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Production to market: Understanding the multi-layered challenges in apple supply chain networks

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Abstract
Background: Apple cultivation is a vital component of the horticultural economy in Himachal Pradesh, India, contributing significantly to Grower's livelihoods and the state's agricultural output. However, growers across the region face a range of persistent challenges that hinder productivity and profitability. This study examines the challenges encountered by apple growers across the major apple-producing regions in Himachal Pradesh, India.
Methods: Using multistage and convenience sampling, 535 growers were given a structured questionnaire with 58 items rated on a 5-point Likert scale. The internal consistency of the four identified dimensions of challenges incorporated in the apple industry—production, marketing, finance, and supply chain—was examined (Cronbach's alpha = 0.917). Welch ANOVA. Assumption testing revealed non-normal data distributions and unequal variances for some variables, necessitating the use of Welch ANOVA and the Games-Howell post hoc test.
Results: The analysis revealed statistically significant block-wise differences in both production challenges and supply chain challenges. Specifically, production challenges were significantly greater in Pooh and Karsog compared to Rohru, while supply chain issues were most severe in Rohru, differing significantly from Pooh, Karsog, and Janjehli. No significant differences were found across blocks for marketing and financial challenges, suggesting these are uniformly experienced.
Conclusion: These findings highlight the need for targeted interventions: infrastructure improvements in Rohru to address supply chain bottlenecks, and localized support in Pooh and Karsog for mitigating production-related difficulties. The use of robust statistical methods strengthens the reliability of these insights and supports evidence-based policy planning to enhance apple farming sustainability in the region.

Keywords: Supply chain management, apple cultivation, regional disparities, agricultural challenges

Introduction

The horticulture sector, particularly apple cultivation, holds immense importance in Himachal Pradesh, both economically and socially. Apples are a major cash crop in the region, contributing significantly to household incomes, rural employment, and state revenue. However, the sustainability and profitability of apple farming are frequently challenged by various structural, environmental, and operational issues. Growers often face difficulties that extend beyond cultivation, including inadequate infrastructure, supply chain inefficiencies, and financial constraints.

In this context, it becomes essential to assess and understand the multidimensional challenges encountered by apple growers. This study aims to analyze these challenges across different regions (blocks) of Himachal Pradesh, using empirical data to explore how factors such as production conditions, logistics, marketing systems, and financial support vary spatially. By doing so, the study provides a foundation for evidence-based planning and the formulation of targeted interventions that can strengthen the supply chain and support growers more effectively.

Literature review

Apple cultivation in India, particularly in Himachal Pradesh, faces persistent challenges that significantly impact both productivity and profitability. One of the most pressing issues is the lack of adequate cold storage and transportation infrastructure, leading to substantial post-harvest losses and limiting growers' access to distant markets. Kumar *et al.* (2019) [9] emphasized that insufficient storage facilities and poor road connectivity compel farmers to sell their produce quickly at lower prices, thereby reducing profit margins. Another major concern is the dominance of intermediaries and volatility in market prices. Sharma (2020) [17] noted that reliance on commission agents and middlemen allows these actors to control the pricing process, leaving farmers with little negotiating power and inconsistent price realization.

The sector also suffers from insufficient technical and financial support. Rana and Singh (2021) [14] observed that many apple growers are unaware of modern horticultural practices and lack access to institutional credit, government subsidies, and timely expert guidance, which are essential for improving productivity and managing uncertainty. Further compounding these challenges are climate-related risks and disease outbreaks, which have intensified due to shifting weather patterns. Pandey *et al*. (2022) [12] documented how unpredictable rainfall, hailstorms, and rising temperatures, along with recurring infestations such as scab and pest attacks, have adversely affected apple yields and quality, threatening the long-term sustainability of the sector. Basharat and Mehak (2023) [3] estimated that nearly 30% of apple production is lost annually due to inefficiencies in harvesting, storage, and transportation. To address these issues, Chen *et al*. (2017) [1] recommended solutions such as low-cost solar-powered cold storage facilities and the use of price forecasting tools to reduce losses and improve farmers' margins.

Market inefficiencies further exacerbate these problems. Sharma (2020) [17] observed that the absence of direct market linkages perpetuates farmer dependence on intermediaries, contributing to exploitation and limited price control. Alternative approaches such as natural farming and farmer producer organizations (FPOs) have been identified as ways to enhance negotiation power, lower production costs, and access niche markets (Down To Earth, 2024) [2]. Moreover, agronomic measures like balanced fertilization and soil health management have been reported to strengthen apple trees' resilience to erratic weather conditions (Yara International, 2024) [18].

