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Potato Peel Waste as a Candidate Substrate for Streptomyces Fermentation Toward Antifungal Antibiotic Production: A Review of Evidence, Constraints and a Research Framework

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ABSTRACT

Potato processing generates peel equal to roughly 15–40% of tuber mass, and this moist, starch-containing residue is mostly diverted to animal feed, fertiliser or biogas. Streptomyces species are leading bacterial producers of antibiotics, and low-cost agro-industrial residues are increasingly tested as fermentation media. Objective. To appraise whether potato peel waste (PPW) can support the production of antifungal metabolites by Streptomyces, and to define the evidence still needed to show this. Narrative review on peel composition and pretreatment, Streptomyces fermentation optimisation and waste-derived media. Values were extracted as printed, and second-hand data were flagged. Sources were gathered without a systematic search, and each claim is labelled as direct evidence on peel, evidence on whole tubers or other substrates, or hypothesis. Findings. PPW composition is highly variable (starch 44.9–52% and ash 7.7–14.6%, reported on differing bases; glycoalkaloids 6.7–3,580 µg/g dry weight), and drying, pesticide residues and endogenous phenolics and glycoalkaloids shape its suitability. The only directly relevant study identified used discarded whole potatoes rather than peel, and transfer of its result to peel remains a hypothesis. In that study, Streptomyces sp. SO6 formed diffusible antifungal metabolites (0.96 mg/g) and pigments (1.75 mg/g) in submerged culture on 16 g/L potato powder, with an extract inhibiting Botrytis cinerea (19 mm at 100 µg/disc); pigment yield was a separate readout, and the active compounds were not identified. Optimisation studies on other media associate antifungal output with starch or other slowly assimilated carbon, low nitrate, initial pH 6.5–8.7, 25–30 °C, 3–9 days and dissolved oxygen above 20% saturation. No reviewed study reports antifungal production on peel itself with statistical optimisation, matrix-controlled bioassays and compound identification. PPW is a plausible but unproven substrate for antifungal production. A five-stage framework is proposed: standardise and decontaminate the peel, compare raw and hydrolysed forms, optimise by response surface design, include uninoculated-peel controls in bioassays, and report yields per kilogram of dry peel.

KEYWORDS: potato peel waste; Streptomyces; antifungal antibiotics; antifungal metabolites; submerged fermentation; response surface methodology; agro-industrial waste valorization

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1. Introduction

Potato (*Solanum tuberosum* L.) is the fourth most important food crop after wheat, rice and maize, and annual production now exceeds 370 million tonnes (Ijaz et al., 2024; Sandeep et al., 2024). Demand for

frozen fries, chips and dehydrated products has shifted consumption toward processed forms, and processing removes peel (potato peel waste, PPW) and rejected tubers in large quantities (Ijaz et al., 2024; Yuksel & Durmaz, 2022). Peel losses of 15–40% of tuber mass is widely quoted and depend on the peeling method (Jimenez-Champi et al., 2023; Nguyen et al., 2024; Sandeep et al., 2024). One review instead gives peel as 3–5% of potato weight and total processing removals as 20–50% (Yuksel & Durmaz, 2022). These figures describe different quantities and should not be used interchangeably. Because peel is moist and carbohydrate-rich, it spoils quickly and creates disposal and pollution problems (Chauhan et al., 2023; Yuksel & Durmaz, 2022).

Peel has traditionally been used for low-value animal feed, fertiliser and biogas, which wastes its nutrients and bioactive compounds (Ijaz et al., 2024; Jimenez-Champi et al., 2023; Sandeep et al., 2024). Reviews describe higher-value routes, including dietary fibre and bakery enrichment, natural antioxidants, edible films, enzymes, bioethanol, lactic acid, biohydrogen and protein or peptide recovery (Arik Kibar et al., 2025; Chauhan et al., 2023; Gaudino et al., 2020; C. Zhang et al., 2026). Most of this work uses chemical extraction or food formulation. Microbial bioconversion of peel into antimicrobial products has received much less attention.

The genus *Streptomyces* is the most prolific source of microbial antibiotics. Estimates put its share of actinobacterial bioactive products between roughly 75% and more than 80% (Almalki, 2020; Yang et al., 2024), and its antifungal products include polyenes such as nystatin and amphotericin (Alam et al., 2022). Production depends strongly on medium composition and culture conditions, so industrial processes often rely on refined carbon and nitrogen sources, which raise costs (Djinni et al., 2023; Schalchli et al., 2021). Starch-rich agro-industrial residues could lower these costs, and peel contains starch, protein, minerals and fibre (Ijaz et al., 2024; Mushtaq et al., 2024).

Two observations motivate this review. First, a body of work shows that *Streptomyces* can be grown and its antimicrobial output tuned in defined or waste-derived media (Djinni et al., 2023; Nazari et al., 2025; Shams et al., 2025). Second, at least one study reports that a *Streptomyces* strain formed antifungal metabolites on a potato-derived powder without added nutrients (Schalchli et al., 2021). That study used discarded whole tubers rather than peel. Peel differs from whole-tuber powder in ash and fibre (Table 2) and is reported to concentrate phenolics and glycoalkaloids (Jimenez-Champi et al., 2023), so whether the result transfers to peel is a hypothesis. The question matters in settings such as Ethiopia where processing waste is expanding but use of waste streams is limited.

This review addresses three questions. (i) What do available sources show about the composition, handling and safety of PPW as a fermentation feedstock? (ii) What evidence exists for *Streptomyces* growth and antifungal metabolite formation on potato-derived and other waste substrates, and which process variables matter? (iii) Which gaps must be closed before antifungal production on PPW can be claimed, and what experimental programme would close them?

2. Scope, Sources and Approach

This is a narrative review assembled during development of a research proposal. It rests on 27 sources published between 2020 and 2026 (Table 1). They comprise reviews of potato peel and potato waste valorisation, experimental studies of peel characterisation and pretreatment, studies of *Streptomyces* fermentation and optimisation, and reviews of agro-industrial substrates and solid-state fermentation. Each source was read in full, and numerical values are reported as printed. Where a source quotes another study, the value is described as second-hand and, whenever possible, attributed accordingly.

