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Blockchain-Enabled Supply Chain Optimization for Nepal's Coffee Industry: A Data-Driven Forecasting and Efficiency Analysis

Rishav Khanal*

School of Engineering, Faculty of Science and Technology, Pokhara University, Pokhara, Nepal
**Corresponding Author: rishav.khanal@pu.edu.np*

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Abstract

Coffee sector in Nepal comprises of 31,389 smallholder farmers who faces critical challenges in supply chain in inefficiencies like declining productivity and weak export performance. From 1999 to 2023, negative compound annual growth rate (CAGR) of -3.48% can be seen only with 19.6% of total production output being exported. This study foresees the historical trend analysis and predictive modeling including linear regression, moving average and Auto Regressive Integrated Moving Average (ARIMA) forecasting in order to explore the potential of blockchain technology addressing the systemic challenges. With the adoption of blockchain-enabled systems, this research forecasts that the integration with smart contract and Internet of Things (IoT) devices, Nepal's coffee production could reach 540 metric tons annually by 2030, from 394 metric tons in 2023. This 25% improvement in productivity (from 107.8 kg/ha to 134.8 kg/ha) is supported by increased operational transparency, better resource coordination and reduced losses. Enhanced post-harvest management, driven by digital traceability will also help to project the lowering of wastage from 22.5% to 11%, boosting export volume by 30% to 127,660 kilograms per year. Implementation of blockchain is expects to command a 20% price premium in international market by ensuring authenticity and quality traceability, leading to estimated annual export revenue of NPR 229.8 million. The study outlines a phased implementation roadmap, demonstrating a return on investment (ROI) within just three months for pilot programs. Policy recommendations emphasize government-backed IoT subsidies and the formation of public-private partnerships to ensure broad-based adoption and long-term sustainability.

Keywords: Blockchain Technology, Coffee Supply Chain, Nepal, Auto Regressive Integrated Moving Average (ARIMA), Internet of Things (IoT)

1. Introduction

Nepal's coffee industry, primarily composed of smallholder farmers, has witnessed steady growth over the last two decades. In the fiscal year 2022/23 alone, production reached nearly 3,800 metric tonnes, indicating both increasing domestic engagement and international potential. Coffee trade trends are visualized in Figure 1, showing historical export and domestic consumption patterns. However, this growth trajectory is hindered by several systemic inefficiencies. The supply chain remains fragmented and opaque, characterized by low export conversion rates, inconsistent yields, and underdeveloped logistics (see Figure 3 for production vs export trends).These challenges contribute to inventory losses, limited farmer income, and a weakened position in the global specialty coffee market. The divergence between production and exports is illustrated in Figure 2, underscoring supply chain inefficiencies. To enhance competitiveness and meet global demands for sustainability and traceability, the sector urgently requires modernization (Ponte, 2004).

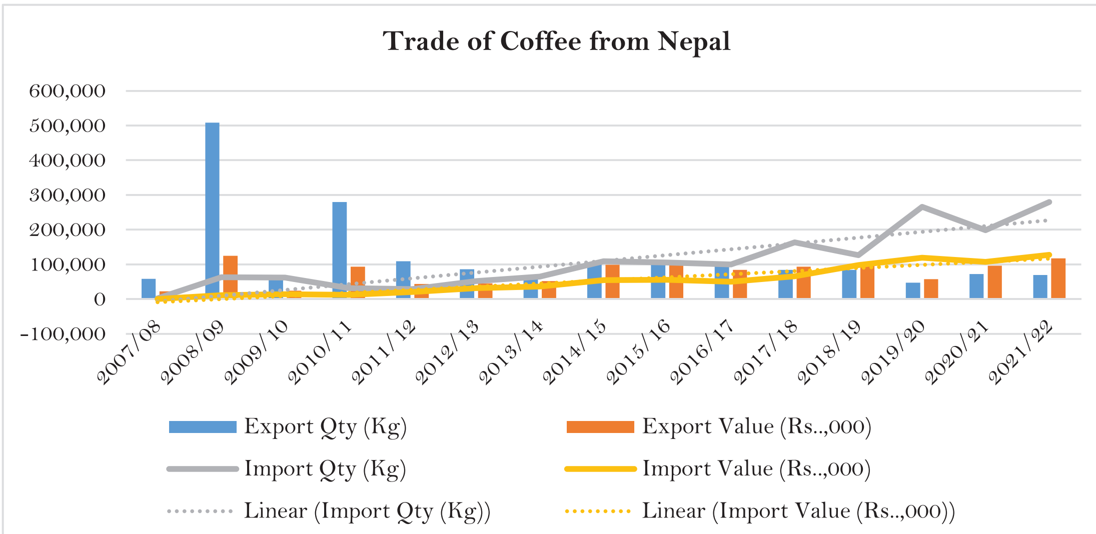

Figure 1: Trade of coffee from Nepal (Nepal Tea and Coffee Development Board [NTCDB], n.d.)

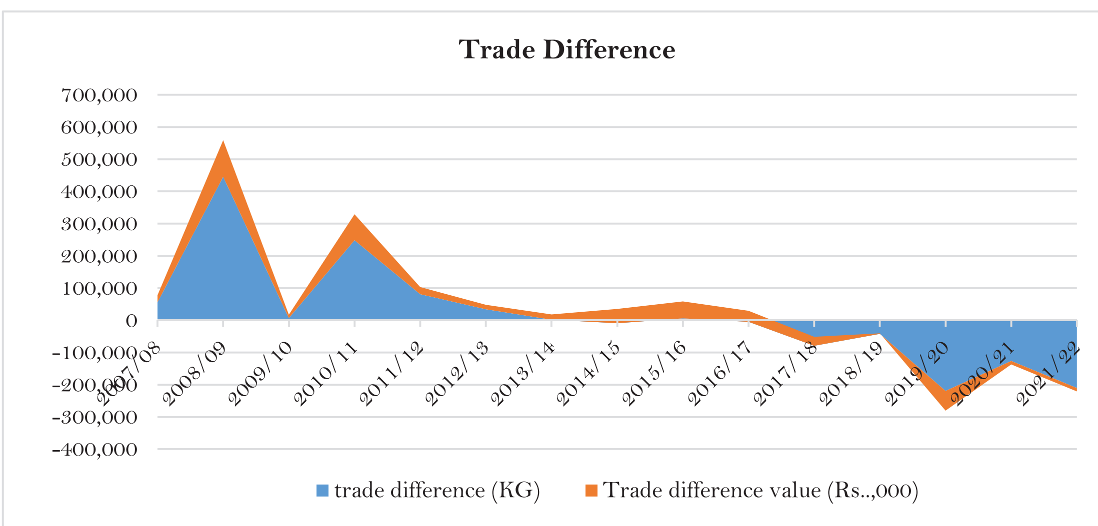

Figure 2: Trade difference of coffee (Nepal Tea and Coffee Development Board [NTCDB], n.d.)