Apple orchards in Himachal Pradesh are also increasingly vulnerable to climate variability. John and Kumari (2024) [7] and Rana *et al*. (2023) [13] found that rising temperatures and reduced snowfall have led to a decline in chill hours, shifting apple cultivation to higher altitudes and causing an 11% drop in productivity. Reports from national dailies such as Hindustan Times (2024) [5] and New Indian Express (2025) [11] have also highlighted late blooming and outbreaks of diseases such as Alternaria blotch, aggravated by unusual rainfall and humidity patterns. Neg *et al*. (2024) [10] documented the widespread incidence of powdery mildew in Kinnaur district, linked to specific temperature and humidity conditions. Similarly, Gupta *et al*. (2020) [4] reported that Apple Scar Skin Viroid (ASSVd) can cause yield losses exceeding 70% in affected orchards. These findings point to the urgent need for early detection and integrated pest management strategies.

Technological innovations offer promising solutions in this context. Shadrin *et al*. (2020) [16], Rouš *et al*. (2023) [15], and Khan *et al*. (2020) [8] demonstrated that hyperspectral imaging, machine learning, and AI-based disease recognition models can detect scab, rust, and mildew with high accuracy, enabling targeted interventions and reducing dependency on chemical treatments. Agronomic advancements are also being promoted to adapt to climatic changes. For instance, the Indian Council of Agricultural Research (ICAR, 2023) [6] has introduced high-density planting techniques and coloured spur-type cultivars such as Gala and Scarlet Spur, which are better suited for mid-hill climates under warming conditions. These varieties not only improve productivity but also enhance fruit quality and marketability.

This body of literature raises critical questions, such as: What difficulties do apple growers face in the supply chain? Does the location of production influence the severity of these challenges? In light of these considerations, the present study examines the situation of apple production in Himachal Pradesh with a focus on location-specific factors affecting production, marketing, and supply chain efficiency.

Methods and Materials

The present study was conducted in eight major apple-producing blocks of Himachal Pradesh, due to their significant contribution to the state's apple production and their diverse geographical and infrastructural characteristics. A sample of 535 apple growers was selected for the study using a combination of multistage and convenience sampling techniques. Data were collected through a structured questionnaire designed to investigate the difficulties faced by apple growers. The instrument included a total of 58 items, with 41 items specifically related to challenges across four key dimensions: production, marketing, financial, and supply chain. Respondents were asked to rate their agreement with each statement using a 5-point Likert scale. This approach enabled the quantification of subjective perceptions and facilitated meaningful statistical analysis. The collected data were then analysed using various statistical tools to assess reliability, factor structure, and group differences across locations.

Analysis & Interpretation

Table 1 demonstrates the demographic profile of the respondents indicates that the majority of apple growers are relatively young, with a mean age of 2.18 on a 4-point scale. Most respondents are well-educated, with the average education level being above graduation (mean = 5.04), and the distribution negatively skewed, indicating that a larger number of growers have higher education levels. The growers are spread across various geographic locations (mean = 4.48), showing a diverse regional representation. The majority belong to the small-scale grower category, as reflected by the strong positive skewness (1.89) and high kurtosis (3.67) in the "Categories of Grower" variable. Regarding work status, the responses are moderately concentrated in higher categories (mean = 4.80), while the average farming experience is moderate (mean = 2.46). Notably, total income levels are on the lower side (mean = 2.07), with a positively skewed and peaked distribution, indicating that most respondents fall into lower income brackets.

Table 1: Descriptive statistics for demographic profile of respondents

Descriptive Statistics									
	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Age	535	1.00	4.00	2.1832	.65350	.360	.106	.393	.211
Educationlevel	535	1.00	7.00	5.0374	1.39907	-1.076	.106	.737	.211
Location	535	1.00	8.00	4.4841	2.28479	.016	.106	-1.231	.211
CategoriesofGrower	535	1.00	5.00	1.4393	.73919	1.886	.106	3.665	.211
Currentworkstatus	535	1.00	8.00	4.7888	1.66655	-.703	.106	-.767	.211
Experience	535	1.00	4.00	2.4579	.85329	.495	.106	-.528	.211
TotalIncome	535	1.00	5.00	2.0729	.76211	.972	.106	2.015	.211
Valid N (listwise)	535								

Table 2 & 3 shows the reliability analysis for the 41 challenge-related statements which yielded a Cronbach's Alpha value of 0.894, indicating a high level of internal consistency among the items and confirming that they reliably measure the underlying construct.

Furthermore, the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy was 0.918, which is well above the recommended threshold of 0.6, indicating that the sample is highly suitable for factor analysis. Bartlett's Test of Sphericity was significant (Chi-square = 20532.467, df = 820, $p < 0.001$), confirming that the correlation matrix is not an identity matrix and that the data are appropriate for structure detection through factor analysis.

