



Nutritional composition, bioactive polysaccharides, and biological activities of *Russula griseocarnosa* X. H. Wang, Zhu L. Yang & Knudsen: A comprehensive review

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Hoai LVN, Quoc LPT, Phuong LBB, Quyen PT, Hao PM. 2025 – Nutritional composition, bioactive polysaccharides, and biological activities of *Russula griseocarnosa* X. H. Wang, Zhu L. Yang & Knudsen: A comprehensive review. Asian Journal of Mycology 9(2), 44–55, Doi 10.5943/ajom/9/2/6

Abstract

This review summarizes the existing studies on *Russula griseocarnosa*, a rare edible mushroom, with the aim of evaluating its nutritional composition and biological activities. The results showed that the mushroom contains high levels of protein, bioactive polysaccharides, essential amino acids, minerals, and unsaturated fatty acids and is rich in phenolic compounds, flavonoids, carotenoids, and ergosterol. The extracted polysaccharides (PRG, PRG1-1) exhibited strong antioxidant, antibacterial, and anticancer activities, mainly through the induction of apoptosis and enhanced ROS production in cancer cells. Compared with many other edible mushrooms, *R. griseocarnosa* exhibits superior nutritional quality and greater potential for biological functionality. This review demonstrates that the mushroom has high value in the development of functional foods and natural medicines; however, its application remains limited due to the limited *in vivo* studies. Future research should focus on sustainable cultivation, polysaccharide standardization, and clinical trials to fully exploit the potential of this mushroom.

Keywords – antioxidant activity – anticancer activity – fatty acid – functional mushrooms

Introduction

Edible mushrooms have long been recognized as valuable functional foods due to their rich nutritional composition and diverse bioactive compounds. *Russula griseocarnosa* X. H. Wang, Zhu L. Yang & Knudsen is an ectomycorrhizal fungus widely distributed in tropical and subtropical forests in Asia, especially in southern China and Southeast Asia (Liu et al. 2024a). This mushroom is prized not only for its unique flavor and texture, but also for its potential health-promoting properties. The macromorphological characteristics of *R. griseocarnosa* are illustrated in Fig. 1, showing the red pileus, white to pinkish stipe, and crowded lamellae typical of the species. Recent studies have increasingly focused on the biochemical composition and pharmacological activity of the mushroom, highlighting its potential as a natural source of antioxidants and antimicrobials (Yang et al. 2025). The comparative species included in this review were chosen according to their economic relevance, frequency of citation in scientific literature, availability of standardized compositional data, and their established roles as functional foods, thereby ensuring consistency and reliability in cross-species evaluation.



Fig. 1 – Fruiting bodies of *Russula griseocarnosa*. Reprinted from Yu & Liang (2019), Data in Brief, licensed under CC BY 4.0.

The nutritional composition of *R. griseocarnosa* includes balanced amounts of protein, carbohydrates, fiber, and essential minerals, making it a promising dietary ingredient for human health (Anh et al. 2024). Furthermore, mushrooms contain a unique fatty acid profile rich in monounsaturated fatty acids, which play an important role in maintaining cardiovascular health and reducing stroke (Chen et al. 2010). The amino acid composition of the mushroom, including essential amino acids, contributes to its high biological value as a protein source.

In addition to its nutritional importance, *R. griseocarnosa* has been reported to exhibit various biological activities, such as antioxidant and antibacterial effects, which are closely related to its phenolic and flavonoid compounds (Yuan et al. 2017). These bioactivities suggest the potential application of *R. griseocarnosa* in the development of functional foods and natural preservative systems. However, comprehensive reviews combining its nutritional composition with its bioactive and pharmacological properties are still limited (Cheng et al. 2024). Therefore, this review aims to summarize and discuss the current knowledge on the proximate composition, mineral content, fatty acid and amino acid profile, as well as antioxidant and antibacterial activities of *R. griseocarnosa*, thereby providing a scientific basis for its use as a functional food ingredient and source of natural bioactive compounds.

Nutrition composition of *R. griseocarnosa*

The nutritional composition of mushrooms provides essential insight into their nutritional value and functions (Table 1). *Russula griseocarnosa* collected in Vietnam contained significant amounts of protein, carbohydrate, and fiber, comparable to many commercially grown species (Anh et al. 2024). On the other hand, the dried fruiting bodies of *R. griseocarnosa* from Mai Chau, China, were reported to contain 4.58–6.45% moisture (Chen et al. 2010), while other edible mushrooms such as *Pleurotus ostreatus* (8.45%), *Boletus aereus* (9.5–32.8%), and *Agaricus campestris* (9.8–10.8%) showed higher values (Manzi et al. 2004, Tolera & Abera 2017, Shbeeb et al. 2019). The low moisture of *R. griseocarnosa* indicates good storage stability after drying and low susceptibility to microbial degradation. Such low water activity is particularly advantageous for long-term storage and processing into functional food formulations in powder or extract form. Protein is the main nutritional component contributing to the dietary quality of mushrooms. The protein content of *R. griseocarnosa* ranged from 18.3–29.0 g/100 g DW in Vietnamese mushroom samples (Anh et al. 2024) and 19.11–32.31 g/100 g DW in Chinese mushroom samples (Chen et al. 2010). These levels are comparable to or even higher than the protein content of some common edible mushrooms, including *Boletus aereus* (17.6–25.5%) and *Pleurotus ostreatus* (25.91%), and close to the high values reported for *Agaricus campestris* (31–32%) (Shbeeb et al. 2019). Such high protein concentration suggests that *R. griseocarnosa* could be an excellent source of non-animal protein. Furthermore, its amino acid profile is characterized by high levels of essential amino acids such as lysine, leucine, and valine (Liu et al. 2018), which confers a high biological value to the protein content and reinforces its potential as a functional ingredient in vegetarian and healthy diets.

