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Research Paper

Comparative Physicochemical and Biological Characterization of Salmon Derived PDRN and Winterberry Derived Phyto-PDRN

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ABSTRACT: *This study directly compared and characterized the physicochemical properties and biological activities of salmon-derived PDRN (S-PDRN) and winterberry-derived PDRN (Wb-PDRN). The results showed that Wb-PDRN exhibited high purity with minimal impurities and a controlled low-molecular-weight distribution (50–1,200 kDa), along with cytocompatibility, cell proliferation, and wound-healing effects comparable to those of salmon-derived PDRN. Mechanistically, Wb-PDRN was confirmed to activate the same adenosine A2A receptor-mediated signaling pathway (p-FAK, p-AKT, p-ERK1/2). These findings establish the molecular and functional equivalence of winterberry-derived PDRN to conventional S-PDRN, demonstrating its potential as a promising non-animal alternative in regenerative biomaterials, cosmeceuticals, and veterinary healthcare.*

KEYWORDS: *PDRN; Phyto-PDRN; Rubus buergeri; Winterberry; salmon-derived PDRN; wound healing; cytocompatibility; A2A receptor; pet healthcare; FBS alternative.*

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I. INTRODUCTION

Polydeoxyribonucleotide (PDRN) is a heterogeneous mixture of DNA-derived fragments distributed within a specific molecular-weight spectrum (typically 50–1,500 kDa or 50–1,500 bp) that has been extensively investigated as a regenerative biomaterial [6, 12, 13]. Conventional commercial PDRN is predominantly extracted from sperm cells or reproductive tissues of salmonid species, such as *Oncorhynchus mykiss* and *Oncorhynchus keta* [8]. The biological effects of PDRN are driven primarily by two mechanisms: binding as a selective agonist to the cell-surface adenosine A_2A receptor (A_2AR) and providing purine/pyrimidine nucleosides for the intracellular salvage pathway of nucleic acid synthesis [6, 15]. These pathways stimulate cellular proliferation, angiogenesis, collagen deposition, and anti-inflammatory cascades.

Despite its clinical efficacy, conventional salmon-derived PDRN (S-PDRN) presents distinct industrial and biological limitations [8]:

- **Allergenicity and Safety:** Residual marine proteins pose risks of IgE-mediated allergic reactions and gastrointestinal hypersensitivity.
- **Contamination Risks:** Exposure to marine heavy metals (mercury, lead, cadmium) and microplastics requires rigorous purification.
- **Organoleptic Issues:** Fishy odors significantly reduce consumer acceptance in cosmetics and cause oral aversion/rejection in companion animals.
- **Sustainability and Supply:** Raw material availability is restricted by seasonal salmon breeding cycles and animal welfare concerns.

To overcome these constraints, the bio-industry is shifting toward plant-derived PDRN (Phyto-PDRN) [10, 11]. Recent green processing developments, such as eco-friendly reduced-pressure extraction of rice bran, highlight the growing demand for non-toxic, sustainable biomaterials [5].

Phyto-PDRN has recently demonstrated groundbreaking application-level success:

- **Cultured Meat Technology:** Aloe vera-derived PDRN bound directly to MyoD and Pax7 muscle

transcription factors, completely restoring the proliferation rate of Hoengseong Hanwoo muscle satellite cells even when fetal bovine serum (FBS) was reduced by 50% [4].

- **Antiviral and Skin Barrier Engineering:** *Platycodon grandiflorus* Saponin-PDRN complexes, purified via dual-functional magnetic bead systems, blocked viral entry of White Spot Syndrome Virus (WSSV) in aquaculture models and upregulated skin barrier proteins (filaggrin, loricrin, SOD1) [3, 14].
- **Veterinary Healthcare:** *Rubus buergeri* (winterberry) Phyto-PDRN complexes protected feline renal tubular cells (CRFK) against H_2O_2- and Cisplatin-induced apoptosis (restoring viability to 94.1%) and promoted chondrocyte proliferation via A_2AR activation to alleviate patellar osteoarthritis in small dogs [2].

The Core Research Gap

Despite these empirical successes in applied fields (pet care, cultured meat media, antiviral agents), a fundamental scientific question remains: Why does plant-derived PDRN perform so exceptionally well, and how do its underlying physicochemical properties and molecular mechanisms compare head-to-head with conventional salmon-derived PDRN? Most existing studies have focused either on single plant species or on final formulation endpoints without establishing a standardized, head-to-head molecular baseline against S-PDRN [7, 9].

Therefore, the objective of this study was to establish a standardized experimental platform to directly compare salmon-derived PDRN (S-PDRN) and winterberry-derived PDRN (Wb-PDRN). By normalizing DNA concentration, we comparatively evaluated their physicochemical purity, molecular-weight distribution, cytocompatibility, cellular proliferation, wound-healing kinetics, and A_2A receptor-mediated downstream signaling pathways (FAK, AKT, ERK1/2) [1].