Table 2: Reliability Statistics for Challenge Statements

Cronbach's Alpha	No. of Items
0.894	41

Table 3: KMO and Bartlett's Test

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.918
Bartlett's Test of Sphericity	Approx. Chi-Square	20532.467
	df	820
	Sig.	.000

Assumption Testing of Analysis of Variance Normality

The Shapiro-Wilk test was conducted to assess the normality of the dependent variables across blocks. As shown in Table 4, all p-values were less than 0.05, indicating a significant deviation from normal distribution for all four types of challenges across all blocks.

Table 4: Tests of Normality (Shapiro-Wilk and Kolmogorov-Smirnov)

Tests of Normality							
	Location	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Production Challenges	Jubbal & Kotkhai	.277	66	.000	.569	66	.000
	Rohru	.268	67	.000	.773	67	.000
	Kullu	.246	70	.000	.769	70	.000
	Naggar	.305	67	.000	.663	67	.000
	Kalpa	.269	67	.000	.610	67	.000
	Pooh	.282	66	.000	.747	66	.000
	Karsog	.273	66	.000	.721	66	.000
	Janjehli	.343	66	.000	.583	66	.000
Marketing Challenges	Jubbal & Kotkhai	.252	66	.000	.552	66	.000
	Rohru	.206	67	.000	.785	67	.000
	Kullu	.201	70	.000	.833	70	.000
	Naggar	.191	67	.000	.821	67	.000
	Kalpa	.218	67	.000	.809	67	.000
	Pooh	.269	66	.000	.786	66	.000
	Karsog	.236	66	.000	.753	66	.000
	Janjehli	.218	66	.000	.779	66	.000
Supply chain Challenges	Jubbal & Kotkhai	.394	66	.000	.497	66	.000
	Rohru	.404	67	.000	.655	67	.000
	Kullu	.419	70	.000	.489	70	.000
	Naggar	.408	67	.000	.492	67	.000
	Kalpa	.412	67	.000	.495	67	.000
	Pooh	.437	66	.000	.450	66	.000
	Karsog	.500	66	.000	.298	66	.000
	Janjehli	.458	66	.000	.365	66	.000
Financial Challenges	Jubbal & Kotkhai	.222	66	.000	.712	66	.000
	Rohru	.221	67	.000	.870	67	.000
	Kullu	.267	70	.000	.829	70	.000

	Naggar	.304	67	.000	.786	67	.000
	Kalpa	.186	67	.000	.895	67	.000
	Pooh	.275	66	.000	.829	66	.000
	Karsog	.332	66	.000	.778	66	.000
	Janjehli	.191	66	.000	.898	66	.000
a. Lilliefors Significance Correction							

Homogeneity of Variance

Levene's test for homogeneity of variances, as presented in Table 5, indicates that the assumption was violated for production challenges (*p* <. 05) and supply chain challenges (*p* <. 05), suggesting significant variation in the spread of responses across different blocks. However, the assumption was met for marketing challenges (*p* =. 057), which was just above the significance threshold, and for financial challenges (*p* =. 803), indicating consistent variance across groups for these two dimensions.

Table 5: Levene's Test of Homogeneity of Variances

Tests of Homogeneity of Variances					
		Levene Statistic	**df1**	**df2**	**Sig.**
Production Challenges	Based on Mean	4.825	7	527	.000
	Based on Median	2.137	7	527	.038
	Based on Median and with adjusted df	2.137	7	349.968	.039
	Based on trimmed mean	3.458	7	527	.001
Marketing Challenges	Based on Mean	1.975	7	527	.057
	Based on Median	1.168	7	527	.319
	Based on Median and with adjusted df	1.168	7	311.852	.321
	Based on trimmed mean	1.415	7	527	.197
Supply chain Challenges	Based on Mean	14.037	7	527	.000
	Based on Median	4.271	7	527	.000
	Based on Median and with adjusted df	4.271	7	355.183	.000
	Based on trimmed mean	11.741	7	527	.000
Financial Challenges	Based on Mean	.541	7	527	.803
	Based on Median	.324	7	527	.943
	Based on Median and with adjusted df	.324	7	411.291	.943
	Based on trimmed mean	.571	7	527	.780

Given these results, Welch ANOVA was used for the variables that violated homogeneity.

