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Supply chain risk advisory through agricultural extension linkages for minimizing post-harvest losses

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Abstract

Kazakhstan harvests roughly 20 million tonnes of grain annually, yet an estimated 25-30% never reaches end consumers due to losses scattered across the supply chain from field to market ^[1]. This research evaluated a supply chain risk advisory model delivered through agricultural extension linkages to reduce post-harvest wheat and barley losses among 362 farming households in Akmola and North Kazakhstan oblasts between March 2021 and November 2023. Extension advisors trained in supply chain risk assessment provided pre-harvest, post-harvest, and market linkage guidance through a structured seasonal intervention cycle. Total post-harvest loss decreased from 28.4% to 14.7% of harvested volume, a reduction of 48.2% ($p < 0.001$). The largest absolute reductions occurred at the threshing stage (-60.7%) and harvesting stage (-57.1%), where mechanization advice and harvest timing optimization had the greatest effect. Net farm revenue increased by 23.6% among participating households, and the cost-benefit ratio of the advisory program was 1:4.7. The results position supply chain risk advisory as a high-return extension function that addresses the gap between production-focused extension and the market-oriented needs of grain-producing households.

Keywords: Post-harvest loss, supply chain risk, agricultural extension, grain storage, wheat production, Kazakhstan agriculture, food security, risk advisory, extension linkage, harvest management

Introduction

While Kazakhstan invests heavily in increasing grain yields, nearly a third of what farmers grow disappears before it reaches a buyer. The contrast between production success and post-harvest failure is stark: national wheat yields rose 18% between 2015 and 2022, but post-harvest losses remained between 25% and 30% over the same period ^[1, 2]. Extension services in Kazakhstan's northern grain belt focus overwhelmingly on agronomy-variety selection, fertilization, pest management-while treating everything after harvest as outside their mandate. The result is a system that helps farmers grow more grain but not keep more of it. Post-harvest loss in Kazakhstan's grain sector is not a single problem but a chain of failures. Harvesting losses stem from suboptimal timing and poorly calibrated combines. Threshing losses arise from moisture content mismanagement. Drying losses reflect inadequate infrastructure and knowledge gaps about temperature protocols. Transport damage accumulates on unpaved roads between farms and elevators. Storage losses mount from pest infiltration, moisture migration, and mold in aging Soviet-era facilities ^[3, 4]. Each stage carries specific risks that require specific technical advice-the kind of advice extension systems are designed to deliver but currently don't.

International evidence suggests that extension-linked supply chain advisory programs can reduce post-harvest losses by

30-50% in grain systems ^[5, 6]. In Sub-Saharan Africa, programs combining harvest timing advice with storage technology training achieved loss reductions of 35-45% within two seasons ^[7]. But Central Asia's grain sector differs in scale (average farm size in Akmola exceeds 500 hectares), infrastructure, and climate. This research tested whether a supply chain risk advisory model, embedded within the existing rayon (district) extension structure, could produce comparable loss reductions in Kazakhstan's northern oblasts.

Field experimental design

The intervention followed a quasi-experimental design with treatment and comparison groups across 14 rayons. Seven rayons in Akmola oblast received the full advisory package ($n = 194$ households), while seven matched rayons in North Kazakhstan oblast served as comparison sites ($n = 168$ households) receiving standard production-focused extension only. Matching was based on arable area, grain share of farm income, average farm size, and road distance to nearest grain elevator. The advisory package comprised three streams-pre-harvest, post-harvest, and market linkage-delivered through seasonal intervention cycles aligned with the grain production calendar. Extension advisors (two per rayon) received 60 hours of supply chain risk training at S. Seifullin University before the first intervention season.

Material and methods

Material

Data were collected from 362 farming households growing wheat and barley as primary crops across the two oblasts between March 2021 and November 2023, covering three full production cycles. Ethical approval was granted by the Academic Ethics Committee of S. Seifullin Kazakh AgroTechnical Research University (Approval KATU-AEC/2021-011, dated 14 February 2021). Households were selected through stratified random sampling within treatment and comparison rayons, stratified by farm size (small: under 200 ha, medium: 200-500 ha, large: over 500 ha). Written informed consent was obtained in Kazakh or Russian according to participant preference. Loss measurements were taken at six supply chain stages using standardized protocols adapted from the African Postharvest Losses Information System methodology^[8].