Table 1 Nutritional composition of dried fruiting bodies of *R. griseocarnosa* and other mushrooms (g/100 g dry weight, DW).

Composition	<i>R. griseocarnosa</i> (Vietnam) (Anh et al. 2024)	<i>R. griseocarnosa</i> (Meizhou, China) (Chen et al. 2010)	<i>Pleurotus</i> <i>ostreatus</i> (Tolera & Abera, 2017)	<i>Boletus</i> <i>aereus</i> (Manzi et al. 2004)	<i>Agaricus</i> <i>campestris</i> (Shbeeb et al. 2019)	<i>Lentinula</i> <i>edodes</i> (Mattila et al. 2002)	<i>Pleurotus</i> <i>sajor-caju</i> (Chirinang et al. 2009)
Moisture (%) *	NT	4.58–6.45	8.45	9.5–32.8	9.8–10.8	8.4	5.32
Protein	18.3–29.0	19.11–32.31	25.91	17.6–25.5	31.0–32.0	1.8	21.30
Fat	0.80–13.7	5.18–7.17	2.18	3.1–7.1	2.1–3	0.31	0.29
Ash	0.89–1.06	6.59–7.84	10.91	5.8–8.2	13.4–15.2	NT	7.95
Fiber	8.7–13.7	8.85–11.72	10.41	NT	10.0	3.3	42.50
Carbohydrate	57.4–68.4	48.10–63.00	42.14	61.6–69.4	40.8–43.2	5.8	65.14

Note: “NT” not tested, “*” Moisture is expressed as a % of the sample.

In terms of lipid content, *R. griseocarnosa* from Vietnam contained 0.80–13.7 g/100 g DW, while the Chinese sample exhibited 5.18–7.17 g/100 g DW (Chen et al. 2010, Anh et al. 2024). These values are higher than the values reported for *Lentinula edodes* (0.31%) (Mattila et al. 2002) and *Pleurotus sajor-caju* (0.29%) (Chirinang et al. 2009), but equivalent to *Boletus aereus* (3.1–7.1%) (Manzi et al. 2004). Although mushrooms are generally low in overall fat content, *R. griseocarnosa* contains a favorable proportion of unsaturated fatty acids, mainly linoleic, oleic, and palmitic acids (Liu et al. 2024a). These components have been linked to improved cardiovascular health and antioxidant capacity, highlighting the nutritional importance of this species (Militelu et al. 2024).

Ash content, an indicator of mineral composition, also varies significantly between species. *Russula griseocarnosa* from Vietnam showed low ash content (0.89–1.06 g/100 g DW), while samples from China showed higher ash content (6.59–7.84 g/100 g DW) (Chen et al. 2010, Anh et al. 2024). These results suggest that environmental factors, especially soil mineral composition and symbiotic relationship with mycorrhizal fungi, significantly influence mineral uptake. Compared with *Agaricus campestris* (13.4–15.2%) and *Pleurotus ostreatus* (10.91%), ash content in *R. griseocarnosa* occupies an intermediate position, but being an ectomycorrhizal species may enhance its ability to accumulate micronutrients such as iron (Fe), zinc (Zn), magnesium (Mg), and selenium (Se), contributing to its functional and health-promoting properties.

In terms of fiber content, both Vietnamese and Chinese *R. griseocarnosa* samples contained significant amounts of 8.7–13.7 g/100 g DW and 8.85–11.72 g/100 g DW, respectively (Chen et al. 2010, Anh et al. 2024). These values are similar to those reported for *Pleurotus ostreatus* (10.41%) (Tolera & Abera 2017) and *Boletus aereus* (10.0%) (Manzi et al. 2004), and showed that *R. griseocarnosa* is a good source of dietary fiber. Unlike *Pleurotus sajor-caju*, which is extremely high in fiber but mostly insoluble fiber (42.50%) (Chirinang et al. 2009), *Russula griseocarnosa* contains significant amounts of soluble polysaccharides, including β -glucan and chitin derivatives, which are associated with immunomodulatory and antioxidant activities (Liu et al. 2024a).