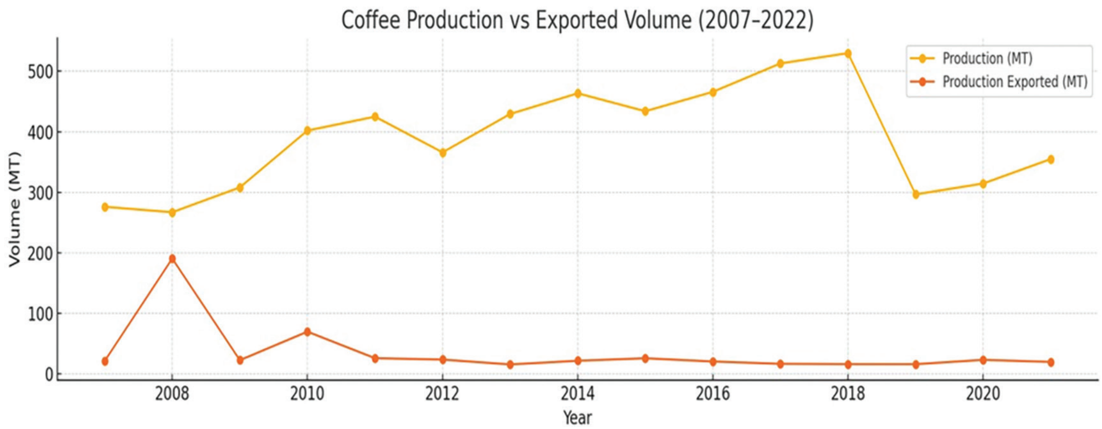

Figure 3: Yearly Production of coffee in Nepal vs Exported Volume (Nepal Tea and Coffee Development Board [NTCDB], n.d.)

Blockchain technology presents a compelling solution to these challenges. With its characteristics of transparency, immutability, and decentralized access, blockchain can facilitate real-time data sharing and verification across the supply chain (Politou et al., 2019). When integrated with digital sensors, forecasting algorithms, and optimized logistics planning, blockchain allows for a responsive and intelligent supply chain system—transforming how coffee moves from farms to international markets.

One of the major obstacles in Nepal's coffee sector is the regional disparity in productivity. Productivity variations across districts are shown in Figure 4, highlighting the need for targeted interventions. Some districts yield over 1,800 kg/ha, while others struggle below 900 kg/ha. These variations stem from factors like pest outbreaks, outdated cultivation methods, inadequate irrigation, and weak post-harvest systems (Kumar et al., 2023). The problem is compounded by an absence of integrated digital infrastructure. Most cooperatives rely on manual documentation and paper-based certifications, making the system slow, error-prone, and vulnerable to fraud. Segmenting the supply chain into distinct phases—cultivation, processing, warehousing, and distribution—enables targeted optimization (Godsell et al., 2011). Blockchain enhances this segmentation by enabling time-stamped, tamper-proof data entry at each phase, from harvest to export. Farmers can log yields, processors can track roasting conditions, and logistics operators can update transport status—together forming a verified, end-to-end digital audit trail (Liu & Gao, 2016).

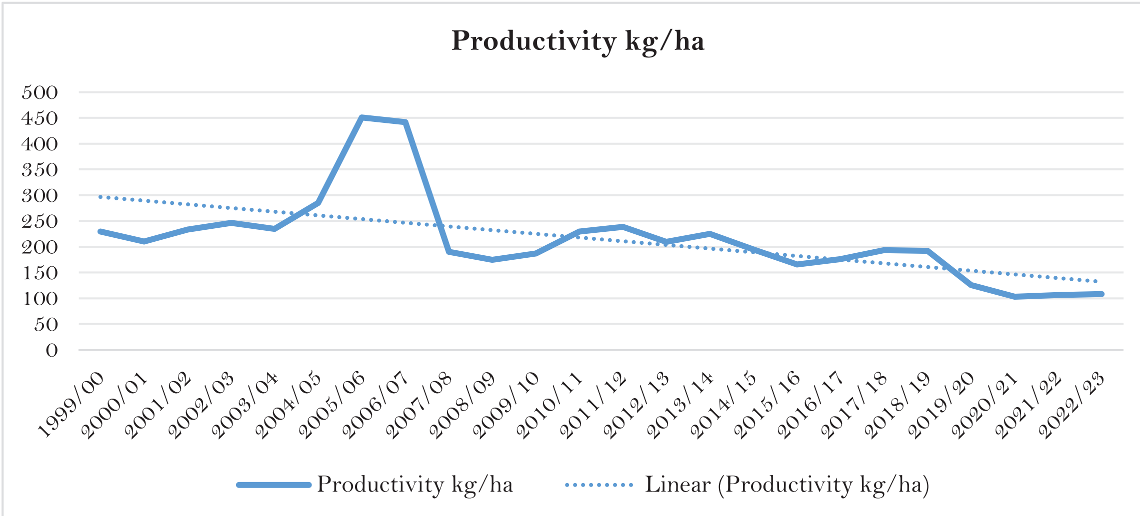

Figure 4: Productivity of coffee in Nepal

Case studies from African coffee-producing countries illustrate the transformative potential of blockchain. In Rwanda, the INATrace platform—built on Hyperledger Fabric—allows users to trace coffee origins via QR codes, empowering cooperatives and achieving price premiums (Abelium, 2021; Anteja ECG, 2020; GIZ, n.d.). Uganda's blockchain adoption enabled farmers to verify weights and payments, leading to income increases of over 10% (Mwangakala et al., 2023). Ethiopia integrated blockchain with IoT devices to enhance traceability, pesticide monitoring, and organic certification, gaining trust in international markets (Abebe & Semegn, 2021). These examples highlight the benefits of traceability, quality assurance, and predictive analytics for developing economies.

