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Piper nigrum and piperine: a review of black pepper composition

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1. ABSTRACT

The review by Meghwal and Goswami examines why black pepper is not synonymous with a single molecule. It gathers data on the composition of *Piper nigrum*, piperine, fruit processing, and the biological activities reported in experimental models and human studies.The publication summary describes black pepper as a spice obtained from the fruits of *Piper nigrum* and characterized by piperine, a natural alkaloid responsible for a significant portion of its pungent sensation. However, the authors also discuss other constituents, including volatile substances responsible for its aroma and non-volatile compounds present in the food matrix—that is, the natural set of substances that remain associated within the product. The review also considers how processing and transformation can alter the chemical profile of pepper. A significant portion focuses on isolated piperine: it summarizes studies on cells, animals, and humans that have evaluated its interactions with enzymes and cellular transporters, as well as biological activities observed in experimental settings. The key takeaway for the reader is methodological: data obtained with pure piperine does not automatically describe the pepper used in cooking. The review is not a clinical trial, does not statistically combine study results, and does not provide clinical proof of benefit for any specific disease. It serves primarily to distinguish between botanical origin, spice composition, concentrated extracts, and the isolated molecule.

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2. WHAT THIS RESEARCH ANALYZED

To understand what black pepper is from a biological perspective, Meghwal and Goswami reconstructed the available knowledge on the fruits, constituents, and processing of *Piper nigrum*. The starting point is simple: pepper is a dried plant-based food, not a piperine tablet. The review treats piperine as the reference alkaloid for pungency, but it also includes essential oils, oleoresins, and other compounds within the food matrix.In detail, the authors discussed analytical studies on composition, research on changes due to processing, and biological studies on piperine. They also summarized data regarding P-glycoprotein, a transporter that can expel substances from cells, and various metabolic enzymes. This means that piperine can be studied for its biological interactions; it does not mean that the culinary consumption of pepper automatically produces the same effects observed with extracts or the isolated substance.

3. WHAT RESULTS EMERGE FROM THE STUDY

The main finding is that piperine accounts for a significant portion of the pungent character of black pepper and is the compound most easily isolated and measured. For the reader, this clarifies why much research refers to piperine rather than pepper in its entirety. However, the review emphasizes that the fruit contains multiple classes of substances, including volatile aromatic fractions that contribute to its sensory profile.The authors also report that processing, extraction, and storage can alter the measurable composition. Biologically, they summarize observations on the antioxidant, anti-inflammatory, and other experimental activities of piperine. These results come from very different models and do not all have the same level of evidence. The presence of an effect in cells or animals does not prove a clinical benefit in humans, nor does it allow for the definition of a useful dose of the spice in cooking.

4. WHY THIS STUDY IS RELEVANT

This review is relevant because it avoids two opposing simplifications: viewing black pepper merely as a flavoring or treating it as if it were pure piperine. In practice, it helps to more accurately interpret labels, studies, and formulations. The whole spice carries a variable composition; an extract concentrates only a portion of the constituents; isolated piperine allows for more controlled experiments, but it does not represent the whole food.Moving from composition to biological effect therefore requires caution. A molecular mechanism can explain how a substance interacts with a cell, but it cannot predict the outcome in an entire organism on its own. The pungency of piperine is supported by experiments on sensory receptors [1], while the variability of preparations is documented by analytical measurements on commercial samples and extracts [2][3].

5. STUDY LIMITATIONS AND WHAT IT DOES NOT DEMONSTRATE

Meghwal and Goswami have published a narrative review. This type of work is useful for connecting different lines of research, but it does not necessarily apply predetermined criteria for study selection, does not calculate an average effect, and does not establish the overall certainty of the evidence. The publication does not provide an overall sample size, follow-up, or statistical values typical of a clinical trial.The review does not prove that black pepper prevents or treats any disease. It also does not demonstrate that a culinary amount of pepper is equivalent to a standardized extract or isolated piperine. Furthermore, a variation in composition alone does not allow for the prediction of taste, absorption, or safety for every product. Subsequent studies indicate that even the response to pungency and the effects of processing depend on the molecules considered and the experimental conditions [4][5].