Carbohydrate content accounted for the majority of dry matter, ranging from 57.4–68.4 g/100 g DW in Vietnamese samples and 48.10–63.00 g/100 g DW in Chinese samples (Chen et al. 2010, Anh et al. 2024). These levels are comparable to or higher than those found in *Pleurotus sajor-caju* (65.14%) and *Boletus aereus* (61.6–69.4%). The high carbohydrate content reflects the abundance of bioactive polysaccharides such as β -glucan and mannogalactan, which contribute to the antioxidant and immunomodulatory effects of *R. griseocarnosa*. The balance between protein, carbohydrate, and fiber content also suggests its potential as a low-fat, nutrient-dense functional food source.

Overall, *R. griseocarnosa* exhibits a balanced nutritional profile, characterized by high protein, complex carbohydrate, and fiber content, along with low fat and moderate mineral content. Compared to widely consumed mushrooms such as *Pleurotus*, *Agaricus*, and *Lentinula*, *R. griseocarnosa* exhibits comparable or superior nutritional properties and provides a rich supply of bioactive metabolites, including phenolic compounds, flavonoids, and polysaccharides. These characteristics

emphasize its dual role as both a nutritious food and a potential functional ingredient for health-promoting applications.

Mineral composition of *R. griseocarnosa* mushroom

The mineral composition of *R. griseocarnosa* in Table 2 shows significant differences between geographical regions, especially when comparing samples collected in Vietnam (Anh et al. 2024) with those from Meizhou, China (Chen et al. 2010). The contents of macro and micro elements not only reflect the biological characteristics of the species but also depend on soil conditions, climate, and sample processing methods.

Table 2 Mineral composition of dried fruiting bodies of *R. griseocarnosa* and other mushrooms (mg/kg DW).

Composition	<i>R. griseocarnosa</i> (Vietnam) (Anh et al. 2024)	<i>R. griseocarnosa</i> (Meizhou, China) (Chen et al. 2010)	<i>Lentinula</i> <i>edodes</i> (Mallikarjuna et al. 2013)	<i>Paxillus</i> <i>involutus</i> (Mleczek et al. 2021a)	<i>Pleurotus</i> <i>ostreatus</i> (Roy et al. 2015)	<i>Armillaria</i> <i>mellea</i> (Mleczek et al. 2021b)
Ca	573.5–1530.1	850–3,690	1,749	74.7	17.8	58.3
Cu	31.0–41.7	34–48	14.8	35.4	280	4.31
Fe	143.2–836.5	500–954	148	125	21.9	350
K	19,835–24,965	16,800–19,800	13,020	33,800	4,250	24,600
Mg	350.4–636.0	380–570	407	518	77.4	485
Mn	6.91–17.6	22–23	10.0	179	190	19.2
Na	299.3–533.1	530–1,340	3,274	64.0	29	62.8
P	2,837.2–3,335.1	1,650–3,420	7,699	8,320	2,120	5,300
Zn	62.5–92.7	72–88	94.4	8.60	5.0	46.6

First of all, potassium (K) is the dominant element in all samples, with values ranging from 19,835–24,965 mg/kg DW in the Vietnamese sample and 16,800–19,800 mg/kg DW in the Chinese sample (Chen et al. 2010, Anh et al. 2024). This level is significantly higher than *L. edodes* (13,020 mg/kg DW; Mallikarjuna et al. 2013) and *P. ostreatus* (4,250 mg/kg DW; Roy et al. 2015), showed that *R. griseocarnosa* has a strong ability to accumulate K. Potassium plays an important role in maintaining ion balance, enzyme activity, and osmotic pressure stability. The K content increases the nutritional value of the mushroom. In terms of phosphorus (P), *R. griseocarnosa* in Vietnam contains 2,837–3,335 mg/kg DW, which is comparable to samples from China (1,650–3,420 mg/kg DW) (Chen et al. 2010, Anh et al. 2024). Although lower *P. involutus* (8,320 mg/kg DW; Mleczek et al. 2021a) and *L. edodes* (7,699 mg/kg DW; Mallikarjuna et al. 2013), it still represents an important natural source of P, which contributes to cell structure and ATP energy metabolism in the body (Jahan et al. 2025).

Calcium (Ca) content in Vietnamese samples (573.5–1,530.1 mg/kg DW) was also high, although lower than Chinese samples (850–3,690 mg/kg DW) (Chen et al. 2010, Anh et al. 2024). This level far exceeded that of *P. involutus* (74.7 mg/kg DW) and *P. ostreatus* (17.8 mg/kg DW), indicating the unique mineral accumulation ability of *R. griseocarnosa*. Calcium is an essential element for bone formation and the regulation of enzyme activity, so the high value enhances the potential use of this mushroom in mineral supplements.

For trace elements, iron (Fe) content ranged from 143.2–836.5 mg/kg DW in Vietnamese samples, compared to 500–954 mg/kg DW in Chinese samples (Chen et al. 2010, Anh et al. 2024). Both were much higher than other edible mushroom species, such as *P. ostreatus* (21.9 mg/kg DW) or *L. edodes* (148 mg/kg DW), suggesting that *R. griseocarnosa* is a potential source of Fe to help prevent anemia (Mallikarjuna et al. 2013, Roy et al. 2015, Kumar et al. 2022). Similarly, zinc (Zn) reached 62.5–92.7 mg/kg DW, which was similar to the Chinese sample (72–88 mg/kg DW) and similar to *L. edodes* (94.4 mg/kg DW), both of which were far superior to other mushroom species (Roy et al. 2015, Mleczek et al. 2021b). Zinc plays an important role in immunity and enzyme function, further confirming the functional value of mushrooms (Oyetayo et al. 2021).