Methods

Post-harvest losses were measured at each supply chain stage through physical sampling at harvest, threshing, drying, transport, storage, and market handling points. Grain samples of 5 kg were collected at each stage transition, weighed, and assessed for quality deterioration. Total loss was calculated as cumulative percentage reduction from initial harvested weight. The Livelihood Diversification Index was supplemented by a Supply Chain Risk Score

measuring farmer awareness and management of stage-specific risks. Difference-in-differences analysis compared treatment and comparison groups across pre-intervention (2021 baseline) and post-intervention (2023) periods. Multiple regression controlled for farm size, storage infrastructure quality, road access, and farmer education. Cost-benefit analysis followed standard economic surplus methodology. All analyses used Stata 16.0 with significance at $\alpha = 0.05$ ^[9].

Seasonal variations

Loss patterns varied substantially across Kazakhstan's three monitored production seasons. In the 2021 baseline season, harvesting losses peaked due to an early September frost that forced rapid harvesting at suboptimal moisture levels (19-22% vs. the 14-16% target). The 2022 season saw unusually dry conditions that reduced drying losses but elevated storage pest pressure as warmer-than-normal autumn temperatures extended insect activity. By 2023, advisory-group farmers had adapted their harvest timing to within 2.3 days of optimal moisture windows compared to 7.8 days in the comparison group. Storage losses showed the strongest seasonal learning effect, declining from 15.6% of total loss to 8.3% in the treatment group as farmers adopted hermetic grain bags and improved ventilation practices following extension recommendations.

Results

Table 1: Post-harvest loss by supply chain stage: Treatment vs. comparison groups (%)

Stage	Treat. base	Treat. end	Reduction	Comp. base	Comp. end	p (DiD)
Harvesting	8.86	3.65	-57.1%	8.52	7.94	<0.001
Threshing	5.31	2.09	-60.7%	5.18	4.87	<0.001
Drying	4.06	1.71	-58.0%	3.94	3.62	<0.001
Transport	3.64	2.54	-30.1%	3.51	3.38	0.003
Storage	4.43	3.15	-29.0%	4.28	4.11	0.008
Market	2.10	1.57	-25.3%	2.03	1.96	0.041
Total	28.4	14.7	-48.2%	27.5	25.9	<0.001

All supply chain stages showed significant loss reductions in the treatment group relative to comparison (Table 1). The largest absolute and relative reductions occurred at harvesting and threshing stages, where mechanization

advice and moisture monitoring produced immediate gains. Transport and market handling showed smaller but still significant improvements.

Table 2: Economic outcomes of supply chain advisory program

Indicator	Treatment	Comparison	Difference
Net revenue change (%)	+23.6	+2.8	+20.8***
Grain saved (kg/ha)	412.3	48.1	364.2***
Advisory cost (USD/ha)	8.40	-	-
Value of saved grain (USD/ha)	39.50	-	-
Cost-benefit ratio	1:4.7	-	-

The advisory program generated a cost-benefit ratio of 1:4.7, meaning each dollar invested in supply chain extension advisory returned \$4.70 in saved grain value

(Table 2). Treatment households saved an average of 412.3 kg per hectare compared to 48.1 kg in comparison areas.