Source selection. Sources were identified through topic-based searches of [databases or search engines to be named by the author] using terms such as “potato peel”, “Streptomyces” and “antifungal”, and by following citations from key papers. A source was retained when it bore directly on one of the three review questions: peel composition, handling, contaminants and bioactivity; *Streptomyces* growth or antifungal output on potato-derived or other waste substrates; or the process variables and optimisation methods used in *Streptomyces* fermentation. Sources judged unrelated to these questions were set aside. Retention was decided by the author against these questions without independent screening, so selection bias is possible, particularly toward sources that supported the original proposal and against unpublished or negative results.

No systematic database search, duplicate screening or risk-of-bias scoring was performed. The review therefore does not claim to be exhaustive, and its conclusions are limited to the evidence base examined. A statement that no study reports a given result means that none was found among these 27 sources, not

that none exists.

Terminology and evidence labels. Where the text uses the term peel or potato peel waste (PPW) it refers to the outer tissue removed during peeling; where it uses potato waste or discarded potato it refers to whole tubers rejected for size or damage, as in the Chilean studies discussed in Section 5. “Antifungal antibiotic production” denotes the formation of antifungal secondary metabolites by *Streptomyces*, and “antifungal metabolites” is used where the active compounds have not been identified. To keep demonstration separate from inference, claims are labelled by evidence type: *direct peel evidence* (data measured on peel), *whole-tuber evidence* (data on discarded whole potato), *other-substrate evidence* (data on other waste or defined media) and *hypothesis* (an extension of any of these to peel or to a new setting that the reviewed sources did not test). Direct peel evidence in this set covers composition, drying, pretreatment, contaminant removal and the antibacterial activity of peel extracts; none of it concerns *Streptomyces* fermentation of peel.

Table 1. Evidence base used in this review, grouped by role.

Group	Sources	Main contribution
Potato peel and potato waste reviews	Ijaz et al. (2024); Jimenez-Champi et al. (2023); Yuksel and Durmaz (2022); Sandeep et al. (2024); Chauhan et al. (2023); Gaudino et al. (2020); Arik Kibar et al. (2025); C. Zhang et al. (2026); Hidayat et al. (2024)	Composition, valorisation routes, bioactives, glycoalkaloids, safety; summary of in vitro bioactivity
Peel characterisation and pretreatment	Tripathi et al. (2025); Batista et al. (2026); Mushtaq et al. (2024); Nguyen et al. (2024); Gebrechristos et al. (2020)	Drying effects; proximate composition; acid and steam hydrolysis; pesticide removal; antimicrobial activity of peel extract
Streptomyces on potato-derived substrates	Schalchli et al. (2021); Astudillo et al. (2024)	Antifungal and pigment formation on discarded potato powder
Streptomyces fermentation and optimisation	Yang et al. (2024); Yang et al. (2025); M. Zhang et al. (2026); Shams et al. (2025); Djinni et al. (2023); Almalki (2020); Nazari et al. (2025); Alam et al. (2022)	Media, pH, temperature, aeration, time, statistical designs, waste-derived media, secondary-metabolite biology
Substrate and process context	Astudillo et al. (2023); Mattedi et al. (2023); Lyu et al. (2022)	Agro-industrial waste as fermentation substrate; solid-state fermentation and scale-up; natural pigment production

Note: two 2026 papers have a first author named Zhang. They are cited as C. C. Zhang et al. (2026), a review of potato peel utilisation, and M. Zhang et al. (2026), a study of *Streptomyces rochei* W71.

3. Potato Peel Waste as a Fermentation Feedstock

3.1 Composition and its variability

Peel is mainly carbohydrate, with smaller amounts of protein, lipid and ash and a fibre fraction that differs strongly among studies (Table 2). Starch is reported at 44.85% in dried peel flour (Batista et al., 2026) and at about 52% of dry material in a review (Gaudino et al., 2020), and total carbohydrate at 65.01% in dried peel (Mushtaq et al., 2024). Protein ranges from 11.70% to 15.45% in these two peel studies, but only 0.83–0.99% in a third that used the same nitrogen conversion factor (Tripathi et al., 2025). Ash ranges from 7.7% to 14.6%. These differences arise from cultivar, geography and peeling method (Ijaz et al., 2024; Jimenez-Champi et al., 2023), but they also reflect inconsistent reporting. Fresh-weight values (moisture 61.9–85.1 g/100 g) cannot be compared with dry-weight values, and some reviews mix both without stating the basis. Table 2 therefore codes each value by source type and reporting basis, and values with different codes should not be compared directly.

Table 2. Reported composition of potato peel and, for comparison, discarded whole potato (values as printed in each source; source type and reporting basis are coded in each cell).

Parameter	Peel (dried flour or powder)	Other peel reports	Discarded whole potato powder
Moisture (%)	7.49 (Batista et al., 2026; P, PF); 10.29 (Mushtaq et al., 2024; P, PF); 4.3–4.5 (Tripathi et al., 2025; P, PF)	Fresh peel 61.9–85.1 g/100 g (Jimenez-Champi et al., 2023; R, FW)	7.8 (Astudillo et al., 2024; Schalchli et al., 2021; P, PF)
Starch	44.85% (Batista et al., 2026; P, PF)	~52% of dry material (Gaudino et al., 2020; R, DW); 7.80 g/100 g (Ijaz et al., 2024, citing Javed; R, NS)	60–71% of dry basis (Astudillo et al., 2024; P, DW)
Total carbohydrate	65.01% (Mushtaq et al., 2024; P, PF); 52.9–54.8% by difference (Tripathi et al., 2025; P, PF)	68.75% dry weight (Ijaz et al., 2024; R, DW)	N-free extract 73.7% (Schalchli et al., 2021; P, PF)
Reducing sugars	—	0.6% of dry material (Gaudino et al., 2020; R, DW)	—
Protein (N × 6.25)	11.70 (Batista et al., 2026; P, PF); 15.45 (Mushtaq et al., 2024; P, PF); 0.83–0.99 (Tripathi et al., 2025; P, PF)	8.0% dry weight (Ijaz et al., 2024; R, DW)	7.9 (Schalchli et al., 2021; P, PF)
Lipid (%)	1.27 (Batista et al., 2026; P, PF); 0.44 (Mushtaq et al., 2024; P, PF); 1.81–2.42 (Tripathi et al., 2025; P, PF)	2.65 (Ijaz et al., 2024; R, NS)	6.2 (Schalchli et al., 2021; P, PF)
Ash (%)	7.73 (Batista et al., 2026; P, PF); 8.81 (Mushtaq et al., 2024; P, PF); 13.8–14.6 (Tripathi et al., 2025; P, PF)	6.35 (Ijaz et al., 2024; R, NS)	3.9 (Schalchli et al., 2021; P, PF)
Fibre	Crude fibre 4.4 (Mushtaq et al., 2024; P, PF); 15.3–15.7 (Tripathi et al., 2025; P, PF)	Dietary fibre ~16.7% (Arik Kibar et al., 2025, citing Sampaio; R, NS)	Crude fibre 0.4 (Schalchli et al., 2021; P, PF)
Glycoalkaloids	—	6.7–3,580 µg/g dry weight (Jimenez-Champi et al., 2023; R, DW); 84–3,526 ppm (Arik Kibar et al., 2025, citing Joshi; R, NS)	Not reported
C/N ratio	—	~10.7 (Ijaz et al., 2024, citing Daimary; R, NS)	—