The copper (Cu) content of Vietnamese mushrooms (31.0–41.7 mg/kg DW) is quite similar to the Chinese sample (34–48 mg/kg DW) and higher than most other common mushroom species (*L. edodes*: 14.8 mg/kg DW; *P. ostreatus*: 280 mg/kg DW) (Chen et al. 2010, Mallikarjuna et al. 2013, Roy et al. 2015, Anh et al. 2024). Meanwhile, manganese (Mn) in the Vietnamese sample (6.91–17.6 mg/kg DW) was lower than that in the Chinese sample (22–23 mg/kg DW) but still much higher than that in *L. edodes* (10.0 mg/kg DW).

Overall, *R. griseocarnosa* showed a strong ability to accumulate macronutrients (K, P, Mg, and Ca) and micronutrients (Fe, Zn, Cu, and Mn), which was superior to many common edible mushrooms. The differences between the Vietnamese and Chinese samples mainly stemmed from the growing conditions and soil characteristics, but overall, this species showed great potential in the field of functional foods and natural mineral supplements.

Fatty acid composition of *R. griseocarnosa*

The fatty acid composition of *R. griseocarnosa* showed a richness and balance between saturated (SFA) and unsaturated fatty acids (UFA), which play important roles in the nutritional value and biological functions of the mushroom. (Table 3). According to Chen et al. (2010), the major fatty acids identified in *R. griseocarnosa* included palmitic (C16:0), oleic (C18:1), linoleic (C18:2), linolenic (C18:3), palmitoleic (C16:1), and arachidonic (C20:4) acids.

Table 3 Fatty acid composition of *R. griseocarnosa* and other mushrooms (%).

Fatty acids	<i>R. griseocarnosa</i> (Chen et al. 2010)	<i>Polyporus squamosus</i> (Ergönül et al. 2013)	<i>Suillus bellini</i> (Ribeiro et al. 2009)	<i>Amanita caesarea</i> (Doğan & Akbaş 2013)	<i>Agaricus bisporus</i> (Das et al. 2023)	<i>Flammulina velutipes</i> (Saini et al. 2021)
C16:0	19.30–30.87	17.21	16.07	15	0.63	161.9
C16:1	0.42–0.90	0.65	1.61	0.63	0.41	118.7
C16:3	0.38–2.04	NT	NT	NT	NT	NT
C18:1	14.20–27.92	33.02	19.10	58	29.06	9.51
C18:2	28.40–50.22	38.91	12.46	19.02	40.33	822.0
C18:3	1.02–1.29	0.27	NT	0.06	0.42	0.00
C20:4	0.48–2.55	0.04	0.15	0.12	0.22	1.27

Note: “NT” not tested

Among them, linoleic acid (C18:2) accounted for the highest proportion, ranging from 28.40–50.22%, similar to or higher than many other mushroom species such as *Polyporus squamosus* (38.91%; Ergönül et al. 2013) and *Agaricus bisporus* (40.33%; Das et al. 2023). Linoleic acid is an essential unsaturated fatty acid (PUFA) that plays a role in lowering cholesterol and preventing cardiovascular disease, and is also a precursor of aromatic compounds, contributing to the characteristic flavor of mushrooms (Chen et al. 2010). Compared with *Suillus bellini* (12.46%; Ribeiro et al. 2009) and *Amanita caesarea* (19.02%; Doğan & Akbaş 2013), the high C18:2 ratio in *R. griseocarnosa* suggests superior biological potential and high nutritional value.

Oleic acid (C18:1) is the second most abundant monounsaturated fatty acid (MUFA) in *R. griseocarnosa*, with a content of 14.20–27.92%. Compared to *Agaricus bisporus* (29.06%) and *Amanita caesarea* (58%), this value is slightly lower but still demonstrates a balance between MUFA and PUFA — important for maintaining membrane flexibility and protecting lipids from oxidation (Doğan & Akbaş 2013).

Palmitic acid (C16:0) was the most abundant saturated fatty acid in the saturated fatty acid (SFA) group of *R. griseocarnosa*, with a value of 19.30–30.87%, equivalent to or higher than *Polyporus squamosus* (17.21%) and *Suillus bellini* (16.07%) (Ribeiro et al. 2009, Ergönül et al. 2013). Although palmitic acid is considered an SFA with little benefit to cardiovascular health in excess, in mushrooms, it plays an important role in maintaining membrane structure and supporting essential lipid synthesis (Galgowska et al. 2022).

