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Host-plant resistance to *Rhyzopertha dominica* (F.) in Indian wheat: A narrative review of cultivar variability, physico-biochemical determinants, and research priorities

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Abstract
Post-harvest insect damage is a major and recurring constraint on the storage of Indian wheat, and the lesser grain borer *Rhyzopertha dominica* (F.) is among the principal Coleopteran contributors. Variation in phosphine sensitivity across Indian *R. dominica* populations has further sharpened the case for cultivar-based host-plant resistance (HPR) as a complementary and sustainable management strand. This narrative review consolidates the Indian literature on cultivar response to *R. dominica*, with attention to physico-biochemical determinants of resistance, the screening methodologies in use, and the comparative *Sitophilus oryzae* corpus on the same cultivars. The Indian record shows broad screening activity across multiple wheat breeding series and agro-ecological zones, repeated identification of more- and less-susceptible cultivar groups, and a discernible mismatch between cultivar resistance to *R. dominica* and resistance to other Coleopteran storage pests — challenging pest-generic "stored-grain resistance" framings. The physico-biochemical correlate analysis routinely applied to *S. oryzae* on Indian wheat has not been comparably executed for *R. dominica*. The screening methodologies in use are functional but heterogeneous in infestation density, storage duration, and pest-strain provenance. Three concrete research priorities follow: (i) a polyphasic biochemistry × *R. dominica* × Indian wheat study modelled on existing *S. oryzae* protocols; (ii) population-stratified screening against field-collected pest populations from contrasting agro-ecologies; and (iii) integration of kernel-hardness phenotyping, including puroindoline-allele characterisation, into the AICRP-Wheat breeding pipeline.

Keywords: *Rhyzopertha dominica*, Indian wheat, host-plant resistance, stored-grain pests, phosphine resistance, narrative review

Introduction

India is one of the world's largest producers of wheat (*Triticum aestivum* L.), and wheat is a staple of the Indian diet. After harvest, wheat passes through a long and structurally varied storage chain — large-volume Food Corporation of India and state procurement godowns, cooperative storage, and smallholder on-farm structures such as mud-bins, metal drums, and jute bags. Insect damage is a substantial economic and food-security loss along this chain.

The lesser grain borer, *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae), is a primary pest of stored wheat in India and is widely distributed across the tropics and warm-temperate zones, occupying a particularly destructive niche [1]. Early-instar larvae bore into intact grain and complete development within the endosperm, emerging through characteristic exit holes; adult females lay eggs on the grain surface [1]. Unlike secondary pest insects such as *Tribolium castaneum* and *Oryzaephilus surinamensis* [1], this hidden immature stage makes *R. dominica* resistant to contact insecticides, surface protectants, and physical sieving. Developmental rate and fecundity are strongly temperature- and humidity-dependent on Indian wheat, and compounding losses from multi-generational build-up under Indian godown conditions can drive infestation beyond commercially acceptable limits. *R. dominica* is among the principal pests of stored Indian wheat, alongside *Sitophilus oryzae* (L.) and *Trogoderma granarium* (Everts).

Current management relies heavily on phosphine fumigation, but Indian *R. dominica* populations now show substantial variability in phosphine sensitivity, with mechanistic differences linked to antioxidant-enzyme physiology [2]. This resistance picture compounds the broader management challenge created by the global phase-out of methyl bromide and the tightening of domestic regulation around chemical residues in stored grain. In this context, host-plant resistance (HPR) — exploiting cultivar differences that reduce pest performance — is a sustainable complement to chemical control [3]. The classical mechanisms of HPR in wheat–stored-product interactions (antixenosis, antibiosis, and tolerance) have been described internationally [3, 4].