Source type: P, measured in the cited paper; R, reported in a review article (second-hand; "citing" names the origin given by the review). Basis: DW, stated as dry weight or dry matter; FW, fresh weight; PF, dried powder or flour as analysed (its moisture content is in the Moisture row, and recalculation to a moisture-free basis is not stated); NS, basis not stated. Values with different codes are not directly comparable, and the peel and whole-potato columns come from different studies.

For fermentation, the practical conclusion is that no single composition can be assumed. Starch, nitrogen and mineral content must be measured on the lot being used. The C/N ratio of about 10.7 reported for peel (Ijaz et al., 2024) suggests moderate organic nitrogen, but this value is second-hand. The whole-potato powder used in the Streptomyces studies discussed below has higher starch, lower ash and much lower fibre than peel in Table 2, although the bases differ, and it may therefore be a more favourable substrate than peel (a hypothesis; no direct comparison was found in the sources reviewed).

3.2 Drying, storage and handling

Fresh peel is highly perishable. High moisture promotes microbial spoilage, so rapid disposal or drying is recommended (Yuksel & Durmaz, 2022), and starch declines in open storage through spontaneous fermentation (Sandeep et al., 2024). Drying conditions then shape the substrate. In red potato peel, tray drying at 45 °C for 16 h gave a water activity of 0.646, whereas vacuum-oven drying at 70 °C for 13 h gave 0.480. Proximate composition, particle microstructure, colour and phenolic content also differed between the two methods (Tripathi et al., 2025). Drying temperature, time and particle size therefore need to be fixed and reported in any fermentation study. Sterilisation adds a second thermal step, and its effect on peel phenolics and sugars has not been characterised in the sources reviewed.

Drying also has an economic dimension. Reducing the moisture content of peel lowers industrial handling cost (Sandeep et al., 2024), but drying consumes energy, and continuous supply at industrial scale remains a stated challenge for peel use (Sandeep et al., 2024). The alternative is to use fresh or wet peel directly, which avoids drying but requires rapid processing, because peel at high water activity is overgrown by wild microbes that deplete soluble carbohydrate (Yuksel & Durmaz, 2022). The trade-off between drying cost and sterile, stable feedstock should be quantified rather than assumed in any process assessment.

3.3 Conversion of starch to fermentable sugars

Starch is the main fermentable fraction, but peel contains little free sugar. Reducing sugars are only about 0.6% of dry material even though starch is about 52% (Gaudino et al., 2020). Bioethanol work therefore uses liquefaction with α-amylase at high temperature followed by saccharification with glucoamylase (Ijaz et al., 2024). Mushtaq et al. (2024) optimised dilute sulphuric acid and steam pretreatment by response surface methodology. With 5% substrate, 0.8% acid and a 6 h residence time, acid-plus-steam treatment released 720.00 mg/g total sugars and 660.62 mg/g reducing sugars from the dried peel, whereas chemical treatment alone released 188.00 and 144.42 mg/g and also released 43.68 mg/g phenolics. Many *Streptomyces* strains secrete amylases, as shown for the strains in Schalchli et al. (2021), so direct use of raw or lightly gelatinised starch may be possible; this is a hypothesis for peel, because amylase activity was shown only on whole-tuber powder. Whether pretreated hydrolysate supports *Streptomyces* growth and metabolite formation has not been tested in the sources reviewed, and a comparison of raw and hydrolysed peel would be a central design question.

3.4 Contaminants and intrinsic bioactivity

Three groups of compounds in peel can confound fermentation work or affect product safety.

Pesticide residues. Residues concentrate in outer tissues (Nguyen et al., 2024). In spiked russet peel, ultrasound (24 kHz, 592 W/L, up to 5 min) reduced Captan and Spirotetramat to non-detectable levels and Azoxystrobin to 7.9% retention, whereas the more lipophilic Chlorpropham and Propiconazole were retained at about 65–70%. Pulsed electric field achieved up to 80% reduction for the hydrophilic compounds and liquid nitrogen immersion about 20%. Removal tracked the octanol–water partition coefficient. Ultrasound retained most phenolics, but pulsed electric field retained only about 54–56% and damaged the tissue (Nguyen et al., 2024). The results come from spiked samples of one cultivar at laboratory scale, but they show that a simple pretreatment can lower residues before fermentation.

Glycoalkaloids. α-Solanine and α-chaconine occur at highly variable levels in peel (Arik Kibar et al., 2025; Jimenez-Champi et al., 2023). Intake above 3–5 mg/kg body weight is hazardous, and the European Food Safety Authority has indicated 1 mg/kg body weight per day as a level without observed adverse effect (Jimenez-Champi et al., 2023). Content rises with light exposure, injury and storage (Arik Kibar et al., 2025; Yuksel & Durmaz, 2022). α-Chaconine has shown antifungal activity against *Fusarium sulphureum* in a study cited by Jimenez-Champi et al. (2023). This matters in two ways: peel-derived glycoalkaloids could carry into organic extracts and contribute to apparent antifungal activity, and they could affect the producing strain. Both possibilities are inferences from the cited data and have not been tested.