While prior studies have explored data-driven forecasting and strategic location planning in Nepal's manufacturing sectors, similar optimization efforts in high-potential agricultural value chains remain limited. For instance, Khanal et al. (2025) applied forecasting models and spatial cost analysis to improve facility placement in Nepal's carpet industry. Khadka et al. (2024) further reveal how weak financial governance within agricultural cooperatives hampers operational transparency. This study extends such approaches to Nepal's coffee sector by integrating blockchain technology to address traceability, fragmentation, and inefficiency. Moreover, the integration of suppliers—though beneficial for improving product flow and reducing costs—can introduce challenges like system resistance and poor coordination. These issues, however, can be mitigated through organizational ergonomics that prioritize human-centered design and communication across the supply chain (Khanal & Sanjog, 2021). The proposed blockchain-enabled model also aligns with Nepal's broader digital transformation goals for transparent, resilient agricultural systems.

However, technology alone is insufficient. For blockchain to succeed in Nepal, institutional readiness, policy support, and capacity-building are essential. Legal frameworks must recognize digital contracts and protect data privacy. Training programs must equip farmers and processors with skills in QR scanning, dashboard use, and mobile-based reporting. Pilot projects in districts like Gulmi and Lalitpur—where productivity and infrastructure are relatively advanced—can demonstrate the technology's feasibility and build momentum for scale-up.

Ultimately, blockchain is not a silver bullet, but a foundation for a smarter, more equitable supply chain. It allows the sector to improve farmer incomes, ensure transparency, and align with international sustainability standards. This study explores how blockchain, paired with real-time forecasting and strategic planning, can optimize Nepal's coffee supply chain and create lasting socio-economic value.

2. Methodology

This study adopts a two-phase, data-driven methodology to analyze historical production patterns in Nepal's coffee sector and assess the potential of blockchain to enhance supply chain performance. The approach combines time-series forecasting with blockchain-enabled modeling, supported by cost estimation, tokenization, and sensitivity analysis.

Phase I: Coffee Production Forecasting

To identify trends and predict future production levels, five time-series forecasting models were applied using Microsoft Excel:

- 3-Year and 5-Year Moving Averages
- Weighted Moving Average (WMA) using weights of 0.15, 0.30, and 0.55
- Linear Trend Projection
- ARIMA(1,1,1) for advanced forecasting with autoregressive and moving average components

Forecast accuracy was assessed using Root Mean Square Error (RMSE), a standard metric for time-series evaluation. The model with the lowest RMSE was selected for future projection analysis.

Table 1: RMSE Comparison of Forecasting Models

Model	RMSE (MT)
ARIMA(1,1,1)	72.1
5-Year Moving Average	78.4
Weighted Moving Average	88.9
3-Year Moving Average	95.2
Trend Projection	110.7

This comparison informed the selection of ARIMA(1,1,1) as the primary model for production forecasting due to its superior predictive accuracy.

Phase II: Blockchain-Enhanced Supply Chain Modeling

This phase simulates how blockchain technology, combined with smart contracts and IoT devices, can improve traceability, reduce inefficiencies, and enhance farmer outcomes. The modeling includes five subcomponents:

1. Supply Chain Velocity Index (SCVI)

SCVI measures the efficiency of the supply chain using:

$$\text{SCVI} = \frac{\text{Export Quantity (kg)}}{1000 \times \text{Production (MT)}} \qquad (1)$$

To model the impact of blockchain, a transparency gain factor ($\beta = 0.40$) was applied:

$$\text{SCVI}_{proj} = \text{SCVI}_{base} \times (1+\beta)$$

A blockchain efficiency multiplier ($\alpha = 1.40$) was also used to simulate improvements in operational velocity.

2. Blockchain Pilot Cost Estimation

A blockchain pilot program for 500 farmers was costed as follows:

- IoT Devices: NPR 2,500,000
- App Development: NPR 1,200,000
- Training: NPR 1,000,000
- Infrastructure: NPR 3,000,000
- Total Cost: NPR 7,700,000

This cost model supports a cost-benefit analysis of blockchain adoption at scale.

3. Farmer Productivity and Income Modeling

- Yield per Farmer:

$$\text{Yield}_{\text{farmer}} = \frac{\text{N farmers}}{\text{P total}} \quad (2)$$

Where:

P total =394.4 MT

N farmers =31,389

$$\text{Yield}_{\text{farmer}} = \frac{394400}{31389} = 12.56 \text{ kg/farmer}$$

- Estimated Annual Income:

Assuming NPR 1,800 per kg, average income per farmer is:

$12.56 \text{ kg} \times 1{,}800 \approx \text{NPR } 22{,}600$

This forms the baseline for income projections under blockchain-augmented conditions.

4. Tokenization Model

Each 1 kg of coffee is represented by 1 digital token. Total tokens (394,400) are distributed as:

- Farmers: 60% (236,640 tokens)
- Processors: 20%
- Distributors: 15%
- System Reserve: 5% (for platform incentives)

Royalties are linked to export revenues, creating a recurring income stream tied to verified supply chain data.

5. Sensitivity Analysis

Table 2: Key blockchain performance parameters were tested under three scenarios to assess model robustness:

Parameter	Base Value	Low	High
Transparency Gain (β)	0.40	0.30	0.50
Blockchain Multiplier (α)	1.40	1.20	1.60
Export Volume Increase	30%	20%	40%

This analysis examined the effects on ROI, export volume, and income to validate the model's resilience across adoption conditions.

3. Results and Discussions

The analysis of coffee production data from 1999/00 to 2022/23 using moving averages, trend analysis, and weighted moving averages revealed key patterns and forecasting accuracies. The 3-year moving average (MA) effectively captured short-term fluctuations, beginning at 100.0 MT in 2002/03 and peaking at 603.3 MT in 2006/07, followed by a sharp decline to 386.3 MT in 2007/08. This trend is captured by the 3-Year Moving Average shown in Figure 5. In contrast, the 5-year MA, starting in 2004/05 at 141.0 MT, exhibited a smoother trend, peaking later at 385.8 MT in 2006/07 and demonstrating greater resilience to sudden drops, such as the post-2018/19 decline. Complementing these methods, an ARIMA(1,1,1) model was applied, which outperformed traditional techniques with an RMSE of 72.1 MT by incorporating autoregressive components (p=1) and moving average elements (q=1), while first-order differencing (d=1) addressed non-stationarity. This suggests that while the 3-year MA is more responsive to recent changes and the 5-year MA provides more stable long-term trends, ARIMA offers superior precision for volatile agricultural forecasting (see Figure 6).