Additionally, *R. griseocarnosa* contains small amounts of palmitoleic acid (C16:1) (0.42–0.90%) and linolenic acid (C18:3) (1.02–1.29%), indicating the presence of highly bioactive compounds. C18:3 is a precursor of eicosanoids and has anti-inflammatory properties, contributing to the health-protective properties of the mushroom (Chen et al. 2010). Notably, the presence of arachidonic acid (C20:4) (0.48–2.55%) — a long-chain PUFA — which is rare in many common edible mushrooms, suggests that *R. griseocarnosa* has special potential as a source of bioactive lipids (Saini et al. 2021).

Overall, *R. griseocarnosa* exhibits a predominant proportion of unsaturated fatty acids (over 60%), reflecting its beneficial nutritional properties and ability to support cardiovascular health. Compared with popular mushroom species, such as *Agaricus bisporus*, *Flammulina velutipes*, or *Pleurotus ostreatus*, the fatty acid composition of *R. griseocarnosa* is more balanced between SFA and UFA and is rich in highly bioactive PUFA. These characteristics confirm the potential application of *R. griseocarnosa* in the development of functional foods and natural pharmaceuticals.

Amino acid composition of *R. griseocarnosa*

The amino acid profile of *R. griseocarnosa* demonstrates high nutritional value, characterized by a rich content of essential and non-essential amino acids, which play important roles in protein structure and physiological processes (Table 4). According to Chen et al. (2010), *R. griseocarnosa* samples from Meizhou, China contained most of the essential amino acids with much higher total contents than many other common edible mushrooms.

Firstly, glutamic acid (Glu) was the predominant component, ranging from 27.14–36.83 mg/g FW, equivalent to *Lentinula edodes* (35.5 mg/g FW; Mattila et al. 2002) and higher than *Hydnum repandum* (11.1 mg/g FW; Bakir et al. 2018) as *Pleurotus ostreatus* (16.91–17.09 mg/g FW; Mendez et al. 2005). Glutamic acid is a non-essential amino acid that plays a role in creating the characteristic “umami” taste and is also involved in nitrogen metabolism and neurotransmission (Takahashi et al. 2011). The high Glu content suggests that *R. griseocarnosa* not only has nutritional value but also has the potential to create an attractive natural flavor.

Proline (Pro) also has a prominent content, reaching 16.81–32.31 mg/g FW, significantly higher than *L. edodes* (9.0 mg/g FW) and *Pleurotus sajor-caju* (3.3 mg/g FW; Chirinang et al. 2009). Proline contributes to protein structure stability and cell protection under oxidative stress conditions, which may be related to the antioxidant capacity noted in this mushroom (Liang et al. 2013).

Alanine (Ala) ranged from 8.60–14.86 mg/g FW, equivalent to or higher than many species such as *L. edodes* (10.4 mg/g FW) and *H. repandum* (7.2 mg/g FW), but lower than *Boletinus pinetorus* (62.01 mg/g FW; Sun et al. 2017). Alanine is an amino acid that creates a mild sweetness, contributes to improving the sensory properties of mushrooms, and participates in glucose metabolism (Jiang et al. 2023).

Notably, *R. griseocarnosa* contained Valine (Val) at high levels of 27.14–28.67 mg/g FW, higher than most of the comparison species, including *L. edodes* (12.4 mg/g FW), *B. pinetorus* (18.13 mg/g FW), and *P. ostreatus* (3.49–3.58 mg/g FW). Valine is an essential branched-chain amino acid (BCAA), which plays an important role in muscle protein synthesis and cellular energy (Dimou et al. 2022).

In addition, aspartic acid (Asp) in *R. griseocarnosa* reached 14.52–23.59 mg/g FW, significantly higher than that in *L. edodes* (1.9 mg/g FW) and *P. ostreatus* (6.80–6.98 mg/g FW), contributing to a strong “umami” taste similar to glutamate (Mattila et al. 2002, Mendez et al. 2005, Chen et al. 2010). Other biologically active amino acids, such as arginine (Arg) (8.60–15.83 mg/g FW) and threonine (Thr) (8.79–14.22 mg/g FW), were also found in higher concentrations than in many other mushroom species, reflecting the good quality protein value and amino acid balance (Jiang et al. 2016).

Notably, *R. griseocarnosa* contained high levels of cysteine + methionine (Cys + Met) (9.69–11.47 mg/g FW), which was twice as high as that of *L. edodes* (5.3 mg/g FW) and superior to other mushroom species in the Table 4 (Mattila et al. 2002, Chen et al. 2010). The aromatic amino acid group (tyrosine + phenylalanine) was also present significantly with values of 15.48–21.32 mg/g FW,

although lower than *L. edodes* (35.4 mg/g FW; Mattila et al. 2002), but similar to *B. pinetorus* (21.92 mg/g FW) (Sun et al. 2017).

Overall, the amino acid profile of *R. griseocarnosa* shows a balance between essential (Val, Leu, Ile, Thr, Met, and Phe) and non-essential (Glu, Asp, Ala, Pro, and Gly) amino acids. Compared with common edible mushrooms, *R. griseocarnosa* exhibits higher levels of most of the key amino acids, especially Glu, Val, Pro, and Cys + Met. This confirms that *R. griseocarnosa* is not only a valuable source of plant protein but also has the potential to be used in nutritionally fortified products or functional foods with high biological value.