II. MATERIALS AND METHODS

Overall Experimental Workflow

The experimental design spans raw material processing, DNA extraction, purification, normalization, physicochemical characterization, in vitro cytocompatibility, wound healing, and mechanistic signaling analysis**.**

Preparation of Winterberry-Derived PDRN (Wb-PDRN)

Rubus buergeri Miquel plant material collected from Jeju Island was authenticated, washed, freeze-dried, and pulverized. To 1 kg of plant powder, 10 volumes of extraction buffer (50 mM Tris-HCl, 100 mM NaCl, 10 mM EDTA, pH 8.0) were added. Cellulase (1.0% v/w) and pectinase (0.5% v/w) were reacted at 45°C for 4 h to degrade plant cell walls. Ultrasonication (20 kHz, 400 W, 30 min) was applied to release genomic DNA ***[10, 11]****.*The extract was purified via Adsorption-Elution-Based Purification (ABT) using DEAE-Sepharose anion-exchange chromatography. Unbound proteins, polyphenols, and polysaccharides were washed away with 0.3 M NaCl buffer. Bound DNA was eluted with 1.2 M NaCl buffer. Controlled fragmentation was performed using DNase I reaction and ultrasonic shearing to yield fragment sizes between 50 and 1,200 bp. Small fragments (< 10 kDa) and enzymes were removed using 10 kDa and 30 kDa molecular weight cut-off (MWCO) ultrafiltration systems. Endotoxins were reduced using Polymyxin B columns.

Preparation of Salmon-Derived PDRN (S-PDRN)

S-PDRN was prepared from salmon reproductive tissue (*Oncorhynchus mykiss*) via standard proteinase K digestion, phenol-chloroform extraction, ethanol precipitation, and controlled enzymatic fragmentation. The resulting DNA fragments were dissolved in nuclease-free water, yielding a distribution predominantly between 50 and 1,500 kDa.

Physicochemical Characterization

- **DNA Concentration and Purity:** Evaluated using UV/Vis spectrophotometry (NanoDrop 2000, Thermo Fisher Scientific) by measuring absorbance at 230, 260, and 280 nm.
- **Molecular-Size Distribution:** Evaluated by 1.2% agarose gel electrophoresis (stained with EtBr/GelRed) and Size-Exclusion Chromatography coupled with Multi-Angle Light Scattering (SEC-MALS).
- **Residual Impurities:** Residual protein was quantified using the BCA protein assay; residual polysaccharides were quantified via the phenol-sulfuric acid method; endotoxin levels were determined using the LAL chromogenic assay.

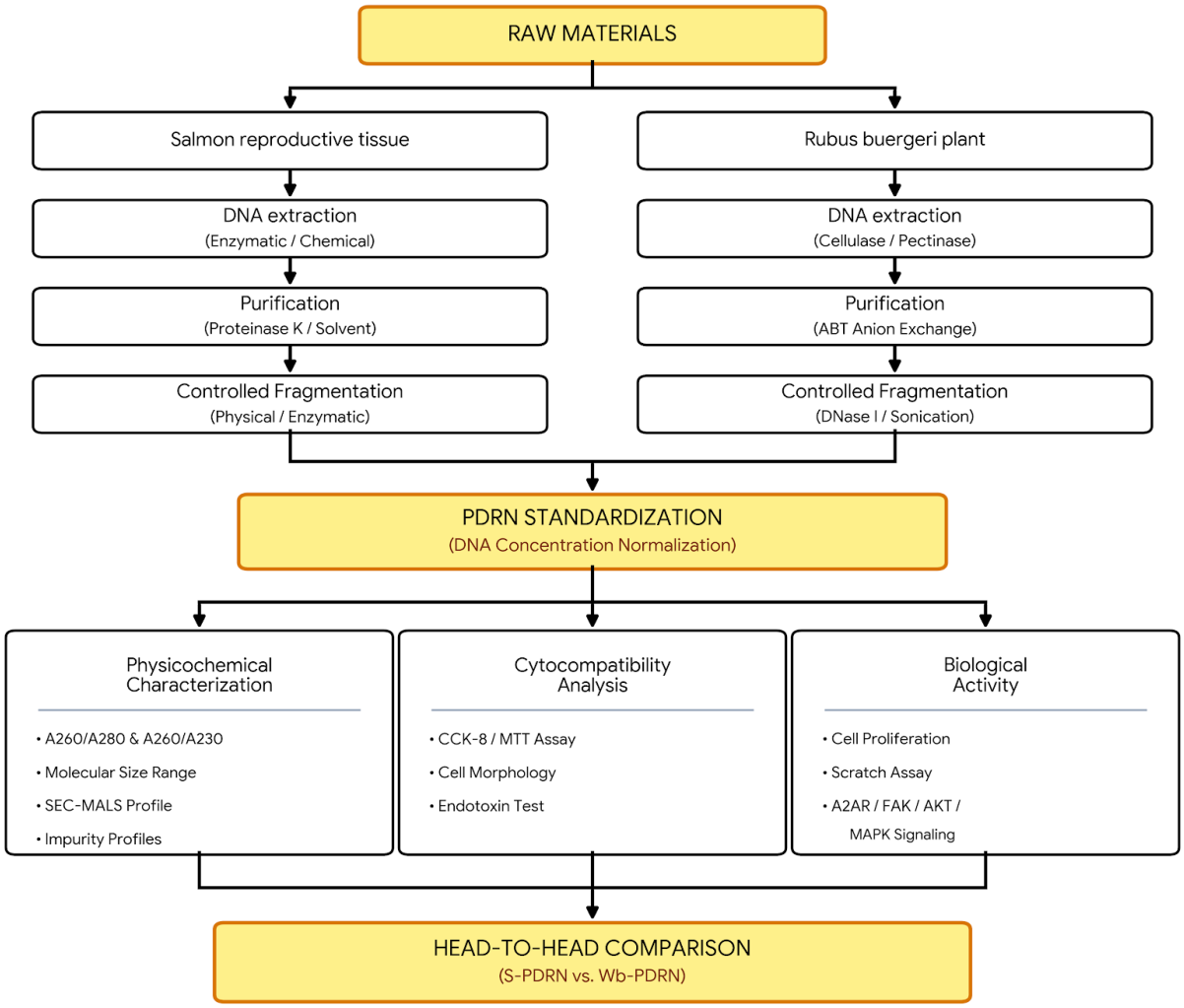


Figure 1. Overall experimental workflow illustrating raw material processing, DNA extraction, ABT purification, fragmentation, normalization, and head-to-head analytical assays