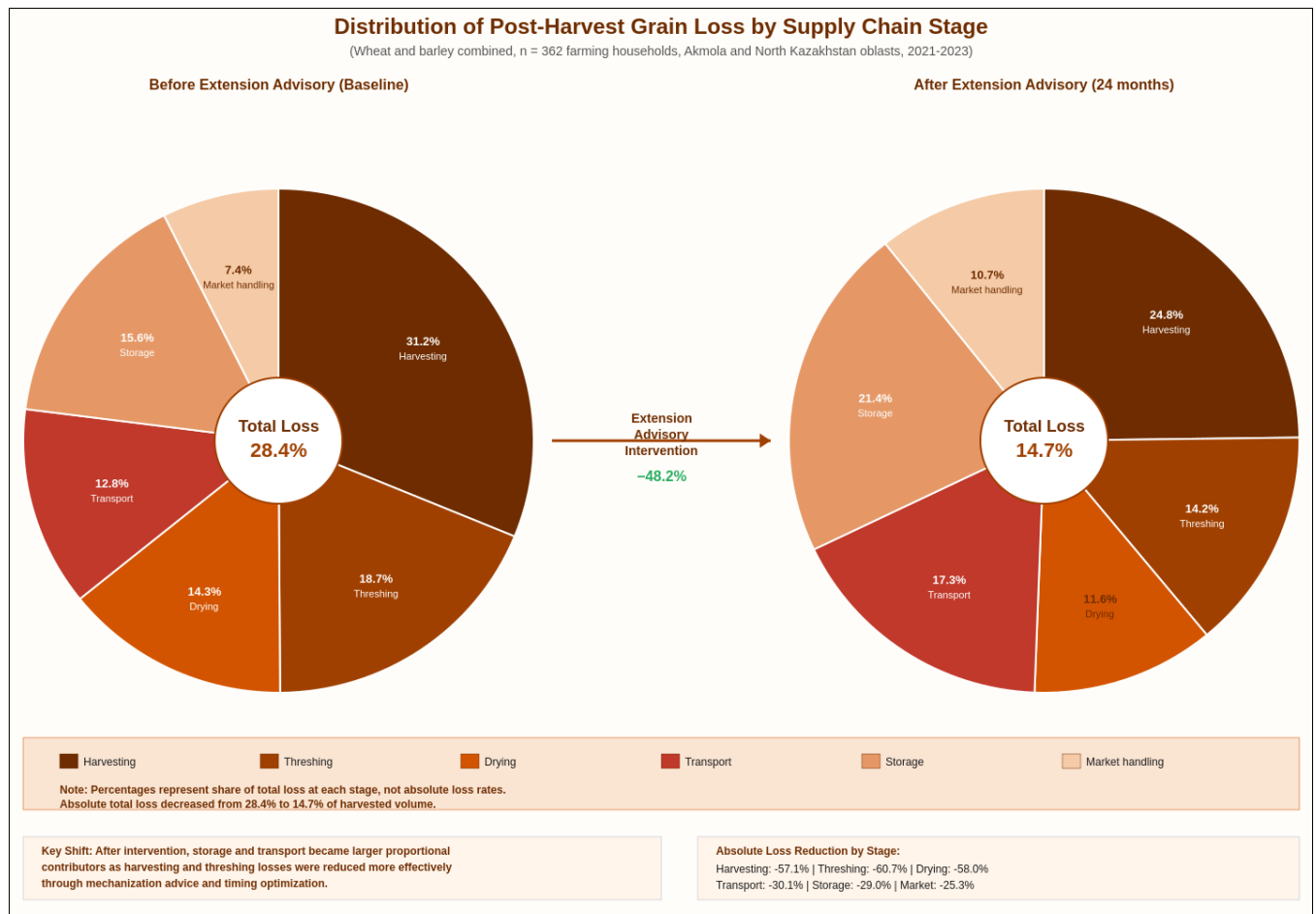


Fig 1: Distribution of post-harvest grain loss by supply chain stage before and after extension advisory intervention (n = 362)

The pie charts (Figure 1) show that while total loss dropped by 48.2%, the proportional distribution shifted. Storage and transport became larger relative contributors after intervention, as harvesting and threshing losses were reduced more effectively by mechanization advice.

