et al 2024; Mazué et al 2015; Beukeboom et al 2023; Martorell-Barceló et al 2023; Benhaïm et al 2023; Boulton et al 2014). However, the degree of repeatability and the presence of syndromes can differ between species, populations, and environments (Pathirana et al 2024; Conrad et al 2011; Mazué et al 2015; Beukeboom et al 2023; Benhaïm et al 2023; Boulton et al 2014) (Table 3).

Table 3

Examples of personality assays and traits in fishes

Behavioural assay / variable	*Inferred trait (axis)*	*Fish examples and notes*	*References*
Emergence from shelter / refuge latency	Boldness (risk-taking)	Repeatable in cichlids, cod, Arctic charr, poeciliids	(Pathirana et al 2024; Mazué et al 2015; Beukeboom et al 2023; Benhaïm et al 2023; Boulton et al 2014)
Time in risky/open zone, track length	Boldness, activity	Stable in freshwater fishes, personality structure tested	(Pathirana et al 2024; Beukeboom et al 2023; Martorell-Barceló et al 2023; Benhaïm et al 2023)
Novel object approach, time near object	Exploration	Repeatable; forms boldness–exploration syndrome	(Pathirana et al 2024; Mazué et al 2015; Beukeboom et al 2023; Martorell-Barceló et al 2023)
Mirror biting, attacks at conspecific	Aggressiveness	Used across fishes, including *Betta splendens*	(Da Silva et al 2025; Ramos & Gonçalves 2019; Conrad et al 2011; Martorell-Barceló et al 2023; Moretz et al 2007).

Betta splendens: Individual Variation and Temporal Stability in Aggression. *Betta splendens* is a classic model for aggression; domesticated lines have been bred for fighting and ornamental traits for centuries (Yue et al 2022; Conrad et al 2011; Lichak et al 2022). Males show stereotyped threat and attack displays toward mirrors or conspecifics, and these assays are widely used to quantify individual aggressiveness (Da Silva et al 2025; Ramos & Gonçalves 2019; Agues-Barbosa et al 2022; Adriaenssens & Johnsson 2010; Iwata et al 2021).

A recent longitudinal study of ornamental male *B. splendens* used weekly mirror tests over three weeks and found large inter-individual variation in aggressive displays, with coefficients of variation of 29–60% across threat and attack behaviours (Da Silva et al 2025). Some individuals showed the full sequence of displays, others only threats, and some no aggression at all (Da Silva et al 2025). Despite this variability, intra-class correlation coefficients (ICC ≥ 0.5) indicated high repeatability of individual aggression levels over weeks, consistent with an aggression personality trait (Da Silva et al 2025).

However, the same study also documented pronounced habituation: aggression toward the mirror declined significantly by the second week, and the degree of habituation varied among individuals (Da Silva et al 2025). Thus, aggressiveness in *Betta* is both consistent at the among-individual level and plastic within individuals over repeated exposures, aligning with the broader fish literature where boldness and activity are repeatable but can change in mean level over time or developmental stage (Pathirana et al 2024; Mazué et al 2015; Beukeboom et al 2023; Benhaïm et al 2023; David et al 2012; Boulton et al 2014).

Other *Betta* work links aggression to reproductive and cognitive traits. In a large sample of males, individuals differed consistently in nest building, aggression, and learning performance; aggressive non-builders showed higher cortisol and were the most aggressive, whereas nest builders were least aggressive with lower hormone levels (Agues-Barbosa et al 2022). This indicates stable multi-trait profiles (e.g. high aggression–high cortisol–low nest building) rather than isolated aggressive acts (Agues-Barbosa et al 2022).

Environmental history also modulates aggressive expression. *Betta* raised continuously in enriched social groups showed lower adult aggression than those isolated at juvenile or subadult stages, and the timing of isolation produced different adult threat versus fighting patterns and hormonal profiles (Iwata et al 2021). These results illustrate that while *Betta* individuals differ consistently, early environment shapes the level and form of expressed aggression (Agues-Barbosa et al 2022; Iwata et al 2021).

Behavioral Syndromes: Correlations Between Aggression, Boldness and Exploration. The notion of behavioural syndromes refers to correlated personality traits across contexts (e.g. boldness–aggression or boldness–exploration axes) (Conrad et al 2011; Mazué et al 2015; Martorell-Barceló et al 2023; Moretz et al 2007; Boulton et al 2014). In fishes generally, shy–bold and exploration–avoidance axes are often correlated, and aggressiveness can covary with boldness or activity (Conrad et al 2011; Mazué et al 2015; Adriaenssens & Johnsson 2010; Martorell-Barceló et al 2023; Moretz et al 2007).

In juvenile convict cichlids, boldness under predation risk and exploratory activity in a novel environment were both repeatable and positively correlated, forming a boldness–exploration syndrome; bolder fish were more exploratory, and both traits showed heritability (Mazué et al 2015). Similar exploration–activity–boldness syndromes have been identified in marine fishes, where individuals with higher exploration and activity scores also exhibit higher boldness, independent of body size and condition (Beukeboom et al 2023; Martorell-Barceló et al 2023).