Cell Culture and Cytocompatibility Assay

Human Dermal Fibroblasts (HDFs) and Human Keratinocytes (HaCaT) were cultured in DMEM supplemented with 10% Fetal Bovine Serum (FBS) and 1% penicillin-streptomycin at 37°C in a 5% CO_2 incubator. Cells were seeded in 96-well plates (1×10^4 cells/well) and treated with S-PDRN or Wb-PDRN at concentrations of 0.1, 0.5, 1.0, 2.5, 5.0, and 10.0 µg/mL for 24 h. Cell viability was measured using the CCK-8 assay [9].

Cell Proliferation and Scratch Wound-Healing Assay

For cell proliferation, HDFs were treated with S-PDRN or Wb-PDRN (0.1–10 µg/mL for 48 h), and proliferation indices were calculated relative to untreated controls.

For the scratch wound assay, HDFs were cultured in 6-well plates to 90% confluence. A linear wound was created using a sterile 200 µL pipette tip. Wells were washed with PBS to remove debris and treated with S-PDRN or Wb-PDRN (10 µg/mL) in low-serum media (1% FBS). Microscopic images were captured at 0, 12, 18, and 24 h. Wound closure percentage was quantified using ImageJ software:

$$\textit{Wound Closure (\%)} = [(A_0 - A_t) / A_0] \times 100$$

where A_0 is the initial wound area at 0 h and A_t is the wound area at time t.

Western Blot Signaling Analysis

HDFs were treated with 10 µg/mL S-PDRN or Wb-PDRN for 24 h. Total protein was extracted using RIPA buffer containing protease and phosphatase inhibitors. Proteins (20 µg) were separated on 10% SDS-PAGE gels and transferred to PVDF membranes. Membranes were incubated overnight at 4°C with primary

antibodies against A_2AR, p-FAK, FAK, p-AKT, AKT, p-ERK1/2, ERK1/2, and β-actin. Protein bands were visualized using ECL substrate and quantified using a ChemiDoc Imaging System [15].

Statistical Analysis

Data are expressed as Mean ± Standard Deviation (SD) from at least three independent experiments. Statistical differences were analyzed using One-Way ANOVA followed by Tukey's post-hoc test ($p < 0.05$ considered statistically significant).

III. RESULTS

Physicochemical Characteristics and Purity Profiles

Spectrophotometric and biochemical evaluations confirmed that both S-PDRN and Wb-PDRN achieved high nucleic acid purity. S-PDRN and Wb-PDRN exhibited A_{260}/A_{280} ratios of 1.85 ± 0.02 and 1.88 ± 0.03, respectively, indicating minimal protein contamination. The A_{260}/A_{230} ratio for Wb-PDRN reached 2.15 ± 0.03, confirming effective removal of plant polyphenols and polysaccharides. Residual protein (< 0.5%) and endotoxin levels (< 0.05 EU/mL) met international safety standards for biological materials

Table 1. Physicochemical properties and purity metrics of S-PDRN and Wb-PDRN

Parameter	S-PDRN	Wb-PDRN	Quality Criterion / Interpretation
DNA Concentration (mg/mL)	5.2 ± 0.2	4.8 ± 0.2	Normalized for downstream biological assays
A260/A280 Ratio	1.85 ± 0.02	1.88 ± 0.03	Pure DNA (1.8–2.0); absence of protein impurities
A260/A230 Ratio	2.20 ± 0.04	2.15 ± 0.03	Pure DNA (> 2.0); absence of polyphenols/salts
Average Molecular Size (kDa)	650 ± 45	580 ± 35	Optimal range for receptor-mediated uptake
Molecular Weight Spectrum	50–1,500 kDa	50–1,200 kDa	Controlled low-molecular-weight fragments
Residual Protein (%)	< 0.5%	< 0.5%	Highly purified; low risk of allergenicity
Residual Polysaccharide (%)	N/A	< 0.2%	Successful plant wall matrix removal
Endotoxin Level (EU/mL)	< 0.08	< 0.03	Satisfies safety limit (< 0.05 EU/mL)

Molecular-Weight Distribution

Agarose gel electrophoresis (1.2%) revealed that both preparations consist of low-molecular-weight DNA fragments rather than intact genomic DNA. S-PDRN displayed a smear band from 50 to 1,500 kDa (peak centered at ~650 kDa), whereas Wb-PDRN exhibited a slightly tighter distribution from 50 to 1,200 kDa (peak centered at ~580 kDa or ~350 bp). SEC-MALS confirmed that both preparations fall within the optimal size range required for binding to cell-surface A_2A receptors.

Cytocompatibility and Cell Proliferation

Cell viability assays using HDFs and HaCaT keratinocytes demonstrated that Wb-PDRN is non-toxic up to 10.0 µg/mL, maintaining > 95% cell viability across all tested concentrations [9]. Both PDRNs promoted HDF cell proliferation in a concentration-dependent manner. At 10.0 µg/mL, S-PDRN and Wb-PDRN increased HDF proliferation to 132.5% ± 4.2% and 128.4% ± 3.8% of untreated control levels, respectively, demonstrating comparable biological activity.