6. INDEPENDENT CONFIRMING EVIDENCE

The most direct chain starts with the pungent sensation. In HEK293 cells, human cells used in laboratories to express specific proteins, McNamara and colleagues showed that piperine activates TRPV1, an ion channel involved in the perception of irritant and thermal stimuli. Activation was blocked by receptor inhibitors; the median effective concentration, or EC50, was 37.9 ± 1.9 micromolar. This data confirms the molecular link between piperine and pungency, with a direct mechanistic level of confirmation. However, it does not demonstrate what intensity a person perceives after a food portion [1].A

second step concerns the actual presence of piperine in the fruit. Kanaki and colleagues isolated piperine from dried *Piper nigrum* fruits through extraction and crystallization; the method obtained a yield of approximately 4.45% by weight and a declared purity of 90%. This confirms that the compound can be separated and analytically controlled, in line with the distinction between spice and isolated molecule proposed by the review. However, this is a chemical experiment on plant material, not an evaluation of the effect in the organism [2].Finally, Morais and colleagues applied a validated analytical method to ten commercial samples of white and black pepper. Piperine was found to be between 1.6% and 2.5%; in the standardized ethanolic extract, it reached 46.7 ± 1.7%. These measurements support the idea that the content depends on the sample and preparation. The relationship with the review is direct regarding the compositional part, but the level of confirmation remains analytical: the study does not compare the dietary effect of the different samples in people [3].

7. CONFLICTING EVIDENCE

Piperine is central, but it does not fully explain pungency. Okumura and colleagues tested 19 compounds found in black pepper in cells expressing TRPV1 or TRPA1, a second sensory channel. In addition to piperine, various compounds activated one or both receptors; for TRPV1, the EC50 of the most active compounds ranged from 0.6 to 128 micromolar. This result does not negate the role of piperine, but it contradicts the idea that a single molecule explains the entire sensory response. Confirmation of the complexity of the matrix is valid at the cellular level, but it does not equate to sensory evidence in humans [4].The effects of processing also do not follow a single direction. Namjoyan and colleagues analyzed an ethanolic extract before and after freeze-drying or oven-drying. Freeze-drying reduced the chromatographic signals of piperine and its isomers by a few percentage points; in oven-dried material, however, the piperine signal increased, while two isomers were no longer detectable. This suggests that the result depends on the method and the molecule being measured, rather than a universal rule of loss. The work concerns an extract, not whole culinary pepper, and does not provide clinical implications [5].

8. QUADRO COMPARATIVO E SINTESI DELLE EVIDENZE

The following publications compare specific parts of the narrative with the review by Meghwal and Goswami.

Quadro comparativo

Publication	Model and main data	Relation to the study	Interpretation and limitation
McNamara et al., 2005 [1]	Human HEK293 cells with TRPV1: piperine as agonist; EC50 37.9 ± 1.9 micromolar.	Confirms the pathway piperine → sensory receptor → pungency.	Direct mechanistic confirmation; does not measure pungency after dietary consumption.
Kanaki et al., 2008 [2]	Chemical experiment on dried fruits: piperine yield approximately 4.45% and 90% purity.	Confirms that piperine can be isolated from the fruit of Piper nigrum.	Analytical confirmation; an extraction method does not describe biological effects.
Morais et al., 2023 [3]	Ten commercial samples: piperine 1.6–2.5%; standardized extract 46.7 ± 1.7%.	Confirms the variability between the plant product and the concentrated extract.	Indirect analytical confirmation; study oriented toward non-food use.
Okumura et al., 2010 [4]	Cells with TRPV1/TRPA1: multiple pepper compounds activated the sensory channels.	Downsizes the idea that piperine alone explains all pungency.	Relevant cellular evidence; does not quantify the human sensory contribution of each compound.
Namjoyan et al., 2012 [5]	Ethanolic extract subjected to two drying processes: different results for piperine and isomers.	Shows that the effect of processing depends on the conditions applied.	Relevant analytical evidence; not automatically transferable to household pepper.

9. SINTESI EDITORIALE E CONCLUSIONI

EDITORIAL CONCLUSION

The review by Meghwal and Goswami clarifies that black pepper is the dried fruit of *Piper nigrum* with a complex composition. Piperine is its most studied compound and contributes significantly to its pungency, but it does not represent the entire spice. Independent studies support three points of the narrative: piperine can activate a human sensory receptor in cultured cells; it can be isolated and measured in the fruits; and its content varies between samples and preparations. At the same time, other substances in pepper may participate in the pungent response, and processing can modify piperine and its isomers in different ways. The most prudent conclusion is therefore to always distinguish between whole pepper, extract, and isolated piperine. The evidence examined here is primarily chemical and preclinical. It describes composition and mechanisms, but does not demonstrate specific clinical effects or guaranteed benefits from daily dietary consumption.

Aggiornato al 24/11/2026. Questo contenuto riflette una sintesi divulgativa delle evidenze scientifiche al momento della pubblicazione e non sostituisce il parere medico.

10. TRANSPARENCY AND SCIENTIFIC RESPONSIBILITY

Artificial Intelligence was used solely as a tool for editorial and documentary support. All content, interpretations, bibliographic citations and conclusions have been verified, reviewed and approved by the author, who assumes full scientific responsibility for them.

The manuscript was also subjected to independent peer review prior to publication.

To ensure the greatest transparency, the complete history of the article, including the dates of submission, revision, acceptance and publication, as well as information on the peer review process, is available on the dedicated Article History page.

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