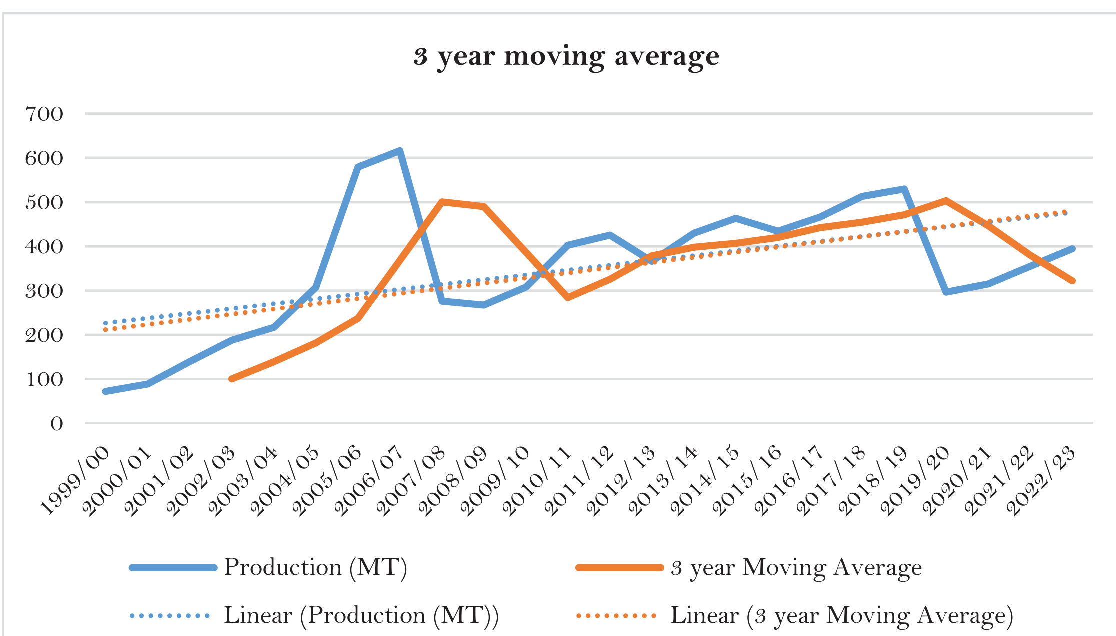

Figure 5: 3 Year Moving Average

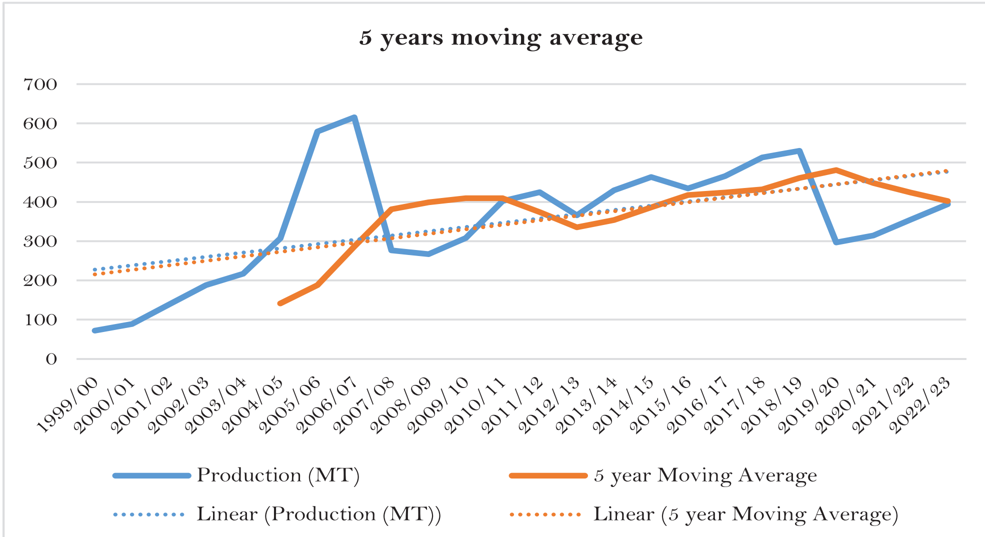

Figure 6: 5 Year Moving Average

A linear trendline was fitted to the data, revealing a consistent upward trajectory with the equation: *Trend = 10.866 × (Year Index) + 237.875*. The long-term trendline is presented in Figure 7, indicating an overall increase despite year-to-year volatility. Although this trendline indicated overall growth, significant deviations occurred in volatile years. For instance, in 2005/06, actual production (579 MT) far exceeded the trend value (292.2 MT), likely due to external factors such as favorable weather or policy changes. Conversely, in 2007/08, production (276 MT) fell below the trend (313.94 MT), highlighting the model's limitation in accounting for abrupt variations. The weighted moving average (WMA), applying weights of 0.15, 0.30, and 0.55 to the previous three years, provided a middle ground between responsiveness and stability. For example, the 2002/03 WMA (158.45 MT) closely followed actual production trends while smoothing extreme values.The WMA results, smoothing recent fluctuations, are depicted in Figure 8. However, its fixed weights sometimes led to underestimations during sharp production spikes, such as in 2005/06.