The Indian research record on wheat × *R. dominica* spans foundational cultivar-screening work through to recent morphological-correlation and nano-emulsion studies [5, 6, 7] Indian studies have screened cultivars from multiple major wheat breeding series — including, among others, the HD, PBW, GW, HI, Raj, HPW, VL, KRL, LOK, CG, and PDW lines — across multiple agro-ecological zones [5, 6, 7, 8, 9, 10, 11]. Several gaps remain. The comprehensive physico-biochemical correlate analysis executed for *S. oryzae* on Indian wheat [12] has not been replicated for *R. dominica*; screening methodologies vary substantially in density, duration, and pest provenance across the Indian corpus; the substantial inter-population variability documented for Indian *R. dominica* [2] is not reflected in the single-strain screening that dominates the cultivar-resistance literature; and no narrative review of this corpus has previously been published. This review (i) collates the Indian evidence on cultivar response to *R. dominica*; (ii) places physico-biochemical correlates of resistance in international context and appraises them for Indian *R. dominica* relevance; (iii) critically discusses the screening methodologies in use; and (iv) identifies research priorities to strengthen HPR as a component of integrated post-harvest pest management of wheat in India.

Scope and Approach

1. Scope

This review covers Indian published work on host-plant resistance of wheat cultivars to *R. dominica*, with attention to (a) cultivar variability, (b) physico-biochemical determinants of resistance, (c) screening methodologies, and (d) *R. dominica* biology in the Indian context. Studies of *S. oryzae* on Indian wheat cultivars were considered as parallel evidence for the discussion of pest-specificity, and international work was drawn on as methodological and mechanistic context where Indian work is sparse.

2. Sources consulted

Literature was identified through ICAR e-publication archives, UGC-CARE listed journals, CAB Abstracts, Scopus, Web of Science, Google Scholar, and the Shodhganga thesis repository. Search terms combined ("*Rhyzopertha dominica*" OR "lesser grain borer") AND ("wheat" OR "*Triticum*" OR "stored grain") AND ("India" OR Indian state names). Reference lists of retrieved papers and of the canonical *R. dominica* review by Edde [1] were hand-searched for additional records.

3. Synthesis approach

The synthesis is narrative rather than systematic. Indian work on *R. dominica* × wheat is heterogeneous in study design, infestation density, storage duration, outcome metrics, and variance reporting; formal meta-analysis across this corpus is not currently warranted. Studies are discussed under four thematic pillars — cultivar variability; *R. dominica* biology and Indian context; physico-biochemical determinants; and screening methodologies — with cross-pest comparisons (*R. dominica* vs *S. oryzae* on the same cultivars) reserved for the Discussion. The review identifies patterns visible across studies at a thematic level and the research gaps these patterns reveal, rather than providing pooled quantitative estimates of cultivar effects.

Indian *R. dominica* × wheat research: themes and findings

1. Cultivar variability against *R. dominica*

Scope: Indian screening of wheat genotypes against *R. dominica* spans foundational work through to contemporary studies. The screened cultivars are drawn from multiple major wheat breeding series associated with the principal Indian agricultural research institutions and State Agricultural Universities, covering — among others — the HD, HPW, VL, CG, KRL, PBW, PDW, LOK, Raj, and MP-series lines. Screening activity is geographically uneven across India's wheat agro-ecological zones, with notable clusters of research output and other regions where coverage is sparse.

The Indian research record: Foundational cultivar-screening work on the Indian wheat gene pool, extended subsequently by Tiwari and Sharma [13], documented inter-cultivar variation in *R. dominica* developmental and emergence outcomes and established the broad framing of cultivar-level differences that has guided downstream Indian work. Contemporary studies — Kumawat *et al*. [10] at RCA Udaipur, Mehta [11] across HPW-series cultivars in the North-Western Himalayan zone, and Syed Mohamed Ibrahim *et al*. [8] in Gujarat using sequential free-choice and forced-choice protocols — have continued to report inter-cultivar variation in *R. dominica* response using standard outcome metrics (% weight loss, F_1 emergence, mean developmental period, Dobie's susceptibility index). Adhikari *et al*. [5, 6] have added morphological-correlation and nano-emulsion work in recent years.