Table 4 Amino acid composition of *R. griseocarnosa* and other mushrooms (mg/g fresh weight, FW).

Amino acid	<i>R. griseocarnosa</i> (Chen et al. 2010)	<i>L. edodes</i> (Mattila et al. 2002)	<i>Boletinus pinetorus</i> (Sun et al. 2017)	<i>Pleurotus sajor-caju</i> (Chirinang et al. 2009)	<i>Hydnum repandum</i> (Bakir et al. 2018)	<i>Pleurotus ostreatus</i> (Mendez et al. 2005)
Glutamic acid	27.14–36.83*	35.5	18.97	42.2	11.1	16.91–17.09
Proline	16.81–32.31	9.0	13.52	3.3	5.3	2.86–3.57
Alanine	8.60–14.86	10.4	62.01	18.0	7.2	3.33–3.99
Glycine	8.79–14.86	9.1	8.02	9.6	3.5	3.83–5.43
Arginine	8.60–15.83	12.7	16.82	25.2	6.2	NT
Aspartic acid	14.52–23.59	1.9	16.96	20.1	8.1	6.80–6.98
Serine	7.45–11.63	10.3	21.53	9.9	4.5	3.60–4.68
Histidine	5.73–7.75	5.6	10.23	5.2	2.2	4.25–6.28
Cysteine + Methionine	9.69–11.47	5.3	54.45	3.4	2.2	NT
Isoleucine	7.26–12.28	7.9	NT	7.5	3.9	3.14–3.68
Threonine	8.79–14.22	9.8	11.91	9.8	4.4	NT
Leucine	10.13–17.77	13.3	2.54	13.0	7.1	4.78–4.99
Tyrosine	15.48–21.32	35.4	21.92	15.3	9.7	NT
+Phenylalanine						
Valine	27.14–28.67	12.4	18.13	9.8	7.7	3.49–3.58

Note: “NT” not tested, “*” Values are converted from mg/g protein to mg/g sample

Extraction and purification of polysaccharides from *R. griseocarnosa*

Besides its high nutritional value, *R. griseocarnosa* is also rich in various bioactive compounds that contribute to its pharmacological properties. Previous studies have demonstrated the presence of phenols, flavonoids, ascorbic acid, ergosterol, and carotenoids in its extracts (Chen et al. 2010), and show strong antioxidant and health-promoting potential. These compounds are known for their ability to scavenge free radicals, protect cellular components from oxidative damage, and enhance immune mechanisms.

Recent studies have focused on the extraction and purification of polysaccharides from the fruiting bodies or spores of *R. griseocarnosa* using hot water methods combined with ethanol precipitation. According to Liu et al. (2024b), the dried *R. griseocarnosa* samples collected in Yunnan Province (China) were ground and extracted twice with distilled water (1:30, w/v) at 80 °C for 3 h. The resulting extract was then deproteinized by the Sevag method, dialyzed, and precipitated with 80% ethanol to obtain the crude polysaccharide fraction (RGP).

This procedure is efficient and environmentally friendly, using water-ethanol solvent instead of toxic chemicals. However, the use of high temperature (80 °C) may alter some thermosensitive polysaccharide structures or cause partial loss of biological activity. Therefore, this study mainly aimed at recovering medium molecular weight and water-soluble polysaccharides, suitable for functional food or pharmaceutical applications.

Similarly, Yuan et al. (2017) improved the polysaccharide extraction process from *R. griseocarnosa* spore coat by pretreating the sample with petroleum ether and 95% ethanol, which helps to remove lipids, pigments, and small molecular impurities. Then, the sample was extracted

with water, precipitated with absolute ethanol, washed with acetone, and dried. This method helps to improve the purity of polysaccharides, limiting the influence of residual phenolic compounds or proteins. Compared with Liu et al. (2024b), the procedure of Yuan et al. (2017) has a more thorough pretreatment step, suitable for more detailed structural and biological activity studies.

Structural features and immunoregulatory activity

In further research, Liu et al. (2024a) isolated and purified a highly active polysaccharide fraction, designated RGP2, from the fruiting body of *R. griseocarnosa*. The results showed that RGP2 has a molecular weight of 11.82 kDa, consisting of the main monosaccharides: glucose, galactose, mannose, glucuronic acid, and glucosamine. The characteristic linkage structure of RGP2 consists of $\rightarrow 6)$ - β -D-Glcp-(1 $\rightarrow$, $\rightarrow 3)$ - β -D-Glcp-(1 $\rightarrow$ and $\rightarrow 6)$ - α -D-Galp-(1 $\rightarrow$), with a β -D-Glcp-(1 $\rightarrow$) branch at the O-3 position of $\rightarrow 6)$ - β -D-Glcp-(1 $\rightarrow$).