Phenolics. Peel is rich in chlorogenic, caffeic and gallic acids (Jimenez-Champi et al., 2023). Gebrechristos et al. (2020) found that an ethanolic peel extract inhibited *Escherichia coli*, *Salmonella enterica* and *Staphylococcus aureus* with minimum inhibitory concentrations of 7.5, 5.8 and 4.7 mg/mL, respectively, and had no effect on *Klebsiella pneumoniae* or *Listeria monocytogenes*. The activity was attributed to caffeic, chlorogenic and neochlorogenic acids. A scoping review of in vitro studies lists the latter two organisms among those inhibited (Hidayat et al., 2024), which differs from the primary report. The milligram-per-millilitre potency of peel extract is far below that of the microgram-per-millilitre values reported for *Streptomyces* extracts (Djinni et al., 2023), so peel phenolics alone are unlikely to explain

strong activity. They could still add background inhibition or inhibit the producer strain, and an uninoculated-peel control is the only way to separate these effects.

3.5 Nitrogen, protein and fibre fractions

Peel supplies nitrogen mainly as protein, and reported protein content spans 0.83% to 15.45% of dry matter (Table 2). Fresh tubers contain about 1.5–4.0% protein, and protease inhibitors alone are reported to make up 20–50% of potato protein (Arik Kibar et al., 2025). Protease inhibitors could in principle interact with microbial proteases, but no study in the set tested this. Schalchli et al. (2021) did observe a 3.8-fold rise in extracellular protein in potato broth inoculated with strain SO6, which indicates that protein hydrolysis and secretion took place. Arik Kibar et al. (2025) also identify autolysis and fermentation as underexplored routes for releasing peptides from peel, so peel fermentation may yield peptide co-products as well as secondary metabolites.

Peel also contains non-starch polysaccharides and lignin. Batista et al. (2026) found 27.55% non-starchy carbohydrate beside 44.85% starch in peel flour, and Gaudino et al. (2020) note lignin units in the cell wall. These fractions are unlikely to be used by most *Streptomyces* within a short run, and they add particulate matter that complicates growth monitoring (Section 7). They do mean that the nominal carbohydrate content overstates the fermentable fraction, and that starch measured by a specific method is the more useful design variable.

4. Streptomyces and Antifungal Metabolite Production

Streptomyces are filamentous, spore-forming Gram-positive bacteria found in soils, marine sediments, plant tissues and extreme habitats, and they dominate microbial natural-product discovery (Alam et al., 2022; Djinni et al., 2023). Antifungal products include polyenes such as nystatin and amphotericin, candicidin and aureofacin, peptides, and smaller molecules with membrane and cell-wall targets (Alam et al., 2022). Commercial agricultural products based on *Streptomyces* spores or metabolites exist, which shows that antifungal output has practical value beyond human medicine (Yang et al., 2024). Genome mining has shown that most biosynthetic gene clusters are silent under standard conditions, so altering medium composition and culture conditions remains an effective way to increase or activate production (Alam et al., 2022; Djinni et al., 2023).

Recent optimisation studies target a range of pathogens. *S. yanglinensis* 3–10 produces reveromycin-type antifungal substances (Yang et al., 2024). *Streptomyces* sp. KN37 inhibits crop pathogenic fungi, and its activity against *Rhizoctonia solani* rose from 27.33% to 59.53% after medium optimisation (Yang et al., 2025). *S. rochei* W71 inhibited *Phytophthora nicotianae* by 92.90% after optimisation (M. Zhang et al., 2026), although *Phytophthora* is an oomycete rather than a true fungus, so this result is not strictly antifungal. *S. lividans* and *S. rochei* isolates suppressed *R. solani* by 92% and 91% on molasses and corn steep liquor, and greenhouse bean survival rose from 25–30% in controls to 75–80% (Shams et al., 2025). Antifungal precedents on waste substrates also exist outside potato: natamycin production by *S. gilvosporeus* in solid-state fermentation on wheat bran, rapeseed cake, rice hull and crude glycerol is cited in a review of agro-industrial substrates (Astudillo et al., 2023).

4.1 Choice of target organisms

The sources test very different targets. They include plant pathogens (*Rhizoctonia solani*, *Botrytis cinerea*, *Fusarium oxysporum*, *Aspergillus niger*), an oomycete (*Phytophthora nicotianae*), and bacteria (MRSA, *Enterococcus*). The potato-based evidence concerns *B. cinerea*, *F. oxysporum* and *Mucor miehei* (Schalchli et al., 2021). For a programme aimed at agricultural biocontrol, plant-pathogen targets are therefore the best supported. Activity against human fungal pathogens such as *Candida albicans* is reported only for peel extract itself in the scoping review of Hidayat et al. (2024), and for polyene antibiotics in general in Alam et al. (2022). Clinical antifungal use would require purification, toxicity testing and regulatory work that goes well beyond fermentation optimisation, and the choice of target should be made explicit at the start of any study because it determines assay design, safety requirements and the meaning of an MIC value.

5. Evidence for Streptomyces on Potato-Derived Substrates

5.1 Antifungal metabolites and pigments on discarded potato

Schalchli et al. (2021) is, in the sources reviewed, the only study to use a potato-derived powder as the sole nutrient source for antifungal production by *Streptomyces*. The authors dried discarded potatoes cut into 1 × 1 cm pieces at 70 °C for 24 h, ground them, and prepared broth at 16 g/L without supplements or pH adjustment. Proximate composition was moisture 7.8%, fat 6.2%, protein 7.9%, crude fibre 0.4%, ash

3.9% and nitrogen-free extract 73.7%. Three soil isolates (SO6, PM1 and PM7) were screened for activity against *Botrytis cinerea*, *Fusarium oxysporum* and the reference fungus *Mucor miehei* in dual-culture plates. Strain SO6 was selected because it inhibited all three targets and kept its pigment production on potato medium.