Patterns across the Indian corpus: Three patterns are visible across studies at a thematic level. First, several Indian studies, conducted independently in different agro-ecologies, have repeatedly identified a small group of cultivars at the resistant end of the *R. dominica* susceptibility distribution; a parallel group of cultivars appears repeatedly at the susceptible end. The convergence of these groupings across regions, laboratories, and years is the strongest qualitative signal in the Indian corpus, though it has not been formally meta-analysed because of methodological heterogeneity (§3.4). Second, Indian studies report cultivars showing markedly different relative susceptibility to *R. dominica* and to *S. oryzae* [8, 12] — pest-specific responses that are central to the cross-pest discussion in §4.1. Third, comparative work between bread and durum wheat cultivars [14] reports durum lines as comparatively less susceptible to *S. oryzae*, consistent with a hardness-mediated component of resistance; direct evidence supporting durum-mediated resistance against *R. dominica* specifically remains sparse in the Indian corpus. Methodological heterogeneity — particularly differences in infestation density and seed-lot biochemistry — partly explains apparent disagreements between studies for the same cultivar.

2. *R. dominica* biology, damage, and the Indian context

Pan-Indian population variability: Ranjith *et al.* [2] characterised *R. dominica* populations from multiple Indian states and reported substantial inter-population variation in phosphine sensitivity, with regional structure and mechanistic correlates in antioxidant-enzyme physiology. The implication for HPR research is direct: cultivar-resistance screening on a single laboratory strain — typically maintained for many generations at one institution — may not generalise to the field populations actually consuming wheat in Indian godowns. None of the Indian cultivar-screening studies reports *R. dominica* strain provenance in sufficient detail to permit such generalisation.

Temperature-modulated biology: Indian work has documented strongly temperature- and humidity-dependent egg-to-adult development and fecundity in *R. dominica* on Indian wheat. This has a direct methodological implication for cultivar-screening studies: in the absence of thermostatic control, seasonal temperature drift can introduce non-trivial variation in observed mean developmental period and F_1 counts, complicating between-study comparisons.

Storage losses and host range: Foundational and subsequent farm-storage loss surveys have established that insect damage represents a substantial fraction of post-harvest grain losses in India. Host-preference behaviour of *R. dominica* relevant to its Indian distribution has been characterised, with wheat among the preferred host substrates and host-switching capacity demonstrated.

3. Physico-biochemical determinants of resistance

The Indian Biochemistry Gap: No Indian study has measured the full physico-biochemical suite that has become the international standard for stored-grain wheat research — kernel hardness, soluble protein, total phenolics, sugars, starch, grain amylolytic activity, and insect-derived digestive enzyme activity — for *R. dominica* on Indian wheat. This integrated multi-trait analysis has been executed on Indian wheat with *S. oryzae* as the test pest [12], but not for *R. dominica*.

The IARI biochemistry framework: The methodologicall y most complete polyphasic study in the Indian corpus is Arya *et al.* [12], who screened IARI-released wheat cultivars against *S. oryzae* and measured a multivariate suite of grain physico-biochemical traits — kernel hardness (texture analyser), soluble protein (Bradford assay [15]), total soluble sugars, starch, grain amylolytic activity, total phenolics (Folin–Ciocalteu), and insect-derived α-amylase and protease activity. Correlation and multivariate analyses produced a coherent pattern: kernel hardness, soluble protein, total phenolics, and grain amylolytic activity were associated with reduced weight loss; while soluble sugars, starch, and insect digestive enzyme activity were associated with increased weight loss. Principal component analysis and agglomerative hierarchical clustering separated cultivars into a resistant and a susceptible pole based on these trait combinations.