Scratch Wound-Healing Kinetics

In the HDF scratch wound assay, both S-PDRN and Wb-PDRN significantly accelerated cell migration into the denuded area compared with the untreated control.

Activation of A_2A Receptor and FAK/AKT/MAPK Signaling Cascade

Western blot analysis demonstrated that both S-PDRN and Wb-PDRN significantly upregulated expression of the adenosine A_2A receptor (A_2AR). Downstream signaling analysis showed equivalent increases in the phosphorylation of Focal Adhesion Kinase (p-FAK), AKT (p-AKT), and Extracellular Signal-Regulated Kinase 1/2 (p-ERK1/2). This confirms that Wb-PDRN functions via the canonical $A_2AR \rightarrow$ FAK/AKT/MAPK signaling axis to promote cell migration and tissue repair [15].

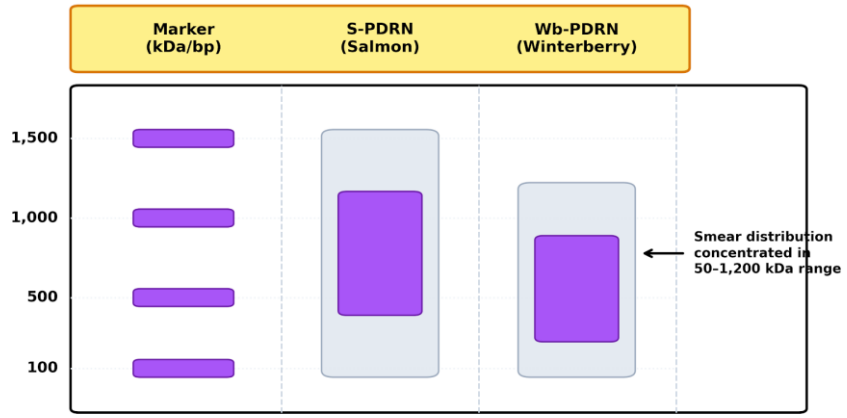


Figure 2. Electrophoretic band patterns and SEC-MALS profiles showing low-molecular-weight DNA distributions for S-PDRN (50–1,500 kDa) and Wb-PDRN (50–1,200 kDa).

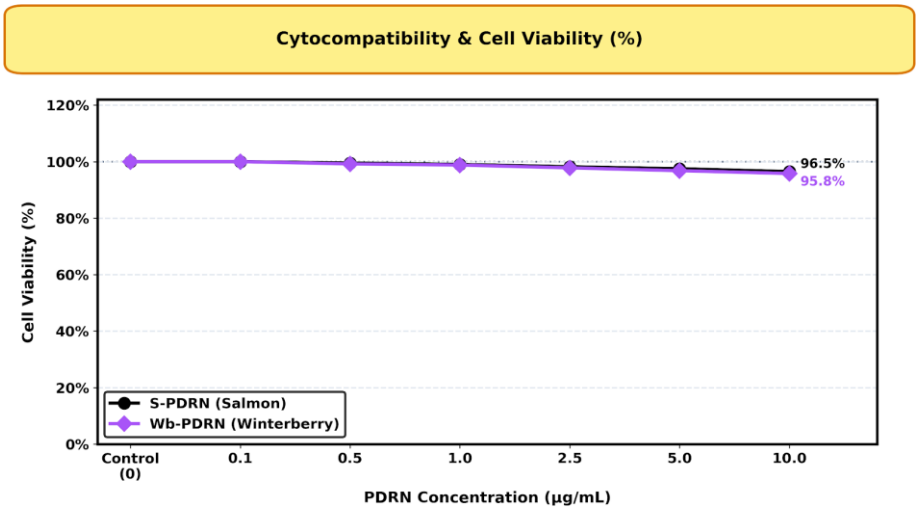


Figure 3. Concentration-dependent cytocompatibility (0.1~10 μg/mL) and cell proliferation in HDFs treated with S-PDRN or Wb-PDRN.

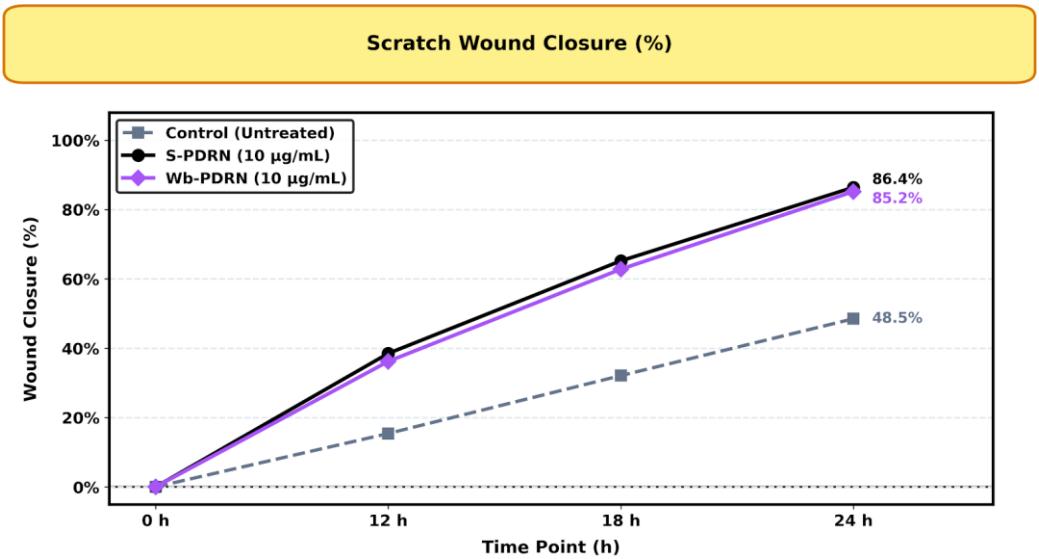


Figure 4. Microscopic image series and quantitative kinetics of HDF scratch wound closure over 24 h.