Aggression's position within syndromes is more variable. In brown trout parr, less explorative individuals were less aggressive but more behaviourally flexible, and this "shy, flexible" type grew faster in the wild, illustrating an exploration–aggression–flexibility syndrome with fitness correlates (Adriaenssens & Johnsson 2010). In zebrafish, correlations between boldness measures and aggression depend on strain and specific behavioural metrics; some populations show a bold–aggressive link, others do not, with overall weak and inconsistent correlations arguing against tight genetic coupling (Moretz et al 2007).

For *B. splendens*, most empirical work has focused on aggression per se rather than explicit boldness–exploration assays. Nevertheless, indirect links between aggression and other axes emerge. In males, combinations of reproductive investment (nest building), aggression and learning performance define distinct profiles with associated hormonal states (Agues-Barbosa et al 2022). Environmental manipulations alter aggression together with endocrine status and sexual maturation, especially in females (Iwata et al 2021). On the conceptual side, aggression is often treated as closely related to boldness, with aggressiveness measures sometimes used as behavioural indicators of boldness in ratings-based studies (Kaiser & Müller 2021).

Across fish, the existence and strength of a boldness–aggression–exploration syndrome are thus species- and context-dependent. Some species and populations show clear positive correlations (e.g. bold–explorative cichlids, trout syndromes linking exploration and aggression) (Mazué et al 2015; Adriaenssens & Johnsson 2010), others show syndromes that exclude aggression (e.g. exploration–activity–boldness without aggressiveness) (Beukeboom et al 2023; Martorell-Barceló et al 2023), and still others exhibit weak or strain-specific links (Pathirana et al 2024; Beukeboom et al 2023; Martorell-Barceló et al 2023; Moretz et al 2007; Boulton et al 2014). These comparative data suggest that, in *Betta*, correlations between aggressivity and exploration/boldness must be tested directly rather than assumed.

Artificial Selection and Domestication: Effects on Aggression and Correlated Traits. *Betta splendens* has an exceptionally long domestication history: males have been selected for staged fights for centuries, followed by intense selection for ornamental traits in the global aquarium trade (Yue et al 2022; Ramos & Gonçalves 2019; Lichak et al 2022; Zhang et al 2022). This makes the species a prime model for studying artificial selection on behaviour.

A direct comparison between a strain selected for staged fights (“fighters”) and a wild-type strain under standard laboratory conditions showed that fighter males were more aggressive than wild-type males across all measured behaviours, and their fight patterns differed qualitatively (Ramos & Gonçalves 2019). Fighter males exhibited higher overall swimming activity, more frequent fast strikes at intruders, and aggressive displays at greater distances, whereas wild-type males were less active and expressed aggression mainly at close range (Ramos & Gonçalves 2019).

Notably, fighter females, which are not used in fights, were also more aggressive than wild-type females, and aggressive behaviours were correlated across male and female fighter siblings (Ramos & Gonçalves 2019). This suggests that selection for male winners has co-selected general genetic and physiological mechanisms that increase aggression in both sexes (Ramos & Gonçalves 2019). The mirror test and live conspecific presentations produced broadly similar strain differences, and mirror responses were less variable, supporting their use for quantifying genetically based aggression (Da Silva et al 2025; Ramos & Gonçalves 2019).

Genomic work in domesticated *Betta* reveals a complex domestication history with extensive introgression from wild species and domesticated breeds carrying a broad array of morphological and behavioural phenotypes (Zhang et al 2022). A genome-wide association study across 727 individuals identified polygenic signals associated with aggression, involving multiple neural system–related genes, alongside loci controlling fin morphology, body size, colour patterns and sex determination (Zhang et al 2022). This indicates that aggressive behaviour in domesticated *Betta* is genetically complex and shaped by selection on networks of neural genes, rather than by single major-effect loci (Zhang et al 2022).

More generally, reviews of domestication effects in fishes highlight that selection in captive or aquaculture environments can produce either increased or decreased aggression, depending on how aggression relates to resource acquisition and growth under the culture regime (Conrad et al 2011; Ruzzante 1994). When selection for rapid growth occurs under competitive, food-limited conditions, indirect selection may favour higher agonistic behaviour; under high-food, low-competition regimes, selection may instead favour reduced aggression (Ruzzante 1994). Domestication-induced changes in aggression can in turn modify schooling, social structure and other behaviours, with potential consequences if domestic stocks interbreed with wild populations (Conrad et al 2011; Ruzzante 1994) (Figure 1).