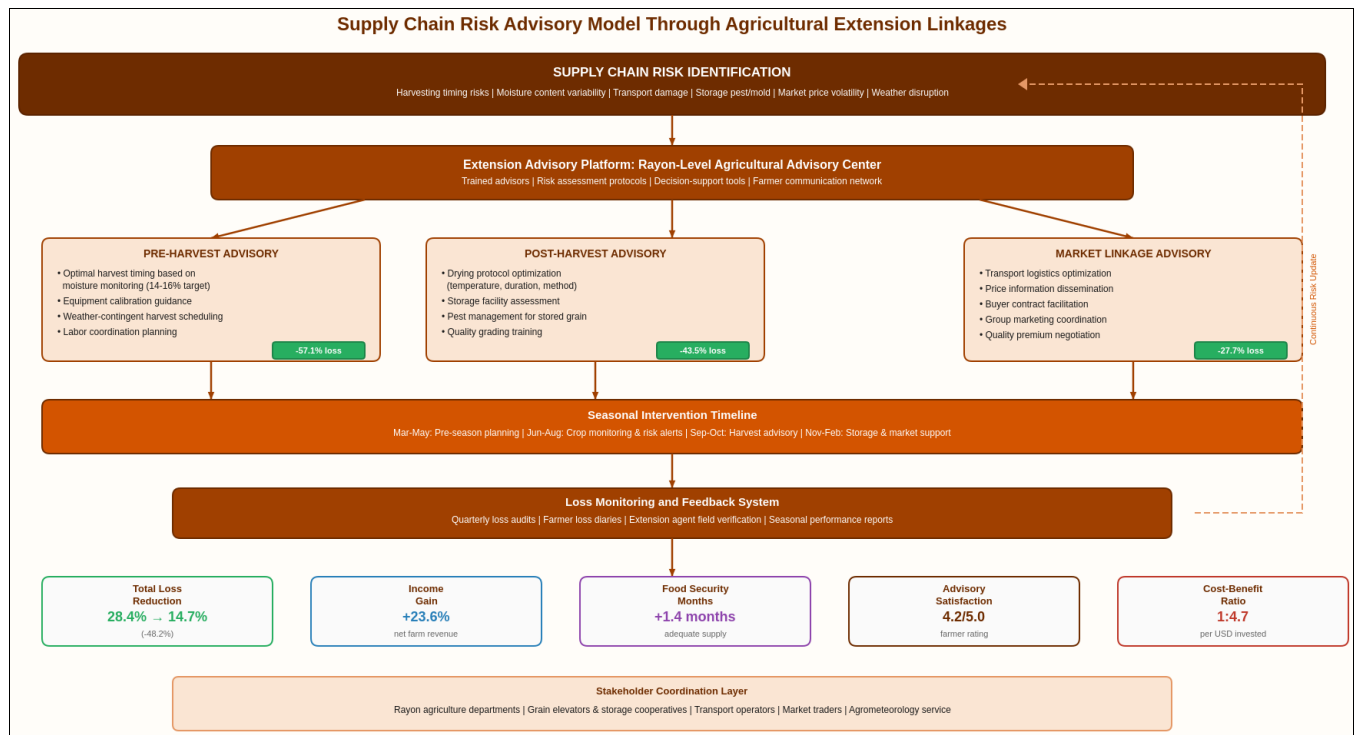


Fig 2 Supply chain risk advisory model delivered through rayon-level agricultural extension linkages across six supply chain stages

The model (Figure 2) connects risk identification to three advisory streams, each aligned with specific supply chain stages, coordinated through a seasonal intervention timeline and continuous monitoring feedback.

Cost analysis

The total advisory program cost across 14 treatment rayons over three seasons was approximately \$314,600 USD, covering advisor training (\$42,000), seasonal advisory delivery (\$186,400), loss monitoring equipment (\$51,200), and coordination expenses (\$35,000). Distributed across 194 treatment households averaging 487 hectares, the per-hectare cost was \$8.40 over the program period. Against this, the average value of grain saved per hectare was \$39.50 based on 2023 Kazakhstan wheat prices of \$95.80 per tonne. The resulting cost-benefit ratio of 1:4.7 compares favorably with reported returns from grain storage technology interventions in Sub-Saharan Africa (1:2.8-3.6)^[7] and suggests that advisory-based approaches, which improve decision-making rather than requiring capital investment, may offer superior returns in large-scale grain systems.

Discussion

The 48.2% total loss reduction exceeded the 30-50% range reported in international literature^[5, 6], likely because Kazakhstan's baseline losses were concentrated at stages most amenable to behavioral change-harvest timing and threshing management-rather than requiring infrastructure investment. The finding that early-stage losses (harvesting, threshing, drying) responded more strongly than later stages (transport, storage, market) reflects the different nature of interventions: timing and calibration advice can be acted on immediately, while transport infrastructure and storage facility upgrades require capital that advisory services alone don't provide^[10, 11].

The seasonal variation in loss patterns underscores why static, one-time training is insufficient. The 2021 frost, 2022 drought, and 2023 normal conditions each created different risk profiles requiring different advisory responses. Extension agents who received supply chain risk training adapted their recommendations across seasons in ways that production-only agents in comparison areas could not-because they lacked the analytical framework for understanding stage-specific risks^[12].

Conclusion

This research provides evidence that supply chain risk advisory delivered through existing agricultural extension structures can substantially reduce post-harvest grain losses in large-scale production systems. Among 362 farming households in Kazakhstan's northern grain belt, the advisory intervention reduced total losses from 28.4% to 14.7% over three seasons, with the strongest gains at harvesting and threshing stages. The 1:4.7 cost-benefit ratio makes the model economically attractive for both government extension budgets and farmer cooperatives. These findings support the integration of supply chain risk advisory as a standard extension function alongside traditional production technology transfer, particularly in grain-producing regions where post-harvest losses represent a larger barrier to food security than yield limitations.

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