Table 2. Quantification of wound closure percentage (%) in HDF cells

Treatment Group	0 h	12 h	18 h	24 h	Statistical Significance vs. Control (24 h)
Control (Untreated)	0.0%	15.4 ± 2.1%	32.1 ± 3.5%	48.5 ± 4.2%	Reference Baseline
S-PDRN (10 µg/mL)	0.0%	38.5 ± 3.8%	65.2 ± 4.1%	86.4 ± 3.5%	$p < 0.001$
Wb-PDRN (10 µg/mL)	0.0%	36.2 ± 3.2%	62.8 ± 4.5%	85.2 ± 3.8%	$p < 0.001$ (No significant difference vs. S-PDRN)

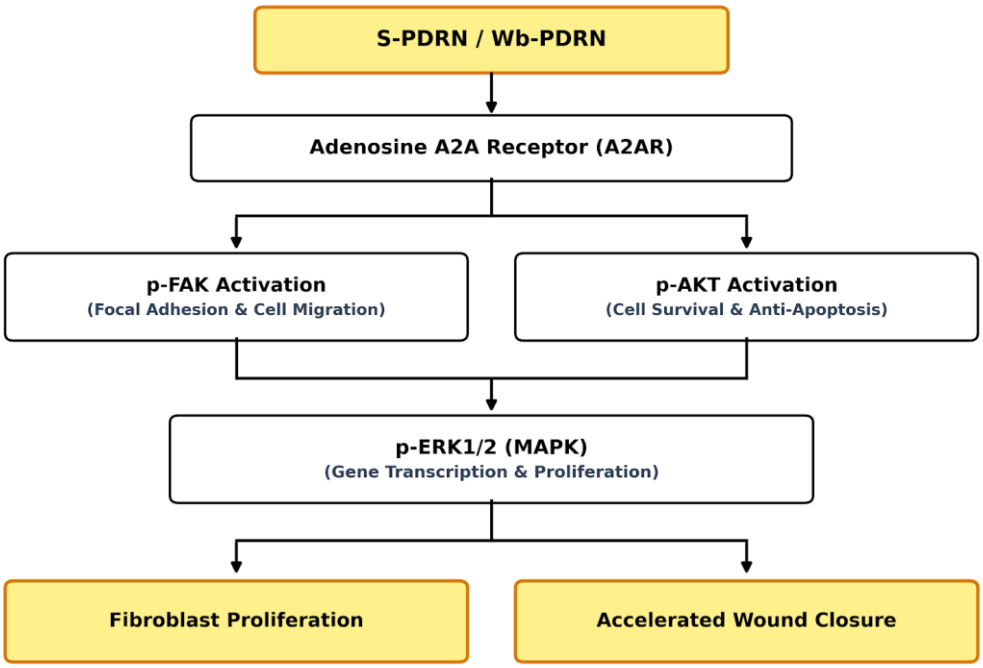


Figure 5: Western blot bands and quantitative phosphorylation ratios for A_2AR, p-FAK/FAK, p-AKT/AKT, and p-ERK1/2/ERK1/2

Proposed A2AR-Mediated Signaling Mechanism of Wb-PDRN

Wb-PDRN is proposed to exert its regenerative activity, at least in part, through adenosine A2A receptor (A2AR)-associated signaling in human dermal fibroblasts (HDFs). Previous studies have established that PDRN can stimulate the proliferation of human skin fibroblasts through purinergic A2 receptor signaling. Thellung et al. reported that PDRN significantly increased the growth of primary human skin fibroblasts, whereas the selective A2 receptor antagonist 3,7-dimethyl-1-propargylxanthine (DMPX) markedly attenuated the proliferative effect of PDRN. These findings provided early evidence that the biological activity of PDRN is associated with activation of A2-type purinergic receptors (16).

The involvement of A2AR signaling in PDRN-mediated tissue repair has also been demonstrated in wound-healing models. Galeano et al. showed that PDRN treatment enhanced wound repair and increased vascular endothelial growth factor (VEGF) expression in diabetic mice. Importantly, co-administration of DMPX abolished the beneficial effects of PDRN on wound healing and VEGF production, supporting a functional role for A2AR signaling in the regenerative response (17). These findings are consistent with the present observation that Wb-PDRN enhanced HDF proliferation and accelerated scratch wound closure, suggesting that A2AR-associated signaling may contribute to the biological activity of plant-derived PDRN.

A particularly relevant precedent is provided by Lee et al., who investigated PDRN isolated from Panax ginseng as a plant-derived alternative to animal-derived PDRN. Panax PDRN promoted proliferation and regeneration of both keratinocytes and HDFs and was shown to activate the A2A receptor. Furthermore, Panax PDRN increased the phosphorylation of focal adhesion kinase (FAK), AKT, SAPK/JNK, and ERK1/2, whereas treatment with the A2A receptor inhibitor DMPX reduced these phosphorylation responses. The authors

therefore proposed an A2AR-dependent FAK–AKT–MAPK signaling pathway underlying the regenerative activity of plant-derived PDRN (7). This finding is particularly important for the present study because Wb-PDRN similarly increased A2AR-associated signaling together with phosphorylation of FAK, AKT, and ERK1/2, suggesting that different plant sources of PDRN may share a conserved signaling mechanism involved in skin regeneration.