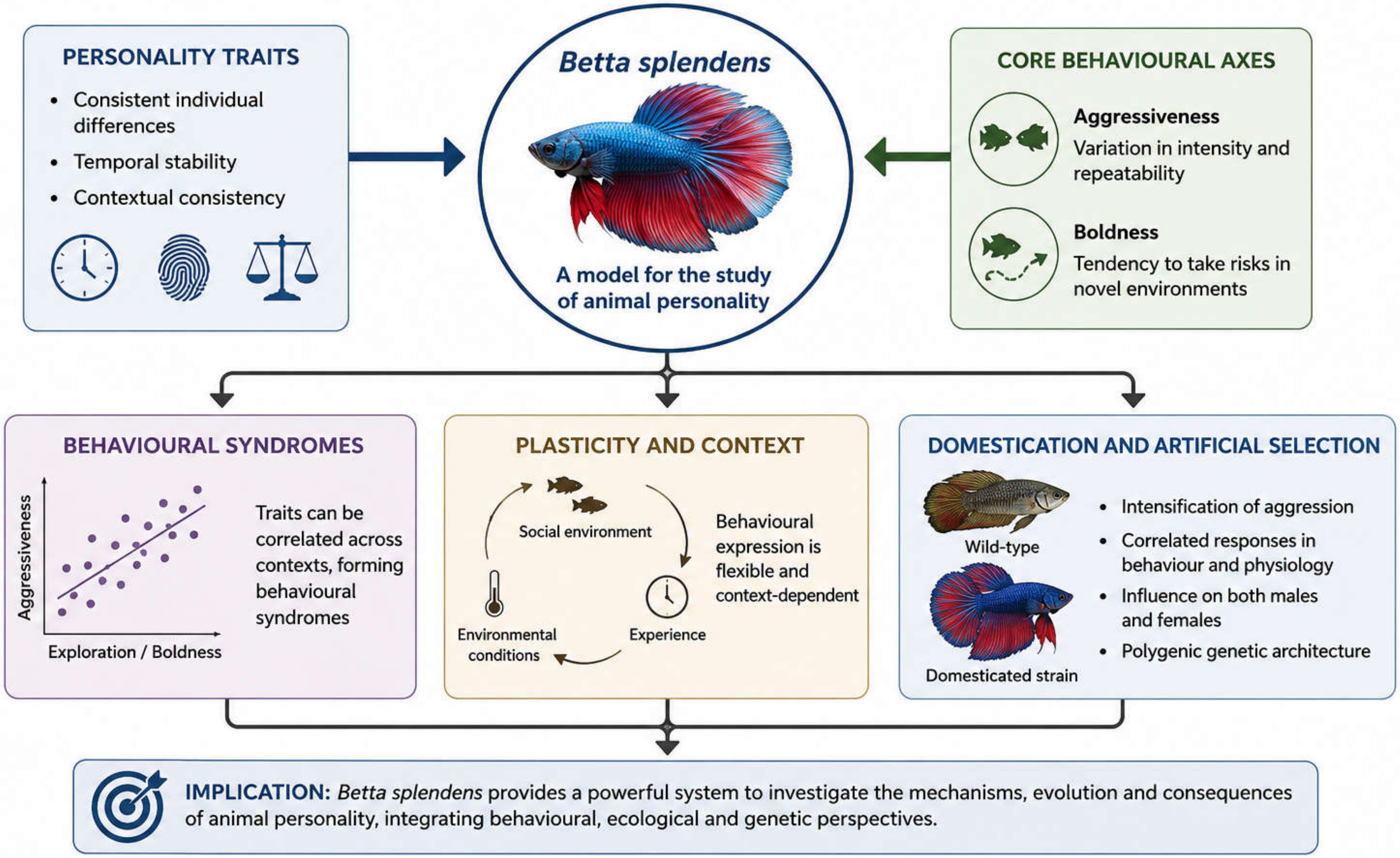

Figure 1. Animal personality in *Betta splendens*: aggressiveness, boldness, syndromes and domestication.

For *Betta splendens*, long-term selection for fighting performance has clearly elevated and reshaped aggressive behaviour patterns in domesticated "fighter" lines and also increased female aggression, consistent with correlated selection on shared genetic and physiological pathways (Yue et al 2022; Ramos & Gonçalves 2019; Zhang et al 2022). At the same time, intensive ornamental breeding and variation in rearing environments (e.g. enriched group rearing versus early isolation) can modulate the expression of aggression, its energetic costs and endocrine correlates (Yue et al 2022; Agues-Barbosa et al 2022; Iwata et al 2021; Zhang et al 2022).

Conclusions. The body of evidence reviewed here supports the conclusion that *Betta splendens* represents a robust and versatile model for the study of animal personality, particularly in relation to aggression. Aggressive behaviour in this species exhibits substantial inter-individual variation alongside high repeatability, satisfying the defining criteria of personality traits. At the same time, within-individual plasticity—manifested through habituation and environmental modulation—underscores the dynamic nature of behavioural expression. The integration of aggression into broader behavioural syndromes remains context-dependent, with correlations to traits such as boldness and exploration varying across studies and experimental conditions. Importantly, the long history of artificial selection in *Betta splendens* has significantly amplified and reshaped aggressive phenotypes, revealing both direct and correlated responses to selection, including effects on females and associated physiological systems. Genomic research further indicates that aggression is governed by a complex, polygenic architecture, reinforcing the view that behavioural traits arise from multifactorial interactions. Collectively, these findings highlight the importance of combining behavioural, ecological, and genetic perspectives when studying personality. Future research should prioritize integrative approaches that explicitly test behavioural syndromes in *Betta splendens*, particularly under varying ecological and developmental conditions, to better understand the evolutionary mechanisms maintaining behavioural diversity.

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