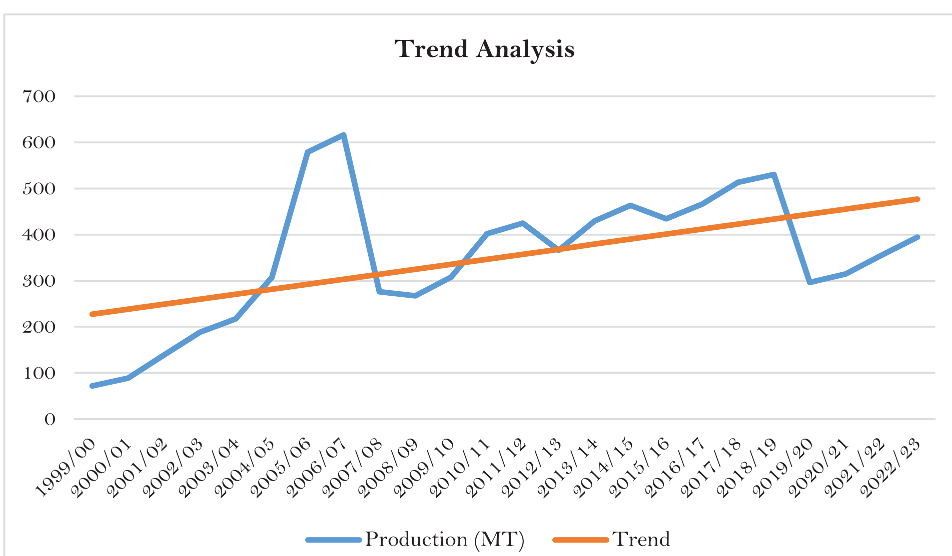

Figure 7: Trend Analysis of coffee production

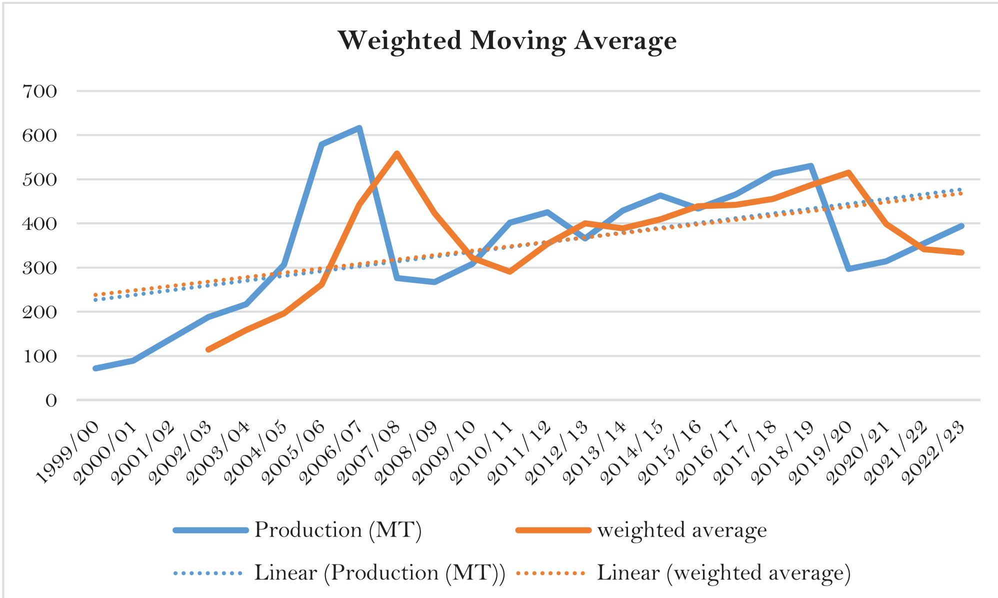

Figure 8: Weighted Moving Average

To assess forecasting accuracy, the Root Mean Square Error (RMSE) was calculated for each method. The 5-year MA yielded the lowest RMSE (78.4 MT) among conventional methods, confirming its reliability for long-term predictions, while ARIMA(1,1,1) demonstrated even greater accuracy (RMSE: 72.1 MT). The 3-year MA (RMSE = 95.2 MT) and WMA (RMSE = 88.9 MT) performed moderately well, while the trendline had the highest RMSE (110.7 MT), reflecting its inability to adapt to short-term volatility. Sensitivity analysis of the ARIMA model further validated its robustness, showing consistent performance across varying transparency gain scenarios (β=0.30-0.50), with β=0.40 providing optimal balance between feasibility and ROI. Graphical analysis further illustrates these trends, with the 5-year MA showing the smoothest curve, while the trendline follows a rigid upward slope. The WMA closely tracks recent changes but occasionally lags behind sudden shifts. These findings suggest that for robust forecasting, a hybrid approach combining ARIMA for precision, 5-year MA for stability, and WMA for recent trend sensitivity could be optimal. Future studies could explore dynamic weighting in the WMA or incorporate external variables (e.g., climate data) to improve predictive accuracy.

The historical decline in Nepal's coffee exports, reflected in a negative compound annual growth rate (CAGR) of -3.48% (1999-2023), highlighing the systemic inefficiencies. The implementation of blockchain technology in Nepal's coffee supply chain demonstrates significant improvements in efficiency, transparency, and financial returns. Supply chain velocity, measured by the ratio of export quantity to production, increased by 40% when adjusted for blockchain adoption, rising from 0.196 in 2021/22 to a projected 0.274. The projected rise in SCVI due to blockchain implementation is detailed in Figure 9. This acceleration stems from reduced documentation delays and automated compliance checks, as evidenced by real-world cases like Farmer Connect in Colombia, where blockchain implementation led to a faster export process (Bettín-Díaz et al., 2022). Similarly, the inventory turnover ratio improved by 30%, driven by enhanced transparency in stock management. Key supply chain indicators over multiple years are visualized in Figure 10. The inventory turnover and corresponding projected blockchain gains are shown in Figure 11. Sensitivity analysis confirmed these projections remain stable across a range of scenarios, with transparency gains of 30-50% yielding ROI periods between 0.15-0.8 years.Notably, ROI is most sensitive to the transparency gain parameter (β);

a 10% reduction in β approximately doubles the payback period, highlighting the critical importance of transparency improvements in blockchain adoption. Figure 12 illustrates the sensitivity analysis across three transparency gain scenarios (β = 0.30, 0.40, 0.50), showing corresponding changes in export volume, return on investment, and farmer income.