The downstream signaling observed in the present study is also supported by previous investigations of PDRN-induced ERK activation in human skin cells. Shin et al. demonstrated that PDRN increased ERK phosphorylation in human dermal fibroblasts and promoted fibroblast proliferation and migration. Inhibition of ERK signaling reduced the regenerative responses induced by PDRN, indicating that ERK activation contributes to PDRN-mediated fibroblast responses. Interestingly, the response was cell-type dependent, because PDRN produced different effects on ERK activity in keratinocytes and fibroblasts (18). Thus, the increased p-ERK1/2 observed following Wb-PDRN treatment in the present study provides additional support for the involvement of MAPK signaling in fibroblast proliferation and wound repair.

The relationship between A2AR signaling and fibroblast function is further supported by studies using selective A2AR agonists. Perez-Aso et al. reported that A2AR stimulation in primary human dermal fibroblasts increased physiological intracellular cAMP levels and enhanced fibroblast proliferation and collagen production. Importantly, A2AR-mediated collagen responses were associated with AKT signaling rather than canonical Smad2/3 activation (19). These findings provide a mechanistic basis for linking A2AR activation with AKT-dependent fibroblast responses relevant to tissue repair.

Taken together, the present findings and previous studies support a model in which Wb-PDRN activates or enhances A2AR-associated signaling, followed by phosphorylation of intracellular signaling molecules including FAK, AKT, and ERK1/2. Activation of these pathways may facilitate fibroblast proliferation, migration, and extracellular matrix-related responses, thereby contributing to accelerated wound closure. In the present study, Wb-PDRN treatment resulted in enhanced HDF proliferation and approximately 85% scratch wound closure at 24 h, which was comparable to the response observed with salmon-derived PDRN. The similarity between Wb-PDRN and S-PDRN in both biological activity and downstream signaling further suggests that the regenerative properties traditionally associated with animal-derived PDRN may be reproduced by a plant-derived PDRN platform.

Therefore, the A2AR–FAK/AKT/ERK1/2 signaling axis may represent an important molecular pathway contributing to the regenerative activity of Wb-PDRN. However, because the present study did not directly examine A2AR inhibition or genetic knockdown, the involvement of A2AR should be regarded as a proposed mechanism rather than a definitively established causal pathway. Further studies using selective A2AR antagonists, receptor knockdown, or pathway-specific inhibitors will be required to confirm the direct contribution of A2AR–FAK/AKT/ERK1/2 signaling to Wb-PDRN-induced fibroblast proliferation and wound closure.

IV. DISCUSSION

The primary objective of this study was to evaluate whether plant-derived PDRN (Wb-PDRN) exhibits fundamental physicochemical and signaling equivalence to conventional salmon-derived PDRN (S-PDRN) **[1]**.

Explaining the Success of Phyto-PDRN in Advanced Bio-Applications

Recent applied studies have demonstrated broad efficacy for Phyto-PDRN across multiple bio-industries:

- **Cultured Meat Media:** Aloe vera Phyto-PDRN replaced 50% of FBS in Hoengseong Hanwoo muscle satellite cell cultures while maintaining 100% cell proliferation via MyoD/Pax7 binding **[4]**.
- **Veterinary Therapeutics:** *Rubus buergeri* Phyto-PDRN complexes reduced oxidative apoptosis in feline kidney cells (CRFK) to restore cell viability to 94.1% and stimulated chondrocyte proliferation by 215.4% via A_2AR binding to mitigate canine patellar osteoarthritis **[2]**.
- **Aquaculture and Skin Barrier:** *Platycodon grandiflorus* Saponin-PDRN complexes suppressed White Spot Syndrome Virus (WSSV) replication by 99.8% and upregulated skin barrier proteins (filaggrin, loricrin, SOD1) **[3, 14]**.

The present findings explain the mechanistic basis for these application-level successes. Wb-PDRN shares the same core functional properties as S-PDRN: a low-molecular-weight DNA fragment profile (50–1,200 kDa) and selective activation of cell-surface **A_2A receptors**. Because Wb-PDRN engages the canonical **A_2AR → FAK/AKT/MAPK** pathway with potency equal to S-PDRN, its regenerative efficacy remains consistent across diverse target tissues (skin, cartilage, kidney, muscle).

Table 3. Multi-dimensional comparison of the present study with previous PDRN research

Study	Source Material	Comparison Framework	Key Endpoints and Mechanisms	Reference
Altavilla et al. (2017)	Salmon sperm	S-PDRN characterization	A2AR agonist, tissue repair, salvage pathway	Altavilla et al. (2017)
Lee et al. (2023)	Panax ginseng	Plant PDRN single study	Keratinocyte proliferation, 3D skin barrier restoration	Lee et al. (2023)
Korean Patent (2024)	Camellia / Broccoli / Rose	Plant vs. Salmon PDRN	Cytocompatibility, scratch wound closure	Korean Patent (2024)
Hong et al. (2026)	Salmon vs. Microbial-origin plant	Direct head-to-head	Physicochemical profiles, A2A-linked signaling dynamics	Hong et al. (2026)
Kim et al. (2026, AJER)	Rubus buergeri	Pet healthcare formulation	CRFK kidney protection, chondrocyte regeneration via A2AR	Kim et al. (2026, AJER)
Kim et al. (2026, WJPSR)	Platycodon grandiflorus	Saponin-PDRN complex	Dual-functional magnetic bead purification, WSSV antiviral	Kim et al. (2026, WJPSR)
Kim et al. (2026, IJEMH)	Aloe vera / Rubus buergeri	Cultured meat & pet health	FBS substitution in Hanwoo cells, blue-light protection	Kim et al. (2026, IJEMH)
Present Study	Rubus buergeri vs. Salmon	Direct standardized comparison	Physicochemical purity + A2A/FAK/AKT/MAPK mechanism	Present Study