The critical interpretive caveat: For *S. oryzae*, an external feeder, females drill pre-oviposition holes and larvae develop in the endosperm. *R. dominica* neonates, by contrast, must themselves penetrate the intact pericarp before establishing in the endosperm — a mechanically more demanding obligate early-larval step. The composition and surface microstructure of the kernel pericarp may therefore matter more for *R. dominica* than for *S. oryzae*, while endosperm protein and starch chemistry may matter relatively less. The magnitude — and conceivably the sign — of individual physico-biochemical correlations with damage may differ between the two pests. The Arya [12] framework remains a powerful template for *R. dominica* work; this hypothesis has not yet been tested.

Other Indian biochemistry-relevant studies: Singh and Sharma [14] compared durum and bread cultivars at PAU Ludhiana and reported physico-biochemical differences consistent with a hardness-mediated component of resistance. Pitchika *et al.* [9] screened recently released IGKV (Chhattisgarh) cultivars in central India and reported associations between cultivar response and grain mineral composition — among the few Indian datasets connecting biofortification with stored-pest response.

International mechanistic anchors: The protein–hardness–resistance triangle that underpinned subsequent multivariate work in this area was set out by Sinha *et al.* [16] and elaborated by Broughton and Dunkel [17]. Nawrot *et al.* [17] showed that kernel surface hydrophobicity and cuticular-wax composition modulate oviposition acceptance in the granary weevil beyond bulk hardness alone — a point that has not been examined in the Indian *R. dominica* literature. Microbiome-mediated effects on *R. dominica* biology have been reported by Kosewska *et al.* [18], linking grain chemistry to gut-microbiome composition and downstream development. The qualitative-loss dimension of stored-pest damage (gluten index, gluten network, starch gelatinisation viscosity) has been documented by Perišić *et al.* [19] and is complementary to the quantitative-loss work that dominates the Indian corpus.

Synthesis: Taken together, the international literature points to kernel hardness and total phenolics as the strongest correlates of resistance against stored-grain Coleoptera in wheat, with soluble protein and grain amylolytic activity as additional contributors and sugars/starch as positive correlates of damage. Two correlates flagged by the international *R. dominica* literature — kernel surface microstructure and cuticular-wax composition, and grain volatile-organic-compound (VOC) profiles affecting adult olfactory preference — remain effectively untested on Indian wheat.

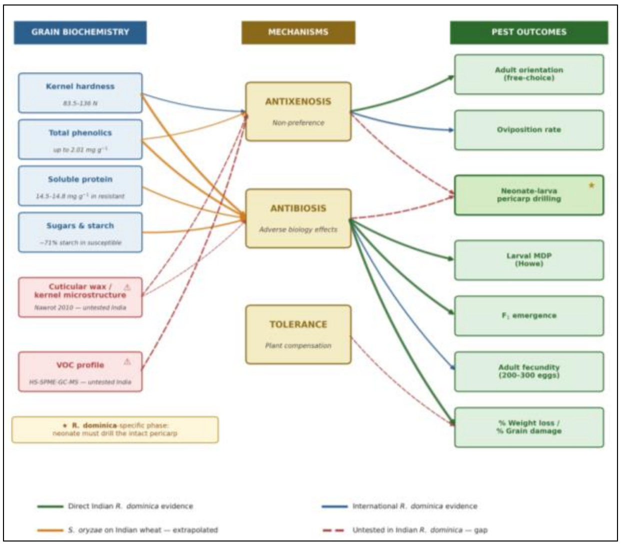

Fig 1: Conceptual framework linking grain physico-biochemistry to resistance mechanisms to pest-biology outcomes for *R. dominica* on Indian wheat. Three-column flow: left, six physico-biochemical traits (kernel hardness, total phenolics, soluble protein, sugars and starch, cuticular wax / kernel microstructure, VOC profile); middle, three classical HPR mechanisms (antixenosis, antibiosis, tolerance); right, measurable pest-biology outcomes including the *R. dominica*-specific neonate-larva pericarp drilling phase. Arrow thickness reflects strength of evidence; line colour indicates source: green (direct Indian *R. dominica* evidence), blue (international *R. dominica* evidence), orange (*S. oryzae* on Indian wheat — extrapolated), red dashed (untested in Indian *R. dominica* literature). Two grain traits (cuticular wax/microstructure, VOC profile) remain entirely untested in Indian *R. dominica* work.