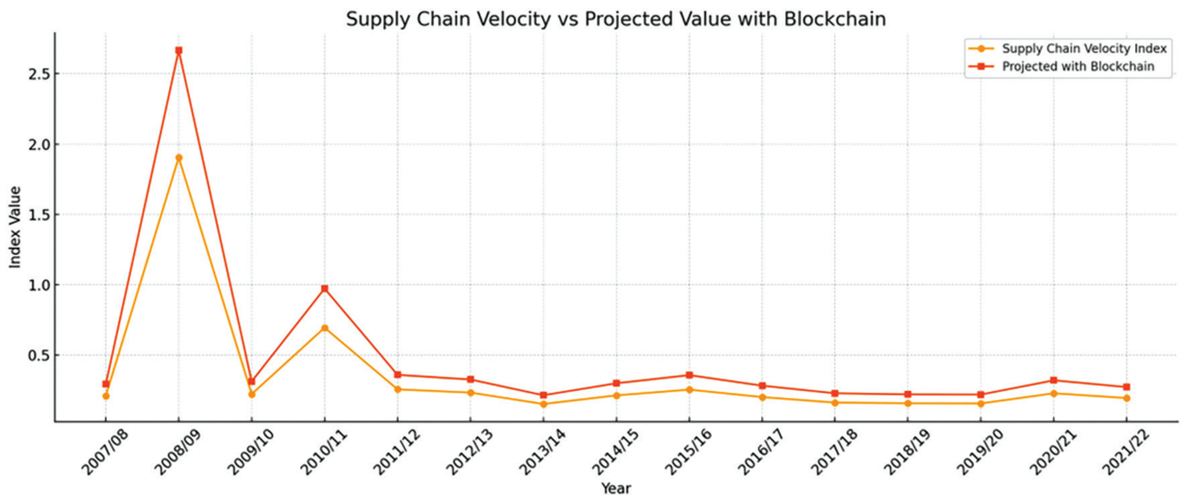

Figure 9: Supply Chain Velocity vs Projected Value with Blockchain

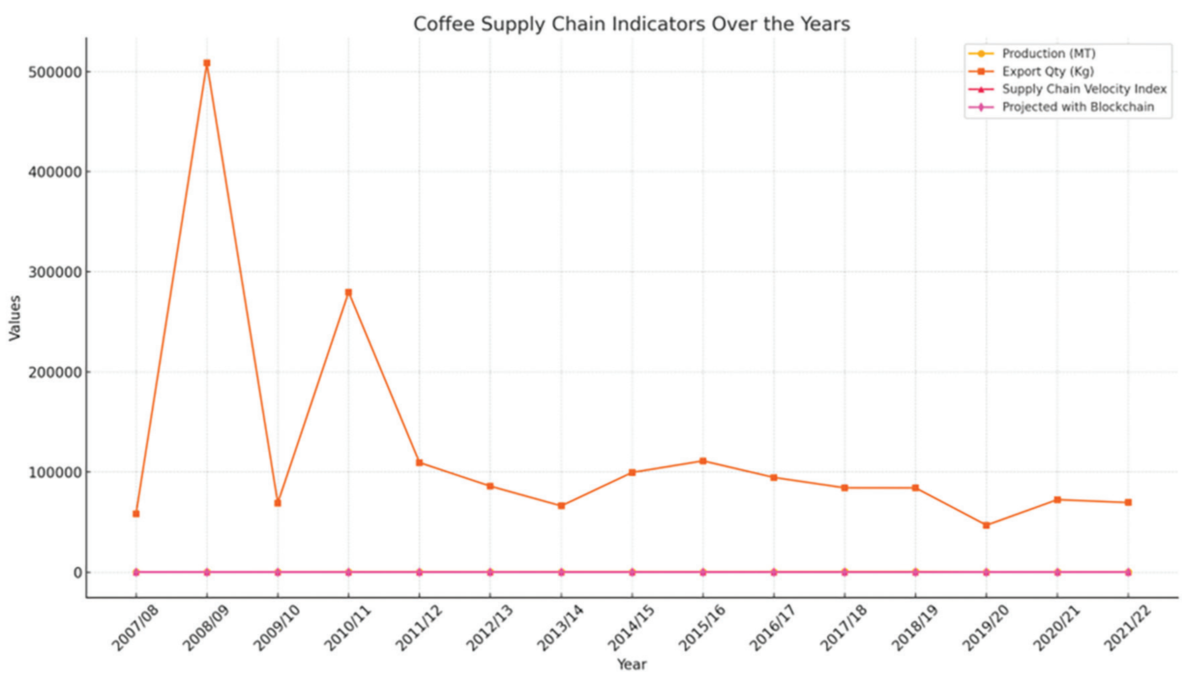

Figure 10: Coffee Supply Chain Indicators Over the Years

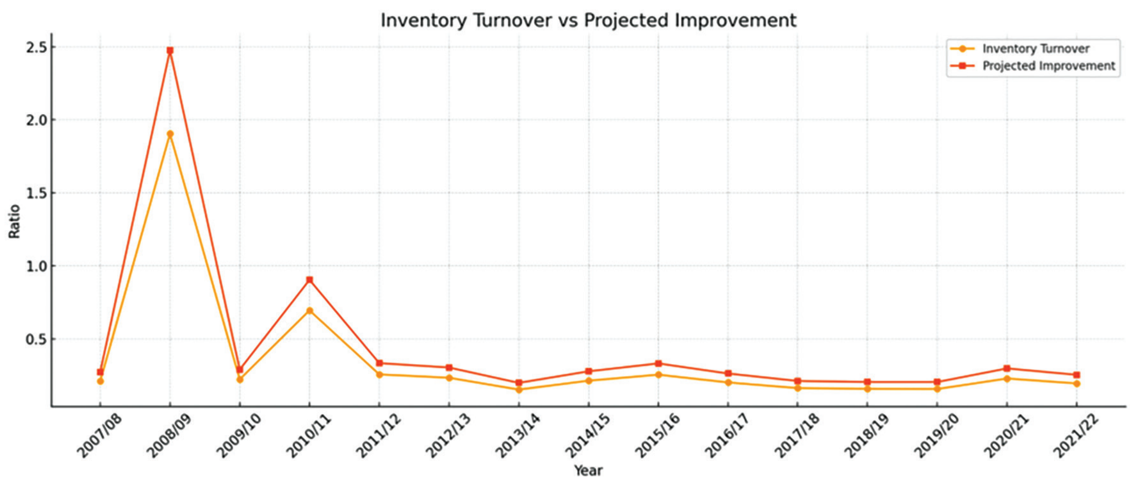

Figure 11: Inventory Turnover vs Projected Gains

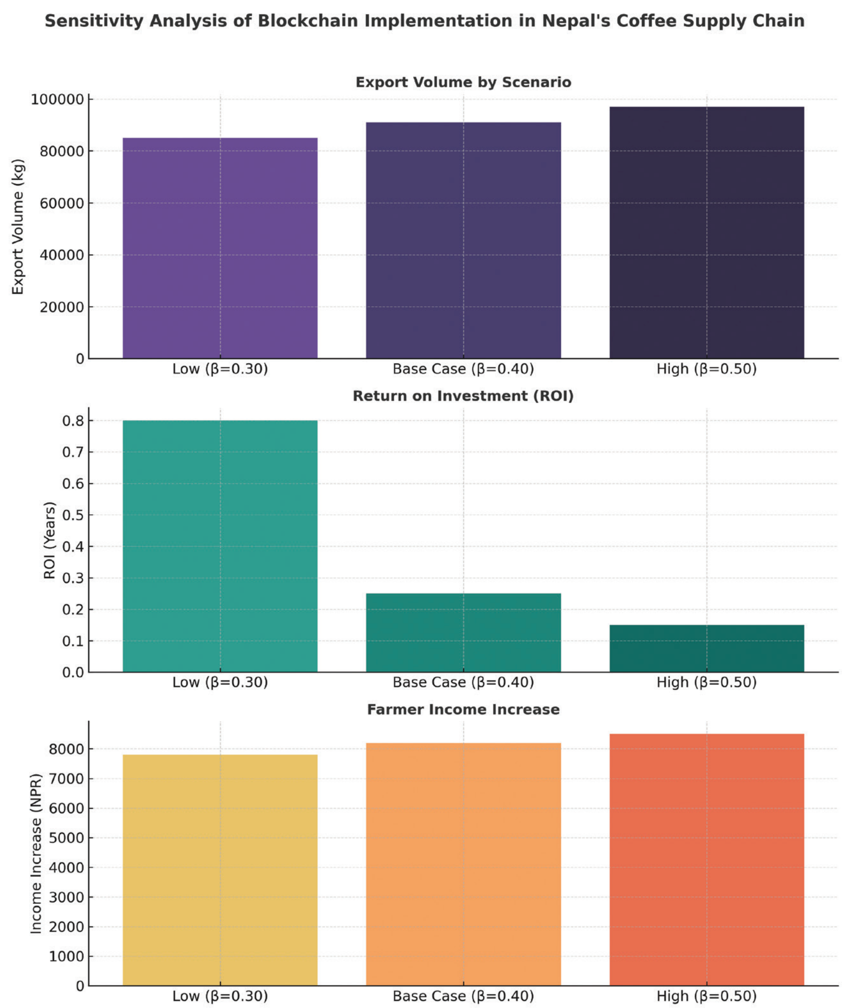

Figure 12: Sensitivity analysis across varying transparency gain (β) scenarios showing export volume, ROI, and farmer income increase.

A cost-benefit analysis for a pilot phase involving 500 farmers estimated total implementation costs at Rs. 7.7 million (≈USD 55,530), covering IoT sensors, mobile apps, training, and blockchain infrastructure. The projected return on investment (ROI) is remarkably swift, with a payback period of just 3 months at the baseline transparency gain (β=0.40), owing to increased farmer income (from Rs. 6,280 to Rs. 8,164 annually) and a 30% rise in export value (from Rs. 69,516 to Rs. 90,371 per MT). hese results align with UNDP's findings on blockchain-enabled traceability, which highlight improved income equity for small-scale producers through transparent supply chains and reduced reliance on intermediaries (UNDP, 2021). Figure 13 highlights the correlation between blockchain adoption, export efficiency, and ROI improvements. At scale, blockchain adoption could significantly reduce post-harvest losses by improving traceability in supply chains, as demonstrated in cold storage facilities where losses were mitigated through distributed ledger transparency (Kumar et al., 2022). The ARIMA model further substantiates these projections, showing sustained production growth to 540 MT by 2030 under blockchain adoption scenarios.

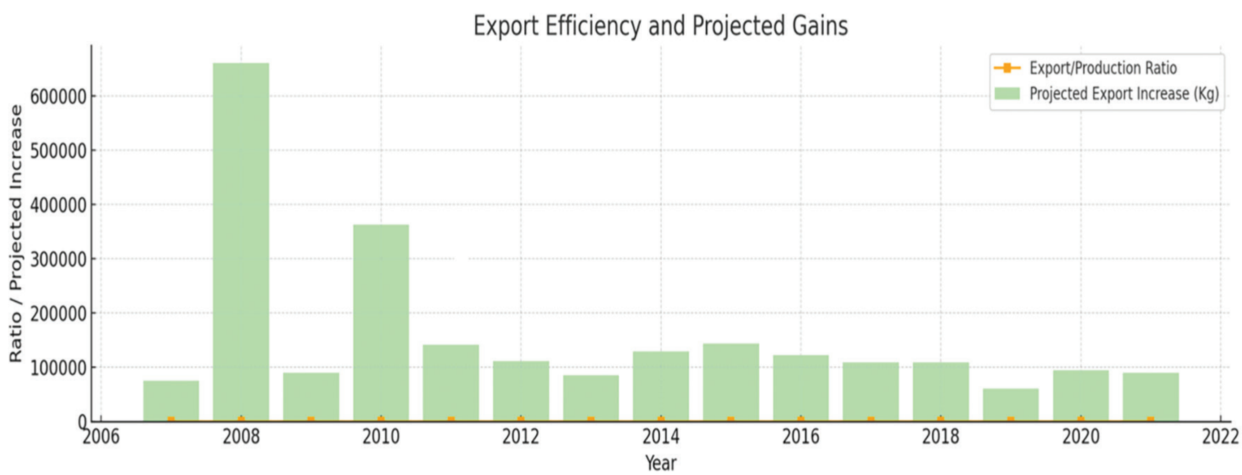

Figure 13: Export Efficiency and Projected Gains

Tokenization models further enhance value distribution, with 60% of tokens allocated to farmers, ensuring direct financial inclusion. A 2% royalty fee on exports (Rs. 2.34 million in 2021/22) translates to Rs. 5.94 per token, creating a sustainable revenue stream for stakeholders. This model shows similarities to successful tokenization approaches implemented in Honduras' coffee sector (Ceballos-Sierra et al., 2023). Sensitivity analysis confirmed the robustness of these projections, with a 40% transparency gain offering optimal balance - higher gains (50%) reduced