V. CONCLUSION

This study established a standardized head-to-head comparison between salmon-derived PDRN (S-PDRN) and winterberry-derived PDRN (Wb-PDRN). Wb-PDRN exhibited high nucleic acid purity, a controlled molecular-weight distribution (50–1,200 kDa), and favorable cytocompatibility in human skin cells. When evaluated at equivalent DNA concentrations, Wb-PDRN promoted cell proliferation, accelerated scratch wound closure, and activated A_2AR-mediated FAK/AKT/MAPK signaling with potency comparable to S-PDRN. These results indicate that *Rubus buergeri*-derived PDRN is a functional non-animal alternative to salmon-derived PDRN for applications in regenerative biomaterials, cosmeceuticals, and veterinary healthcare.

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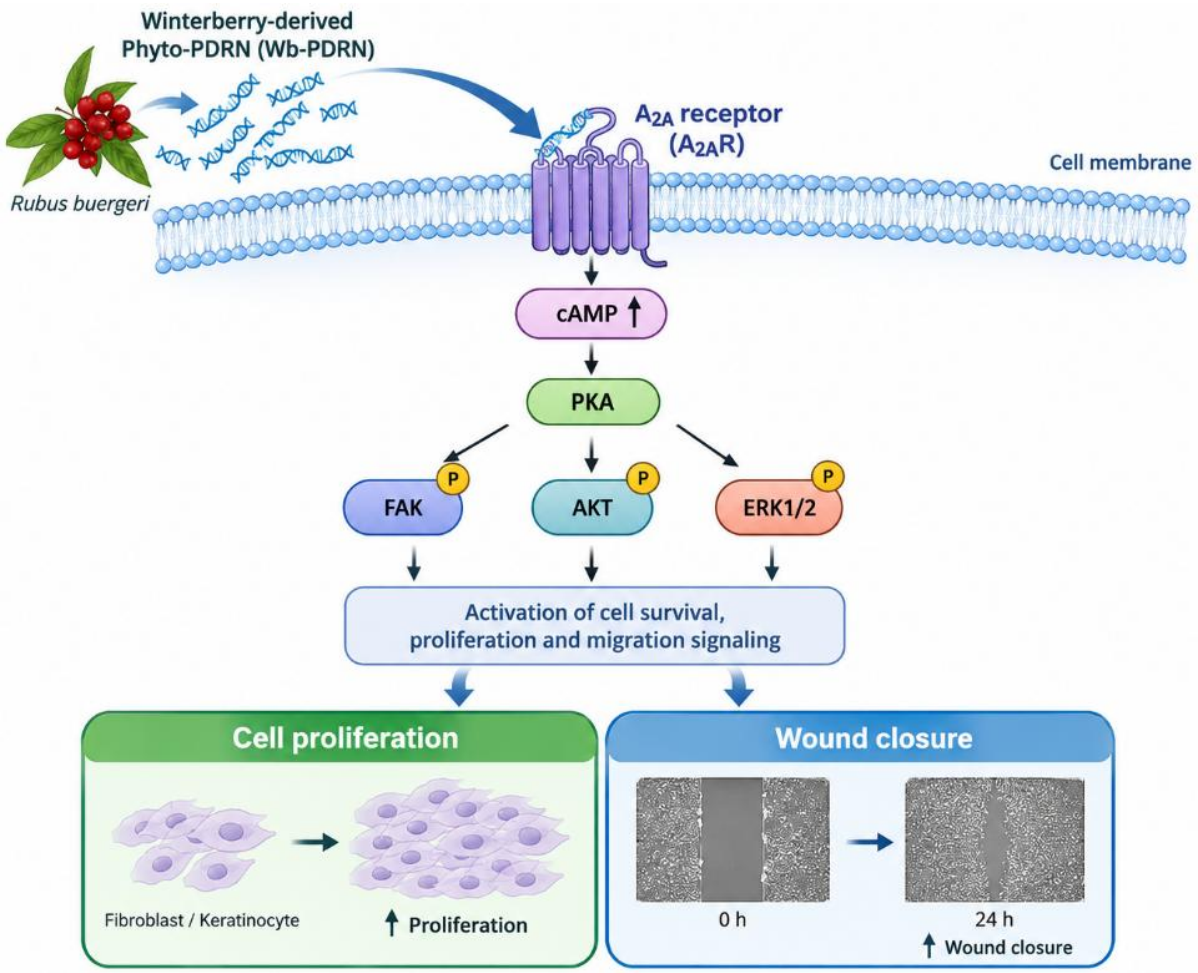


Figure 6. Proposed molecular mechanism of Wb-PDRN-induced A2AR signaling, kinase phosphorylation, cell proliferation, and wound closure.