4. Screening methodologies

The de facto Indian protocol

The Indian protocol for screening wheat cultivars against *R. dominica* typically consists of four elements: a free-choice test performed at fixed intervals; a forced-choice (no-choice) test conducted with fixed pairs of adults in grain samples of varying size, with an oviposition window followed by an incubation period; computation of the mean developmental period (MDP) using the Howe [19] formula ($\Sigma F_1 \times$ days / ΣF_1); and computation of Dobie's susceptibility index (SI) [21] as ($\log_{10} F_1$ / MDP) × 100. The commonly reported outcome variables are % weight loss, % grain damage, F_1 emergence, MDP, and SI.

Methodological limitations

Several limitations reduce comparability across the Indian corpus:

- **Incubation conditions vary across studies:** Some studies report fully incubator-controlled storage, while others report ambient laboratory conditions. Seasonal drift in ambient settings can introduce variation in observed MDP across studies.
- **Infestation density varies substantially:** Cultivar differences are typically more pronounced at lower densities and become compressed at higher densities, limiting between-study comparability.
- **Susceptibility-index thresholds:** The classification thresholds in common use originate from a single regional trial and have not been validated across India's agro-ecological diversity.
- **Storage duration varies widely:** An optimal phenotyping window that captures a complete generation plus an oviposition period for the next generation is required for cross-study comparability, and many studies do not align with this window.
- **Sex ratio and pest provenance:** Few Indian studies report the sex ratio of the adult inoculum, despite the female-biased fecundity of R. dominica that makes F_1 counts sensitive to inoculum sex composition. Although substantial inter-population variability has been documented across India [2], pest-strain provenance (long-maintained laboratory culture vs recent field collection; regional origin) is rarely characterised in the Indian cultivar-screening literature.

Methodological gaps

Indian work has concentrated on the core resistance outcomes (% weight loss, F_1 emergence, MDP, SI), with free-choice and forced-choice testing well represented. Coverage falls off sharply for full life-table analysis (R_0, r_m, generation time [22]), degree-day standardisation, VOC profiling, and multivariate ordination. Multivariate statistical treatment in the Indian context has been confined to *S. oryzae* work [9,12].

International benchmarks

The international stored-product literature retains Howe's [19] and Dobie's [21] formulae, applies standardised infestation densities and study durations across one- and two-generation designs, and explicitly characterises pest strains. Life-table protocols [22] in addition to Dobie-SI screening yield demographic parameters that allow antibiosis to be distinguished from tolerance. Indian institutions are well placed to implement these benchmarks, but uptake has been uneven.

Discussion

The Indian *R. dominica* × wheat research programme is empirically productive but methodologically uneven and mechanistically incomplete. Five themes emerge from the corpus.

1. Resistance to *R. dominica* does not transfer to S. oryzae

The most consequential pattern from the Indian corpus is the absence of a consistent relationship between cultivar-level resistance to *R. dominica* and cultivar-level resistance to other stored-grain Coleoptera, notably *S. oryzae*. Several Indian cultivars show pest-specific discordance: a cultivar ranked among the less susceptible to one pest can rank among the more susceptible to the other [8, 12]. The biological basis is mechanistic. *S. oryzae* is an external feeder whose adults drill oviposition holes with strong mandibles; *R. dominica* neonates must instead penetrate the intact pericarp themselves, an obligate early-larval step. Pericarp hardness and surface microstructure may therefore impose a stronger constraint on *R. dominica* than on *S. oryzae*. The breeding implication is that pest-generic "stored-grain resistance" labels are not biologically defensible. Reference cultivar sets for *R. dominica* should be developed, evaluated, and maintained separately from those for *S. oryzae* or *T. granarium*.