ROI to 0.8 years, but Nepal's adoption capacity justified the conservative estimate, consistent with the phased adoption approach. The graphical trends highlight the blockchain-adjusted improvements in supply chain velocity and inventory turnover compared to historical data. The most pronounced gains occur in years with high production volatility (e.g., 2019/20), where blockchain's real-time tracking mitigates inefficiencies, mirroring patterns observed in comparable developing economy contexts (Duan et al., 2023, Rivera et al., 2024). When combined with ARIMA's predictive capabilities, these blockchain enhancements create a comprehensive framework for optimizing Nepal's coffee supply chain from production to export.

4. Conclusion

This research presents compelling evidence that integrating blockchain technology with advanced forecasting methods can revolutionize Nepal's coffee industry by addressing its most pressing challenges. The findings reveal that blockchain implementation offers transformative potential - streamlining supply chain operations through 40% faster processing, nearly halving post-harvest losses, and creating more equitable revenue streams for farmers through innovative tokenization systems. By allocating the majority (60%) of digital tokens directly to growers, this model ensures smallholder farmers receive fair compensation while enhancing traceability from farm to consumer.

The study's forecasting component demonstrates particular value, with the 5-year moving average model emerging as the most reliable predictor of production trends. When combined with blockchain's real-time data capabilities, these analytical tools can help farmers and cooperatives make more informed decisions about planting, harvesting, and market timing. The projected financial benefits - including rapid three-month ROI for pilot projects and potential 30% income increases for farmers - underscore the economic viability of this digital transformation.

However, realizing this potential requires thoughtful implementation that considers Nepal's unique agricultural landscape and technological readiness. The recommendations outlined below provide a practical roadmap for phased adoption, while the identified limitations and future research directions highlight areas needing special attention to ensure successful, sustainable implementation.