REFERENCES

[1]. Proposed Title. Comparative Physicochemical and Biological Characterization of Salmon-Derived PDRN and Winterberry (Rubus buergeri)–Derived Phyto-PDRN. (Draft manuscript).
[2]. Kim DM, Lee JK, Lee WK, Moon HA, Cho YJ, Bae JY, Kim JW, Choi YM. Protective Effects of Plant-Derived PDRN and Phytochemical Complex from Rubus buergeri Miquel on Pet Renal Cells, Patellar Osteoarthritis Alleviation, and Functional Soft Chewable/Freeze-Dried Formulation Research. American Journal of Engineering Research (AJER). 2026;15(8):53-60.
[3]. Kim DM, Lee JK, Lee WK, Kim JY, Park SR, Choi YH. Purification of Saponin-PDRN Complex Derived from Platycodon grandiflorus Based on a Dual-Functional Magnetic Bead-Column System and Validation of its In Vitro / In Vivo Skin Regeneration, Barrier Enhancement, and WSSV Antiviral Efficacy. World Journal of Pharmaceutical Science and Research (WJPSR). 2026;5(9):77-87. doi:10.5281/zenodo.22159135.
[4]. Kim DM, Lee JK, Lee WK, Moon HA, Cho YJ, Bae JY, Kim JW, Choi YM. Purification and Bioactivity Verification of Multi-purpose Plant-derived PDRN (Phyto-PDRN): A Study on Cell-Cultured Meat Media for Hoengseong Hanwoo (FBS Alternative), Skin Barrier Recovery, and Pet Kidney/Joint Protection. International Journal of Engineering, Management and Humanities (IJEMH). 2026;7(5):26-35. doi:10.5281/zenodo.22655282.
[5].Kim DM, Lee JK, Lee WK, Moon HA, Cho YJ, Bae JY, Kim JW, Choi YM. A Study on the High-Efficiency Production and γ-Oryzanol Enrichment of Rice Bran Extract Using an Eco-Friendly Reduced-Pressure Mixed-Solvent Process. International Journal of Pharmaceutical Research and Applications (IJPRA). 2026;11(5):99-107. doi:10.5281/zenodo.22705881.
[6]. Altavilla D, Bitto A, Polito F, et al. Pharmacological activity and clinical use of PDRN. Front Pharmacol. 2017;8:224. doi:10.3389/fphar.2017.00224.
[7]. Lee KS, Lee S, Wang H, et al. Analysis of Skin Regeneration and Barrier-Improvement Efficacy of Polydeoxyribonucleotide Isolated from Panax ginseng (C.A. Mey.) Adventitious Root. Molecules. 2023;28(21):7240. doi:10.3390/molecules28217240.
[8]. Baker BJ, et al. Applications of Marine Organism-Derived Polydeoxyribonucleotide: Its Potential in Biomedical Engineering. Mar Drugs. 2021;19(6):296. doi:10.3390/md19060296.
[9]. Hong CY, Jung DW, Lee YB, et al. Comparative Analysis of Salmon-Derived, Plant-Origin, and PEG-Conjugated PDRN: Cytocompatibility and A2A-Linked Signaling Dynamics in Human Skin Cells. J Korean Soc Appl Sci Technol. 2026;43(1):197–209. doi:10.12925/jkocs.2026.43.1.197.
[10]. Korean Patent KR 10-2707680 B1. Preparation method of high-purity plant-derived PDRN with excellent storage stability and composition for anti-inflammation, skin regeneration and wound healing containing the same.
[11]. International Patent Application WO2025037843A1. Method for producing PDRN from plant.
[12]. Nguyen TH, Wang SL, Nguyen VB. Recent advances on polydeoxyribonucleotide extraction and its novel application in cosmeceuticals. Int J Biol Macromol. 2024;282:137051.

[13]. Chinese Journal of Plastic and Reconstructive Surgery. Polydeoxyribonucleotide: A promising skin anti-aging agent. 2022;4(4):187–193. doi:10.1016/j.cjprs.2022.09.015.
[14]. Zhang RJ, Zhao X, Xu W, Lee S. Platycodin D, a natural component of Platycodon grandiflorum, prevents both lysosome- and TMPRSS2-driven viral infection by hindering membrane fusion via lipid raft modulation. Exp Mol Med. 2021;53(5):956-972.
[15]. Sini JM, et al. A2A Adenosine Receptor Agonism Downregulates Inflammatory Cytokines and Matrix Metalloproteinases in Articular Chondrocytes. J Cell Physiol. 2020;235(11):8112-8123.
[16]. Thellung S, Florio T, Maragliano A, Cattarini G, Schettini G. Polydeoxyribonucleotides enhance the proliferation of human skin fibroblasts: involvement of A2 purinergic receptor subtypes. Life Sciences. 1999;64(18):1661–1674. doi:10.1016/S0024-3205(99)00104-6.
[17]. Galeano M, Bitto A, Altavilla D, et al. Polydeoxyribonucleotide stimulates angiogenesis and wound healing in the genetically diabetic mouse. Wound Repair and Regeneration. 2008;16(2):208–217. doi:10.1111/j.1524-475X.2008.00361.x.
[18]. Shin SM, Baek EJ, Kim KH, Kim KJ, Park EJ. Polydeoxyribonucleotide exerts opposing effects on ERK activity in human skin keratinocytes and fibroblasts. Molecular Medicine Reports. 2023;28:148. doi:10.3892/mmr.2023.13035.
[19]. Perez-Aso M, Fernandez P, Mediero A, Chan ES, Cronstein BN. Adenosine 2A receptor promotes collagen production by human fibroblasts via pathways involving cyclic AMP and AKT but independent of Smad2/3. FASEB Journal. 2014;28(2):802–812. doi:10.1096/fj.13-241646.