2. The biochemistry-correlate gap is the field's most fertile research direction

Predictions of cultivar resistance using a full polyphasic biochemistry framework are available in the international literature [16, 17, 18, 19] and have been partially applied to wheat × *S. oryzae* work in India [9, 12, 14] — but not yet to *R. dominica*. Replicating that polyphasic protocol on *R. dominica* using a curated set of Indian cultivars, including those already characterised for *S. oryzae*, is the single most informative experiment that could be performed in this area over the next five years. It would directly test the mechanistically grounded hypothesis that kernel hardness and pericarp microstructure correlate more strongly with *R. dominica* damage than with *S. oryzae* damage, while endosperm biochemistry correlates more strongly with *S. oryzae* damage.

3. Methodological heterogeneity is remediable, not intrinsic

The methodological conventions discussed in §3.4 — infestation density range, storage timeframe, susceptibility-index thresholds, incubation conditions, and reporting of sex ratio — are remediable. The international literature points toward more stringent and standardised protocols [20, 21]; there is no consensus protocol for *R. dominica* × wheat screening in the Indian literature that ensures reproducibility between laboratories. The AICRP-Wheat and AICRP Stored Grain Pest networks have the institutional reach and methodological expertise to harmonise these conventions. The cost is administrative coordination; the benefit is the possibility of a future formal quantitative synthesis over a methodologically harmonised Indian corpus.

4. Single-strain screening underestimates field reality

The substantial inter-population variability in phosphine sensitivity and antioxidant physiology reported across Indian states [2] further complicates the interpretation of cultivar-resistance work conducted against a single laboratory strain. The inference drawn in any one Indian institution is not "resisting *R. dominica*" generically but "resisting the specific laboratory population used". The practical question for godown managers, procurement agencies, and varietal-release decisions is whether cultivar resistance generalises to field populations. Population-stratified direct tests, using *R. dominica* populations sampled from contrasting Indian agro-ecologies on a curated cultivar panel, would address this geographic-generalisability question directly.

5. Durum kernel hardness is an under-exploited breeding lever

The bread-versus-durum contrast reported in Indian work [14], together with the directional performance of durum-derived lines reported elsewhere in the corpus, supports a longstanding wheat-breeding intuition that kernel hardness — controlled in part by the Pin-a (Puroindoline-1) and Pin-b (Puroindoline-2) genes on chromosome 5DS — is a tractable breeding lever for storage-pest resistance, with the inherently harder kernel of *Triticum durum* a contributing factor. For *R. dominica* specifically, kernel hardness is mechanistically more salient than for any other major Indian stored-grain Coleopteran, because of the obligate neonate-pericarp drilling step. ICAR-IIWBR's expanding kernel-hardness phenotyping infrastructure — already established to support chapati and bread quality grading — is well placed to be repurposed for *R. dominica* screening at minimal additional investment.

Interlocking Themes

These themes interlock. The biochemistry-gap argument (§4.2) becomes more pressing given the pest-specificity finding (§4.1). The convergent qualitative patterns visible in §3.1 cannot be confirmed by formal meta-analysis given the methodological heterogeneity discussed in §4.3. Geographic-generalisability questions (§4.4) further qualify the inference space, and methodological standardisation is needed before stronger quantitative claims can be evaluated. The durum-hardness argument (§4.5) is the most immediately translatable into breeding activity and the most mechanistically secure of the avenues identified.

Research Priorities

Three concrete, anchored, institutionally feasible priorities follow.