In submerged culture (28 °C, 120 rpm, 4% inoculum, 10 days), pH rose from about 5.8 to 8.0 by day 2 and settled near 6.4. Reducing sugars rose from 0.6 mg/mL to a maximum of 3.6 mg/mL on day 6, and extracellular protein increased about 3.8-fold. The study reports three separate things, which are kept apart here: an antifungal result, a pigment result, and the absence of compound identification.

Antifungal result (whole-tuber evidence). Ethyl acetate extract of the cell-free broth produced a 19 mm inhibition zone against *B. cinerea* at 100 µg per disc. Two active fraction groups (F7 and F8, 28 mg in total) gave zones of 9 ± 1 and 19 ± 3 mm, and the yield of diffusible antifungal material was reported as 0.96 mg/g. In dual-culture assays on potato agar, inhibition of *B. cinerea* (5.7 mm) was smaller than on commercial potato dextrose agar (15.3 mm), whereas inhibition of *M. miehei* was larger (19.0 versus 18.0 mm), so potato medium did not uniformly improve activity.

Pigment result (whole-tuber evidence). A reddish-purple pigment appeared from day 4, and its yield was reported as 1.75 mg/g. Pigment formation was a selection criterion for strain SO6 and was measured as a separate readout. It is not itself an antifungal result.

Compound identification (not done). The compounds responsible for the antifungal activity and for the pigment were not identified, so neither result can be linked to a known antibiotic or pigment class. The authors stated that chemical characterisation and optimisation were in progress.

The study has further limits that bear on the present question. The substrate was whole discarded tubers, not peel. The assay description mentions a solvent control but not an extract of uninoculated potato medium, so background activity of the substrate was not excluded. The extract activity data come from a single plant pathogen, and the authors note that solid particles hindered growth measurement.

A follow-up from the same group used discarded potato broth for blue pigment production by strain PM7, identified as *S. lydicus* (Astudillo et al., 2024). Potato broth gave the highest blue pigment yield (about 0.97 g/L) among six media, followed by ISP5 (about 0.36 g/L). A powder concentration of 16 g/L outperformed 4, 8 and 32 g/L, and reducing sugars of about 5 g/L appeared on day 5 when pigment formation began. The main pigment was identified as actinorhodin, which the authors describe as a pH-responsive bacteriostatic antibiotic. The work confirms that *Streptomyces* can degrade potato waste and divert metabolism toward secondary products, but its readout is pigment rather than antifungal activity.

Table 3. Studies reporting Streptomyces secondary metabolites on potato-derived substrates.

Study	Substrate	Strain	Outcome and main limitation
Schalchli et al. (2021)	Discarded whole potato powder, 16 g/L, no supplements	*Streptomyces* sp. SO6 (also PM1, PM7)	*Antifungal:* extract 19 mm vs. *B. cinerea* at 100 µg/disc; 0.96 mg/g. *Pigment:* 1.75 mg/g, a separate readout. *Identification:* none for either. Whole tuber, not peel; no uninoculated-substrate extract control described
Astudillo et al. (2024)	Discarded potato broth, 16 g/L optimal	*S. lydicus* PM7	Blue pigment (actinorhodin) ~0.97 g/L. Pigment readout; no antifungal assay
Chauhan et al. (2023)	Review of potato waste	Cites SO6	Describes the Schalchli result as potato powder use; secondary source
Astudillo et al. (2023)	Review of agro-industrial substrates	Cites potato pigment work	Lists *Streptomyces* pigment on discarded potato; secondary source

5.2 What the evidence does and does not show

Taken together, these studies show that some *Streptomyces* strains can solubilise potato powder through amylase and protease activity, release sugars, and form secondary metabolites without supplementation. They do not show that peel supports the same performance. The evidence is separated here by type.

Direct peel evidence. None of the sources reviewed reports *Streptomyces* growth, antifungal activity or any other secondary metabolite on peel. Direct peel data are limited to composition, drying, pretreatment, contaminant removal and the antibacterial activity of peel extracts (Section 3).

Whole-tuber evidence. Discarded potato powder supported antifungal metabolite formation by one strain against one plant pathogen, with unidentified compounds (Schalchli et al., 2021), and blue pigment formation by a second strain (Astudillo et al., 2024).

Other-substrate evidence. Antifungal production and its optimisation have been reported on starch media and on molasses, corn steep liquor, millet, wheat bran and other substrates (Section 6).

Hypotheses, not tested in the sources reviewed. That peel supports the same growth and metabolite formation as whole-tuber powder; that the higher ash and fibre of peel, and its phenolics and glycoalkaloids, slow starch access or inhibit the producer strain; and that conditions optimised on other media apply to a peel medium. The conclusion that PPW has been proven as a *Streptomyces* substrate for antifungals, which appears in some secondary summaries, is not supported by the primary data. The accurate statement is that discarded potato powder supports antifungal metabolite formation by one strain against one plant pathogen, with unidentified compounds.

Several differences between tuber powder and peel make transfer uncertain, and each is a hypothesis rather than a result. Peel has more ash and fibre and a different starch share in the data compared in Table 2, although those data come from different studies and bases. Peel particles may be tougher, and drying and milling may produce a different particle size distribution, which would affect gelatinisation and enzyme access. Peel phenolics and glycoalkaloids are reported to be concentrated in the outer tissue (Jimenez-Champi et al., 2023), so peel could be more inhibitory to the strain. Against this, peel may be a more consistent waste stream in processing plants, whereas rejected whole tubers may vary more in supply; neither point is supported by data in the sources reviewed. A direct comparison of peel and whole-tuber powder with the same strain would settle the question and is among the first experiments needed.