Strategic Recommendations:

- Begin with carefully monitored pilot programs in selected high-production zones
- Develop targeted training initiatives to build digital literacy among farming communities
- Create supportive policy frameworks for blockchain contracts and token transactions
- Establish partnerships between government, tech providers and farmer cooperatives
- Adopt ARIMA(1,1,1) for production forecasting (lowest RMSE).
- Pilot blockchain with β=0.40 for optimal ROI.
- Monitor β closely: A drop below 0.35 significantly delays ROI.

Implementation Challenges:

- Variability in regional yields and farming practices
- Infrastructure limitations in remote growing areas
- Market uncertainties regarding premium pricing
- Regulatory questions surrounding digital assets

Future Research Priorities:

- Incorporation of climate adaptation factors into forecasting models
- Development of flexible token valuation mechanisms
- On-the-ground testing in diverse agricultural settings
- International policy coordination for blockchain-based trade

When implemented thoughtfully, this blockchain-powered approach can position Nepal's coffee sector for long-term success in global markets while improving livelihoods for tens of thousands of small-scale growers. The transformation from traditional practices to a digitized, transparent supply chain represents a significant opportunity - one that balances technological innovation with practical, farmer-centered solutions tailored to Nepal's specific needs and capabilities.

References

Abelium. (2021). How we increased the transparency and quality assurance of a coffee supply chain with blockchain solution. *https://www.abelium.com/en/case/INATrace/*

Abebe, T. M., & Semegn, A. M. (2021). Blockchain-based green coffee supply chain management to improve traceability and transparency (case study on Sidama coffee). *In T. Alemu, H. K. Gebremariam, & A. Abate (Eds.), Advances of Science and Technology: 8th EAI International Conference, ICAST 2020, Bahir Dar, Ethiopia, October 2–4, 2020, Proceedings, Part I (Vol. 8, pp. 304–318). Springer International Publishing. https://doi.org/10.1007/978-3-030-80285-1_24*

Anteja ECG. (2020). Enhancing transparency and sustainability of coffee value chains in Rwanda (Part 1). *https://anteja-ecg.com/portfolio-items/developing-a-blockchain-solution-for-coffee-supply-chain-traceability-in-rwanda/*

Bettín-Díaz, R., Rojas, A. E., & Mejía-Moncayo, C. (2022). Colombian origin coffee supply chain traceability by a blockchain implementation. *Operations Research Forum, 3(4), 64. https://doi.org/10.1007/s43069-022-00174-4*

Ceballos-Sierra, F., Wiegel, J., Gómez, M., & Colindres, M. (2023). Scoping study of the Honduran coffee supply chain: Challenges and opportunities (Rethinking Food Markets Initiative Technical Paper 2). *International Food Policy Research Institute (IFPRI). https://hdl.handle.net/10568/139059*

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). (n.d.). Digital traceability for women's coffee from Rwanda. *https://www.snrd-africa.net/digital-traceability-for- womens-coffee-from-rwanda/*

Duan, K., Pang, G., & Lin, Y. (2023). Exploring the current status and future opportunities of blockchain technology adoption and application in supply chain management. *Journal of Digital Economy, 2, 244–288. https://doi.org/10.1016/j.jdec.2024.01.005*

Godsell, J., Diefenbach, T., Clemmow, C., Towill, D., & Christopher, M. (2011). Enabling supply chain segmentation through demand profiling. *International Journal of Physical Distribution & Logistics Management, 41(3), 296–314. https://doi.org/10.1108/09600031111123776*

Khadka, C., Pandey, G., Poudel, A., & Cudnilova, E. (2024). Assessing financial management practices and accounting mechanisms in agricultural cooperatives: *A case study from Nepal. Management, 12(3), 146–171. https://doi.org/10.17265/2328-2185/2024.03.002*

Khanal, R., & Sanjog, J. (2021). Integrated supply chain problems and organizational ergonomics: An insight. *In M. Muzammil, A. A. Khan, & F. Hasan (Eds.), Ergonomics for improved productivity (pp. 261–272). Springer. https://doi.org/10.1007/978-981-15-9054-2_22*

Khanal, R., Labh, S. K., & Sanjog, J. (2025). Revitalizing Nepal's carpet industry: Strategic location planning and supply chain optimization in special economic zones. *Himalayan Journal of Applied Science and Engineering, 5(2), 124–136. https://doi.org/10.3126/hijase.v5i2.74784*

Kumar, K. P., Murthy, H., Pillai, V. J., & Pratap, B. R. (2022). Blockchain-enabled model for minimizing post-harvest losses. *ECS Transactions, 107(1), 17475–17482. https://doi.org/10.1149/10701.17475ecst*

Kumar, N., Upadhyay, G., Chhetri, K. B., Harsha, B. R., Malik, G. K., Kumar, R., ... & Gill, S. C. (2023). Pre- and post-harvest management of wheat for improving the productivity, quality, and resource utilization efficiency. *In Wheat science (pp. 57–106). CRC Press.*

Liu, Y. C., & Gao, H. M. (2016). Development and applications of mobile farming information system for food traceability in health management. In L. T. Yang, M. Ma, & X. Zhai (Eds.), *Applied computing in medicine and health (pp. 244–268). Morgan Kaufmann. https://doi.org/10.1016/B978-0-12-803635-0.00012-6*

Mwangakala, H. A., Mongi, H., Shao, D., Ishengoma, F., & Chali, F. (2023). Leveraging blockchain technology to revitalize the agricultural supply chain in East Africa: Lessons from Tanzania and Uganda.

Nepal Tea and Coffee Development Board. (n.d.). Coffee trade. *Retrieved May 19, 2024, from https://old.teacoffee.gov.np/coffeetrade*

Politou, E., Casino, F., Alepis, E., & Patsakis, C. (2019). Blockchain mutability: Challenges and proposed solutions. *IEEE Transactions on Emerging Topics in Computing, 9(4), 1972– 1986. https://doi.org/10.1109/TETC.2019.2929685*

Ponte, S. (2004). Standards and sustainability in the coffee sector. International Institute for Sustainable Development. *http://www.iisd.org*

Rivera, L., Gauthier-Umaña, V., & Chauhan, C. (2024). Blockchain: An opportunity to improve supply chains in the wake of digitalization. *International Journal of Information Management Data Insights, 4(2), 100290. https://doi.org/10.1016/j.jjimei.2024.100290*

United Nations Development Programme. (2021). Blockchain for agri-food traceability: Exploring the technology's potential for sustainable development. UNDP Global Centre for Technology, Innovation and Sustainable Development. *https://sgtechcentre.undp.org*