This suggests that RGP2 is a branched heteropolysaccharide, with a heterogeneous structure — a feature often associated with potent biological activity, especially in immunomodulation. Indeed, experiments in mice immunosuppressed by cyclophosphamide (CTX) showed that RGP2 has a significant immunostimulatory effect, as demonstrated by enhanced macrophage activity and improved serum immunoglobulin index (Liu et al. 2024a).

Structural analysis revealed that the β -glucan linkage (β -D-Glcp) plays an important role in the activation of the innate immune system, similar to the polysaccharides found in *Ganoderma lucidum* or *L. edodes* (Han et al. 2020). Therefore, RGP2 has the potential to be applied as a natural immune enhancer in functional foods or biopharmaceuticals.

These findings indicate that *R. griseocarnosa* contains primary and secondary metabolites, including polysaccharides, phenolics, and terpenoid-related compounds, which may act synergistically to produce the observed antioxidant, antibacterial, and immune-enhancing effects. Based on these constituent studies, further studies focused on optimizing the extraction process and elucidating the structural features of each polysaccharide fraction to better understand their biological mechanisms.

Antioxidant activity of *R. griseocarnosa*

Russula griseocarnosa is recognized as one of the mushrooms with strong antioxidant activity due to its high content of natural biological compounds, such as phenolics, flavonoids, ascorbic acid, ergosterol, and carotenoids (Chen et al. 2010). These compounds play a central role in neutralizing free radicals, preventing lipid oxidation, and protecting cells from oxidative stress (Table 5).

According to Dong et al. (2012), the fruiting bodies (sporocarps) of *R. griseocarnosa* collected from Changchun, China, showed very high free radical scavenging ability — with levels of 75% for DPPH (2,2-diphenyl-1-picrylhydrazyl) assay at a concentration of 6 mg/mL. At the same time, this sample also exhibited strong scavenging activity against hydroxyl radicals, demonstrating its ability to protect cells against strong oxidants (Table 5). Yuan et al. (2017) reported that the polysaccharide PRG extracted from *R. griseocarnosa* yielded 5.42% under optimal conditions (77.3 °C, 4 h, liquid/solid ratio 42.5 g/L). This fraction exhibited strong antioxidant activity similar to the total extract, suggesting that the polysaccharide also contributed significantly to the free radical neutralization ability of the mushroom. In a similar study (Anh et al. 2024), *R. griseocarnosa* in Vietnam recorded significant antioxidant activity with reducing power reaching 2.05–2.60 mg/mL, DPPH activity ranging from 11.65–13.88 mg/mL, hydroxyl radical scavenging 7.13–11.80 mg/mL, and ferrous ion chelating ability reaching 2.33–5.99 mg/mL. Compared with *Pleurotus sajor-caju* (DPPH: 13.38–58.44 mg/mL; Chirinang et al. 2009) and *Hydnum repandum* (13.98 mg/mL; Mendez et al. 2005), *R. griseocarnosa* showed comparable or greater free radical scavenging efficacy at lower concentrations, demonstrating remarkable antioxidant activity. The simultaneous presence of phenolic compounds, flavonoids, polysaccharides, and ergosterol groups can create a synergistic effect, significantly enhancing the total antioxidant capacity of the mushroom. Compared to other highly active mushroom species, such as *Amanita caesarea* with $IC_{50} = 0.7615$ mg/mL (Doğan &

Akbaş 2013), the antioxidant activity of *R. griseocarnosa* is lower due to differences in dominant compounds and mechanisms of action.

In conclusion, *R. griseocarnosa* showed strong antioxidant activity through multi-mechanisms, including free radical scavenging (DPPH, ABTS, hydroxyl), iron reduction, and endogenous antioxidant enzyme enhancement. The combination of polyphenols, polysaccharides, and carotenoids makes this mushroom a potential natural source for the development of functional foods, anti-aging pharmaceuticals, and health promoting applications.

Table 5 Antioxidant activity of *R. griseocarnosa* and other mushrooms (mg/mL).

	<i>R. griseocarnosa</i> (Anh et al. 2024)	<i>Pleurotus sajor-caju</i> (Chirinang et al. 2009)	<i>Hydnum repandum</i> (Mendez et al. 2005)
Reducing power	2.05–2.60	NT	NT
DPPH	11.65–13.88	13.38–58.44	13.98
Hydroxyl free radicals	7.13–11.80	NT	NT
Ferrous ions	2.33–5.99	1.07–2.09	NT

Note: “NT” not tested

Anticancer activity of *R. griseocarnosa*

Polysaccharides isolated from *R. griseocarnosa*, including PRG and its purified fraction PRG1-1, have demonstrated antiproliferative activity against cervical cancer cell lines. Yuan et al. (2017) reported that PRG exhibited IC₅₀ values of 156 µg/mL for HeLa cells and 186 µg/mL for SiHa cells, indicating moderate cytotoxic effects compared with conventional chemotherapeutic agents such as cisplatin, while showing lower toxicity toward normal cells. Similarly, Liu et al. (2018) found that PRG1-1 inhibited the proliferation of HeLa and SiHa cells with IC₅₀ values of 190.4 µg/mL and 213.7 µg/mL, respectively. Mechanistic investigations revealed that PRG1-1 induces apoptosis via the mitochondrial pathway, characterized by increased intracellular reactive oxygen species (ROS) generation, cytochrome c release, caspase-3 activation, and enhanced cleaved PARP expression. These findings suggest that polysaccharides from *R. griseocarnosa* exert measurable anticancer effects through apoptosis-related mechanisms and warrant further investigation as potential natural anticancer agents.