6. Process Variables and Optimisation Strategies

6.1 Carbon and nitrogen sources

Starch has repeatedly outperformed glucose as a carbon source. In *S. yanglinensis* 3–10, 3% starch gave larger inhibition zones than any glucose level (Yang et al., 2024). A starch–nitrate medium for *S. rochei* CMB47 gave the strongest anti-MRSA activity among four media, and a central composite design placed the optimum at only 2 g/L starch (Djinni et al., 2023). Nitrate acted negatively: higher $NaNO_3$ lowered activity. Peel supplies organic nitrogen (protein 11.7–15.5% in two studies), so a peel medium might need little or no added nitrate, although this is a hypothesis. Complex low-cost nutrients can also work. Molasses and corn steep liquor alone supported antifungal activity in two *Streptomyces* species (Shams et al., 2025), millet was the key factor for *Streptomyces* sp. KN37 together with yeast extract and K_2HPO_4 (Yang et al., 2025), and a spent-yeast and sucrose medium with 10% composting leachate gave 7.80×10^7 CFU/mL in 48 h for *Streptomyces* sp. BEI-18A (Nazari et al., 2025). The last of these measured growth and plant-growth promotion rather than antibiotic output. Lactose and glycine increased inhibition when added to wheat bran in a marine isolate (Almalki, 2020), but those results come from a single-factor design.

6.2 pH, temperature, time and aeration

Reported optima cluster in a narrow range (Table 4). Initial pH varies from near-neutral (6.5) to alkaline (8.0–8.7, and 11 in one case), and temperature from 25 to 30 °C. Incubation time ranges from 72 h to 9 days, and a long shake-flask run is typical for secondary metabolites. Aeration matters at fermenter scale. In *S. yanglinensis* 3–10, dissolved oxygen above about 20% saturation was needed for high growth and activity. The best conditions were 200 rpm and 0.75 vvm, and activity at 5, 15 and 30 L was similar (mean inhibition zone 44 mm at 30 L; maximum 50 mm at 5 L) (Yang et al., 2024). Yields in that paper were estimated from inhibition zones with a calibration equation (4.2 g/L at 200 rpm), so they are indirect values, not isolated mass.

Table 4. Optimised or reported conditions in selected Streptomyces studies.

Study	Strain and target	Key conditions	Reported outcome
Yang et al. (2024)	*S. yanglinensis* 3–10; *Aspergillus niger*	Starch 3%; pH 6.5; 28 °C; 200 rpm; 0.75 vvm; DO > 20%; 72 h; 5–30 L	Zones up to 50 mm (5 L), mean 44 mm (30 L); yield inferred from zones
Djinni et al. (2023)	*S. rochei* CMB47; MRSA	Starch 2 g/L; $NaNO_3$ 3 g/L; pH 11; 7 d (30-run rotatable CCD)	18.5 mm observed vs. 20 mm predicted; R^2 = 0.85; MIC 0.439 µg/mL (crude extract)
Yang et al. (2025)	*Streptomyces* sp. KN37; *R. solani*	Millet 20 g/L; yeast extract 1 g/L; K_2HPO_4 0.5 g/L; 150 rpm; 25 °C; pH 8; 9 d; 4% inoculum	Antifungal rate 27.33% → 59.53%
M. Zhang et al. (2026)	*S. rochei* W71; *P. nicotianae* (oomycete)	Maltose 20 g/L; yeast extract 2.5 g/L; NaCl 1 g/L; pH 8.66; 29.8 °C; 200 rpm; 8 d; inoculum 5.55%	Inhibition 92.90% (6.78-fold increase)
Shams et al. (2025)	*S. lividans* AC 82; *S. rochei* AC 143; *R. solani*	Molasses 25 or 20 mL/L; corn steep liquor 5 mL/L; inoculum age 3 or 5 d; 8 d for *S. rochei*	92% and 91% suppression vs. 94.9% and 92.6% predicted; bean survival 75–80% vs. 25–30%
Schalchli et al. (2021)	SO6; *B. cinerea*	Potato powder 16 g/L; initial pH ~6.2; 28 °C; 120 rpm; 4% inoculum; 10 d	19 mm at 100 µg/disc; 0.96 mg/g antifungals; compounds unidentified
Almalki (2020)	SCA-7 (marine); *Enterococcus* sp.	Solid-state, wheat bran 5 g, 75% moisture; 7 d; lactose 1% added	22 mm (wheat bran); 25 mm (with lactose)

6.3 Experimental design

The optimisation studies share a common logic: screen many factors with a Plackett–Burman design, climb toward the optimum, and then refine with a central composite or Box–Behnken design (Shams et al., 2025; Yang et al., 2025; M. Zhang et al., 2026). The same approach has been applied to peel processing. Batista et al. (2026) used a rotatable central composite design with desirability analysis to find the ultrasound extraction conditions for peel phenolics (66.9 min, 44.9 °C, solid-to-solvent ratio 1:46.82), and Mushtaq et al. (2024) used a Box–Behnken design for acid and steam pretreatment. Statistical models should be reported with their limits. For example, the anti-MRSA model reached an R^2 of 0.85 and an F value only moderately above the tabulated value (Djinni et al., 2023), and models with R^2 above 0.99 in some studies (Shams et al., 2025) deserve scrutiny of replication and lack-of-fit.

6.4 Solid-state versus submerged fermentation

Peel can be used as a solid substrate or suspended as a broth. Solid-state fermentation uses little free water, can use agricultural residues directly and may cut energy use, but heat accumulation and heterogeneity complicate scale-up (Mattedi et al., 2023). Submerged culture allows control of pH, dissolved oxygen and sampling, and it is the format used for the potato-derived work (Astudillo et al., 2024; Schalchli et al., 2021). Solid-state work with wheat bran produced inhibition against *Enterococcus* (Almalki, 2020), and solid-state fermentation of wheat bran-based substrates produced natamycin (Astudillo et al., 2023). Because peel is already a solid with 60–85% moisture when fresh, both formats are plausible, and a direct comparison on a single peel lot is missing from the literature examined.

6.5 Integration with peel biorefining

Peel supports several valorisation routes that could be combined with fermentation. Ultrasound-assisted extraction recovers phenolics at moderate temperature (Batista et al., 2026), emerging extraction technologies have been reviewed by Gaudino et al. (2020) and C. Zhang et al. (2026), and acid and steam pretreatment releases both sugars and phenolics (Mushtaq et al., 2024). A cascade in which phenolics are extracted first and the starch-rich residue is then fermented might lower the phenolic load on the producer strain and give a marketable co-product (a hypothesis). The effect of prior extraction on residual starch availability and on *Streptomyces* performance has not been tested. Pigments are another co-product: the same potato medium gave a reddish-purple pigment at 1.75 mg/g and, with a different strain, actinorhodin (Astudillo et al., 2024; Schalchli et al., 2021), and the market for natural pigments is growing (Lyu et al., 2022). Whether pigment and antifungal pathways compete for precursors in a single culture is unknown

and should be measured.