1. A polyphasic biochemistry × *R. dominica* × Indian wheat study

Apply the Arya *et al.* [12] protocol — measuring kernel hardness, soluble protein, total phenolics, sugars, starch, grain amylolytic activity, and insect-derived α-amylase and protease activity — to a curated panel of Indian wheat cultivars representing both ends of the apparent *R. dominica* susceptibility distribution and including the cultivars already characterised for *S. oryzae* [12]. The standard outcome suite (WL, F_1, MDP, SI) should be supplemented by an *R. dominica*-specific outcome variable: latency time to pericarp drilling by neonate larvae. The output would be a correlation matrix directly comparable to Arya *et al.* [12], enabling formal cross-pest tests of the pericarp-versus-endosperm hypothesis. ICAR-IARI (New Delhi) and ICAR-IIWBR (Karnal) are the natural lead institutions.

2. Population-stratified screening using field-collected *R. dominica* strains

Re-screen a curated cultivar panel against *R. dominica* populations sampled from contrasting Indian agro-ecologies — high phosphine-resistance northern bulk-storage regions, arid zones, semi-arid coastal regions, central-eastern regions, and lower-resistance reference regions per [2]. Characterise each population for baseline antioxidant-enzyme activity, sex ratio, and time since field collection. A cultivar × population analysis of variance would directly quantify the extent to which cultivar-level resistance generalises across the pan-Indian pest complex. ICAR-NBAIR (Bengaluru) and the AICRP Stored Grain Pest network are well placed to coordinate this multi-site work.

3. Integrate kernel-hardness phenotyping into AICRP-Wheat

Advanced breeding lines of wheat at ICAR-IIWBR (Karnal) are currently advanced primarily for chapati and bread quality grading; the same kernel-hardness phenotyping infrastructure can be repurposed for stored-pest resistance screening. Two specific recommendations follow: (1) introduce a short, standardised forced-choice *R. dominica* assay on a subset of advanced lines as an additional phenotyping trait within AICRP-Wheat, and (2) introduce marker-assisted screening for Puroindoline alleles (Pin-a, Pin-b on chromosome 5DS) and durum allelic counterparts, flagging hard-kernel allelic combinations for fast-tracked screening. Integrating storage-pest resistance into the breeding pipeline in this way reframes it from an experimental afterthought into a routinely phenotyped trait.

These priorities would be implemented sequentially across approximately five years: Priority 1 establishes the mechanism; Priority 2 tests the generalisability of that mechanism across the pan-Indian pest complex; Priority 3 routes the mechanism into breeding-pipeline practice.

Conclusion

A substantial body of empirical data has accumulated on *R. dominica* × Indian wheat over decades of research, but the data remain fragmented in methodology, location, and depth of analysis. Across the Indian corpus, studies show convergent qualitative identification of cultivar groupings at both ends of the susceptibility distribution across multiple agro-ecological regions of the country.

Three qualifications attach to this maturity. First, cultivar resistance to *R. dominica* does not transfer cleanly to *S. oryzae*, and vice versa — multiple Indian cultivars show pest-specific discordance, with direct implications for breeding-programme assumptions about generic stored-grain pest resistance. Second, unlike the case of *S. oryzae* — for which the physico-biochemical correlates of resistance in Indian wheat have been measured [12] — the mechanism(s) of cultivar variation in *R. dominica* response on Indian wheat remain inferred rather than demonstrated. Third, the *R. dominica* populations actually consuming Indian wheat are physiologically heterogeneous across the subcontinent [2], yet the cultivar-screening literature has been built almost entirely on single-laboratory-strain work.

Host-plant resistance should be repositioned as a primary management tool rather than a secondary or back-up tactic and should become more widely used. The three priority points of action identified — a polyphasic biochemistry × *R. dominica* × Indian wheat study using the protocol of Arya *et al*. [12]; re-screening of the apparent convergent resistant cluster against field-collected pest populations from contrasting agro-ecologies; and introgression of kernel-hardness phenotyping and puroindoline-allele characterisation into the ICAR-IIWBR-Karnal wheat breeding pipeline — would together convert the existing descriptive literature into a research programme with a scientifically grounded mechanism, uniform and translatable evidence, and a platform on which HPR can be standardised and adopted within integrated post-harvest pest management for Indian wheat.

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