Potential and challenges of *R. griseocarnosa*

Russula griseocarnosa shows great potential in the field of functional foods and medicinal preparations due to its rich nutritional profile, high protein content, bioactive polysaccharides, diverse amino acids, essential minerals, and unsaturated fatty acids. Numerous studies have demonstrated that the mushroom possesses strong antioxidant, antibacterial, and anticancer activities via apoptosis-related pathways, and contains valuable bioactive compounds, such as phenolics, flavonoids, carotenoids, ergosterol, and polysaccharides (Chen et al. 2010, Yuan et al. 2017, Liu et al. 2018). These findings highlight promising opportunities to develop *R. griseocarnosa* as a raw material for functional foods, dietary supplements, anti-aging formulations, and natural anticancer agents.

Despite its significant biological potential, *R. griseocarnosa* faces substantial challenges that hinder its broader application and commercialization. One major limitation is its strict seasonality. The mushroom is typically harvested only during the rainy season and is highly sensitive to environmental fluctuations, resulting in inconsistent annual yields (Guo & Xu 2025). Additionally, *R. griseocarnosa* predominantly grows in remote mountainous forests under specific ecological conditions (Liu et al. 2024a). Harvesting requires manual collection on steep terrain, leading to high labor costs and elevated market prices, often making the mushroom less accessible to consumers. To date, there are no reliable cultivation techniques for producing *R. griseocarnosa* on farms or in household settings, so supply depends entirely on wild foraging, which further limits availability and standardization.

Post-harvest handling also presents major challenges. Like many wild mushrooms, *R. griseocarnosa* has a high moisture content, fragile texture, and rapid enzymatic degradation,

resulting in poor shelf life (Guo et al. 2023). It is rarely consumed fresh and is typically dried immediately after harvest to avoid spoilage and maintain its bioactive compounds. However, drying conditions have not been standardized, potentially leading to the loss of thermolabile components such as phenolics and certain polysaccharides. Advanced preservation strategies—including freeze-drying, controlled hot-air drying, or the use of nano-enabled active packaging—have been proposed but remain largely unexplored (Uwineza & Zhang 2026). Optimizing these technologies will be essential to retain nutritional quality and stabilize bioactive compounds during storage and transport.

From a scientific perspective, several research gaps persist. Current studies mainly focus on basic chemical composition and *in vitro* biological activities (Anh et al. 2024), with little to no research on developing functional food products, nutraceuticals, beverages, or herbal preparations from this mushroom. Standardization of extraction methods, quality control parameters, and active ingredient quantification is still lacking. Furthermore, nearly all biological activity studies are limited to *in vitro* experiments, without *in vivo* evaluations, toxicity assessments, pharmacokinetic studies, or clinical investigations to confirm efficacy and safety in human applications. Additionally, the absence of cultivated samples restricts the ability to compare batch-to-batch consistency or perform large-scale industrial studies.

In summary, while *R. griseocarnosa* holds remarkable nutritional and pharmacological potential, significant challenges remain in terms of sustainable supply, high harvesting costs, limited preservation techniques, and insufficient applied research. Addressing these gaps — particularly in cultivation technology, processing optimization, product development, and clinical validation — will be essential to unlock the full value of this rare and highly prized mushroom.

Conclusions

Russula griseocarnosa exhibits great potential in terms of nutritional value and bioactivity, including high protein, diverse minerals, essential amino acids, unsaturated fatty acids, and bioactive polysaccharides. Current studies have demonstrated the antioxidant, antibacterial, and anticancer properties of the mushroom. Compared with many other edible mushrooms, *R. griseocarnosa* stands out in terms of its quality and bioactive compounds content. However, its application in functional foods or pharmaceutical products remains limited due to the lack of *in vivo* validation, insufficient toxicological and safety data, the absence of standardized extraction protocols, and the lack of stable cultivation systems. The available evidence suggests that *R. griseocarnosa* holds promise as a natural source of nutraceutical ingredients, particularly for antioxidant and adjunct anticancer applications. To facilitate its practical utilization, future research should emphasize comprehensive *in vivo* studies to confirm biological efficacy, detailed safety and bioavailability evaluations, and systematic characterization and standardization of its bioactive polysaccharides. In addition, developing reliable and controlled cultivation techniques will be essential to ensure sustainable production, quality consistency, and large-scale application. Strengthening these research directions will help bridge the gap between experimental findings and real-world health and nutritional applications.

Acknowledgements

The authors extend their appreciation to all colleagues who supported this work.

Conflict of Interest

The authors declare that they have no conflict of interest

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