6.6 Scale-up considerations

Scale-up depends on keeping oxygen supply and mixing adequate. In the reveromycin-producing strain, activity at 5, 15 and 30 L was similar when agitation, aeration and dissolved oxygen were held in the same ranges (Yang et al., 2024), which supports transfer from flask to stirred tank for a defined, mostly soluble medium. A peel medium is a slurry of particles, and the sources reviewed do not report oxygen transfer, viscosity or shear in such a medium. Solid-state fermentation avoids slurry handling but accumulates metabolic heat and is heterogeneous, which are the main obstacles at larger scale (Mattedi et al., 2023). Both formats therefore need characterisation at intermediate scale before cost estimates are credible.

7. Methodological Constraints and Confounders

Several recurring problems limit how far existing results can be interpreted (Table 5). The most consequential for this topic are the absence of matrix controls, the equation of crude-extract potency with pure-drug potency, and the mixing of peel with whole-tuber waste.

Table 5. Issues noted in the reviewed sources and suggested handling.

Source or theme	Issue	Suggested handling
Peel vs. whole potato	Streptomyces work used discarded tubers (Astudillo et al., 2024; Schalchli et al., 2021), but some summaries describe it as peel	State substrate precisely; test peel directly
Matrix controls	Extract of uninoculated potato medium not described in the antifungal assay (Schalchli et al., 2021)	Extract sterile, uninoculated medium under identical conditions; subtract
Antifungal vs. pigment vs. identification	Schalchli et al. (2021) report an antifungal extract, a pigment yield and no compound identification; some summaries merge these into one outcome	Report the antifungal result, the pigment result and compound identity as three separate findings
Crude vs. pure potency	Crude-extract MIC compared with pure vancomycin (Djinni et al., 2023)	Report potency of purified fractions; normalise crude extract to dry residue
Target organism	Oomycete reported as fungus (M. Zhang et al., 2026); plant pathogens only	Distinguish oomycetes from fungi; add human-relevant fungi
Indirect yields	Yield derived from inhibition-zone calibration (Yang et al., 2024)	Quantify by HPLC against a standard or isolated mass
Internal inconsistencies	Almalki (2020): MIC given as 25 and 24 µg/mL; best nitrogen source glycine (Results) vs. skimmed milk (Discussion); NMR signals at 9.61–12 ppm and 284.3 ppm do not fit the assigned saturated structure	Treat structure as unverified; do not cite compound identity
Units and bases	Tripathi et al. (2025): phenolics printed as mg GAE/100 g, unusually low; protein 0.83–0.99%	Convert to dry-weight basis; check units against primary data
Citation chains	Review statements attributed to unrelated papers in some secondary reviews	Trace each claim to its primary source before citing
Conflicting secondary report	Hidayat et al. (2024) list organisms as inhibited that Gebrechristos et al. (2020) report as negative	Prefer the primary paper

Two further constraints are specific to solid substrates. Particles interfere with turbidity, dry weight and optical density, so growth is hard to follow, as Schalchli et al. (2021) noted. Extraction of metabolites from a solid residue can also be incomplete. Both call for indirect growth markers (for example DNA content, soluble protein or colony counts of filtered fractions) and for recovery tests with spiked standards. Finally, acid and thermal pretreatments release phenolics (Mushtaq et al., 2024), and sterilisation may generate further inhibitors. Their effect on *Streptomyces* growth must be measured, not assumed.

Safety and waste handling also need attention. Pesticide residues removed from peel by washing end up

in wash water, and Nguyen et al. (2024) note that the environmental fate of these residues in wastewater is itself an issue. Residues that are not removed may reach spent broth, extracts and sludge. Glycoalkaloid carry-over matters for any food or feed use of fermentation products, given the exposure limits cited above (Jimenez-Champi et al., 2023). Where the product is intended for agricultural use, regulatory acceptance of products made from waste feedstocks must be confirmed. In Ethiopia, the Pesticide Registration and Control Proclamation No. 674/2010 provides that a pesticide may not be formulated, manufactured or traded unless it is registered with the ministry responsible for agriculture (Federal Democratic Republic of Ethiopia, 2010), so an antifungal product intended for crop protection would need to follow that route. Whether the proclamation applies in the same way to a microbial fermentation extract is not addressed in the sources reviewed and would need to be confirmed with the registering authority.

8. A Research Framework for Antifungal Production on Potato Peel Waste

The literature supports a staged programme (Figure 1). The stages are designed so that each addresses a gap identified in Sections 3 to 7, and the order lets earlier results narrow later experiments. Each stage tests one or more of the hypotheses below, because none of them has been demonstrated on peel in the sources reviewed.

H1: peel supports *Streptomyces* growth and starch use comparable to whole-tuber powder. *H2:* washing, drying and hydrolysis reduce peel-borne inhibitors enough that they do not suppress the producer strain. *H3:* conditions optimised on other media apply, at least in range, to a peel medium. *H4:* the extract of inoculated peel is more antifungal than the extract of uninoculated peel. *H5:* the active compounds are microbial products, and the yield per kilogram of dry peel justifies scale-up.

Stage 1: *substrate standardisation.* Use a single documented cultivar and peeling method, wash the peel (power ultrasound is an option for residue reduction; Nguyen et al., 2024), and dry at 45–50 °C to constant weight. Mill and sieve to a defined particle size. Report moisture, starch, nitrogen, ash, phenolics, glycoalkaloids and pesticide residues on a dry-weight basis, because composition varies so widely between sources (Table 2). Tests H2.

Stage 2: *substrate and strain screening.* Compare raw, thermally gelatinised and hydrolysed peel (α-amylase, or dilute acid with steam) with a reference starch medium run in parallel. Screen several strains for amylase and antifungal activity, since strain performance differed markedly among the three isolates in the potato study (Schalchli et al., 2021). Tests H1 and H2.