Analysis of Variance

As shown in **Table 6**, the one-way ANOVA results revealed statistically significant differences across blocks for both production challenges (*F*(7, 527) = 2.830, *p* =. 007) and supply chain challenges (*F*(7, 527) = 4.271, *p* <. 001). These findings indicate that the severity of these challenges varies notably between locations. In contrast, no statistically significant differences were found for marketing challenges and financial challenges (*p* >. 05), suggesting that these issues are more uniformly experienced across the different blocks.

Table 6: One-Way ANOVA Summary

ANOVA						
		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Production Challenges	Between Groups	106.054	7	15.151	2.830	.007
	Within Groups	2821.692	527	5.354		
	Total	2927.746	534			
Marketing Challenges	Between Groups	247.310	7	35.330	1.991	.054
	Within Groups	9352.682	527	17.747		
	Total	9599.993	534			
Supply chain Challenges	Between Groups	366.295	7	52.328	4.271	.000
	Within Groups	6457.480	527	12.253		
	Total	6823.776	534			
Financial Challenges	Between Groups	160.662	7	22.952	1.466	.177
	Within Groups	8248.770	527	15.652		
	Total	8409.432	534			

Due to the violation of the homogeneity of variance assumption for some variables, Welch ANOVA was employed as a more robust alternative. As presented in **Table 7**, the results showed a statistically significant difference across blocks for production challenges (*F*(7, 223.77) = 3.468, *p* =. 002) and supply chain challenges (*F*(7, 224.02) = 3.072, *p* =. 004). These findings further confirm the presence of meaningful variation in these challenges across different locations.

Table 7: Welch Robust Tests of Equality of Means

Robust Tests of Equality of Means					
		Statistic[a]	**df1**	**df2**	**Sig.**
Production Challenges	Welch	3.468	7	223.767	.002
Supply chain Challenges	Welch	3.072	7	224.018	.004
a. Asymptotically F distributed.					

Post Hoc Comparisons

The Games-Howell post hoc test was conducted to identify specific group differences in challenges across locations (see Annexure Table A1 for full results). The analysis revealed significant differences in production challenges, specifically between Pooh and Rohru (p =. 020) and Karsog and Rohru (p =. 047), suggesting that both Pooh and Karsog face more intense production-related issues than Rohru. In terms of supply chain challenges, significant differences were observed between Rohru and Pooh (p =. 006), Rohru and Karsog (p =. 010), and Rohru and Janjehli (p =. 021), indicating that Rohru is experiencing notably higher supply chain difficulties compared to these other locations.

Discussion

The analysis clearly highlights block-wise disparities in challenges faced by apple growers:

Pooh and Karsog faced much greater production difficulties, which might have been brought on by a lack of labour, limited infrastructure, or terrain-related issues. In Addition, Rohru experienced the worst supply chain problems, presumably as a result of insufficient cold storage facilities, transportation networks, or distribution channels. The absence of notable diversity in the marketing and financial challenges points to the possibility that these problems are shared by all blocks and may call for systemic or policy-level solutions. Importantly, robust techniques like Welch ANOVA and Games-Howell were needed to address assumption breaches (normality and equal variances), guaranteeing the accuracy of the reported differences. This strengthens the case for targeted, block-specific agricultural planning and support.

Conclusion

The intricacy and regional variance of the difficulties faced by Himachal Pradesh's apple growers are highlighted by this study. Some problems are more localised and context-specific, while others are systemic and universal. Inadequate cold storage and poor transportation networks continue to result in substantial post-harvest losses, often forcing farmers to sell at suboptimal prices (Kumar *et al*., 2019; Basharat & Mehak, 2023) [9, 3]. Market inefficiency, particularly the dominance of intermediaries, further erodes growers' bargaining power, leaving them dependent on commission on agents and vulnerable to price volatility (Sharma, 2020) [17]. Addressing these challenges requires unique approaches that transcend standardised agriculture regulations. Evidence from Chen *et al*. (2027) [1] demonstrates the value of low-cost cold storage and forecasting tools, while the work of Shadrin *et al*. (2020) [16], Rous *et al*. (2023), and Khan *et al*. (2020) [8] illustrates the potential of AI-based disease detection in reducing losses and chemical use. Likewise, the development and promotion of climate-resilient high-density apple cultivars (ICAR, 2023) [6] offer promising adaptation pathways. A balanced strategy is needed to address issues in apple agriculture, combining regionally tailored fixes with more extensive structural changes to infrastructure, financial access, and market systems.

Crucially, the study emphasises that close collaboration between apple growers, local government representatives, legislators, and supply chain participants is necessary to accomplish significant improvements in the apple supply chain. In order to ensure that the perspectives and reality of apple growers on the ground guide future, interventions must be inclusive and data-driven. Using this method, apple cultivation in Himachal can move toward greater resilience, efficiency, and long-term sustainability.

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