Stage 3: *statistical optimisation.* Screen factors with a Plackett–Burman design, then use a central composite or Box–Behnken design. Plausible factors and ranges, taken from the optimisation studies above, are peel load (10–50 g/L), supplemental nitrogen (0–5 g/L), initial pH (6.0–8.5), temperature (25–32 °C), incubation time (3–10 d) and agitation (150–250 rpm), with dissolved oxygen monitored in stirred tanks (Yang et al., 2024). Responses should include biomass or a validated growth proxy, reducing sugar and antifungal activity as an MIC rather than only a zone diameter. Tests H3.

Stage 4: *bioassay with matrix controls.* Extract broth and mycelium with ethyl acetate or a comparable solvent. Extract an uninoculated, sterile peel medium incubated under identical conditions, and test both against a panel that includes human-relevant fungi such as *Candida albicans* as well as plant pathogens. Use broth microdilution to obtain MIC values, and subtract or explain background activity. Tests H4.

Stage 5: *chemistry and feasibility.* Fractionate active extracts under bioassay guidance and characterise them by HPLC with diode-array and mass-spectrometric detection, with dereplication against known *Streptomyces* antifungals. Report mg of purified product per kg of dry peel and per litre of broth, together with a mass balance, energy needs and the local supply of peel. For Ethiopia, documentation of peel quantity, seasonality and collection routes is required. Tests H5.

Decision criteria. To keep the programme from drifting, explicit criteria should be set in advance. These are proposals for the research design rather than values taken from the literature. Examples include growth on raw or lightly hydrolysed peel that reaches a defined fraction of the reference medium; antifungal activity of the inoculated extract that exceeds the uninoculated-peel extract by a statistically defined margin; reproducibility across at least three independent peel lots and three biological replicates; and a yield and mass balance that justify scale-up. Meeting the first three criteria would show that peel supports antifungal production, and the last would show whether it is worth pursuing.

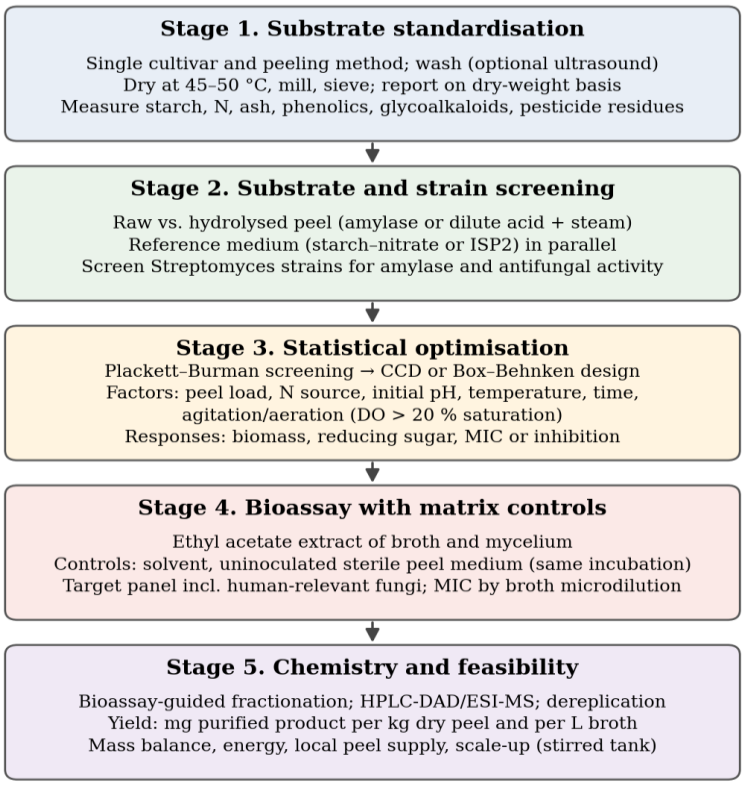


Figure 1. Proposed five-stage framework for developing antifungal production on potato peel waste. CCD, central composite design; DO, dissolved oxygen; MIC, minimum inhibitory concentration.

9. Limitations of This Review

This review rests on 27 sources published between 2020 and 2026 and assembled during proposal development, and it was not built from a systematic search (Section 2). The set may therefore overrepresent certain topics, such as peel composition and *Streptomyces* medium optimisation, and underrepresent others, for example other actinomycetes, fungal fermentations of peel, or antifungal work on different agro-wastes. Because the author judged which sources to retain, selection bias is possible, and negative or unpublished results are unlikely to be captured. Source studies come from different countries, cultivars, assay formats and reporting conventions, which limits direct comparison, and several values are second-hand. Conclusions about the absence of evidence, including the statement that no reviewed study reports antifungal production on peel, apply to this set only. This is a boundary of the narrative design rather than a deficiency of it: a systematic review with a documented, reproducible search protocol would be required before any comprehensive claim about the broader literature could be made.

10. Conclusions

Potato peel is abundant, starch-containing and cheap, and its composition, drying behaviour and contaminant profile are reasonably well described, although values vary widely and are often reported on unclear bases. *Streptomyces* fermentations can be optimised statistically and can grow densely on waste-derived media. The only study found that combined a potato-derived powder with *Streptomyces* and antifungal readout used discarded whole tubers, tested a single plant pathogen, and left the active compounds unidentified. Antifungal production on potato peel itself therefore remains unproven.

Progress requires a controlled and statistically designed programme that standardises the substrate, compares raw and hydrolysed peel, separates microbial products from peel-intrinsic activity by uninoculated controls, reports yields per unit of dry peel, and identifies the active compounds. Until such

data exist, claims that potato peel is a validated substrate for antifungal production should be avoided. If the approach works, it would link waste reduction with a lower-cost route to agricultural fungicides and, possibly, to antifungal drug leads.

Declarations

Conflict of interest: none declared. Data availability: no new data were generated; all values are from the cited publications. **Author Contributions: M.A.H.**: Writing – review & editing. Acknowledgements: The author thanks the Department of Chemical Engineering, Faculty of Technology, Debre Tabor University, for institutional support and technical assistance during the preparation of this work.

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