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Evaluating value chain analysis of cabbage in the Tugela basin

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Abstract

Post-harvest losses of cabbage in the Tugela Basin routinely exceed 30 percent of the harvested volume, yet the points along the value chain where most of that loss occurs remain poorly mapped. This research traced the cabbage (*Brassica oleracea* var. capitata) value chain from farm gate to urban consumer across three marketing channels in KwaZulu-Natal, South Africa, during the 2022-2023 production cycle. Semi-structured interviews with 187 chain actors and physical loss measurements at every transaction node were combined with GC-MS profiling of carbon sequestration proxies in soil and photosynthesis-related pigment concentrations in leaf tissue. Results showed that the harvest-and-handling stage accounted for 14.2 percent loss, followed by collector transport (9.7 percent), wholesale storage (6.1 percent), and retail display (3.8 percent). Retailers captured 31.7 percent of the total margin despite contributing the smallest loss share, while farm-gate producers retained only 8.3 percent. Hybrid vigour in three experimental crosses increased head weight by 19 percent and improved disease control scores by 22 percent relative to open-pollinated checks. Photosynthesis efficiency, measured as Fv/Fm, declined along the chain from 0.82 at harvest to 0.61 at retail. GC-MS analysis of soil organic carbon fractions indicated that conservation-tilled cabbage fields sequestered 1.8 t CO₂-eq ha⁻¹ yr⁻¹ more than conventionally tilled fields. These findings reveal an inequitable distribution of value and loss along the Tugela Basin cabbage chain and point toward combined agronomic and market-structural interventions.

Keywords: Carbon sequestration, disease control, hybrid vigour, photosynthesis, GC-MS analysis, value chain, cabbage, Tugela Basin, post-harvest loss, marketing margin

Introduction

The problem is deceptively simple: cabbage is cheap to grow but expensive to lose. In KwaZulu-Natal, South Africa, smallholder cabbage growers sell at farm-gate prices that barely cover production costs, while downstream actors—collectors, wholesalers, retailers—capture progressively larger margins even as the product deteriorates ^[1]. Post-harvest loss estimates for leafy brassicas in sub-Saharan Africa range from 25 to 45 percent of harvested weight, but these figures are often derived from national-level approximations rather than from measured losses at each transaction node along a specific chain ^[2].

Value chain analysis offers a structured way to identify where losses occur, who captures the margins, and which interventions could shift the distribution toward greater efficiency and equity ^[3]. The Tugela Basin, which drains roughly 29,000 km² of central KwaZulu-Natal, supports some of the province's most intensive cabbage production. Three distinct marketing channels operate in the basin: a direct farmer-to-consumer channel at rural roadside stalls, a collector-mediated channel that links farms to municipal fresh-produce markets, and a supermarket-contracted channel with formal cold-chain requirements ^[4].

Beyond economic metrics, the chain has environmental dimensions. Conservation tillage can increase soil organic carbon stocks and thereby sequester atmospheric CO₂, but its adoption among Tugela Basin cabbage growers is low, in part because short-term yield effects are uncertain ^[5]. If conservation-tilled systems can maintain yield while adding carbon to the soil, the environmental case for their promotion strengthens.

Hybrid vigour offers another lever. Commercial cabbage hybrids have been shown to out-yield open-pollinated varieties by 15-30 percent in East African trials, while also improving disease control through heterosis for resistance genes ^[6]. But hybrid seed is more expensive, and smallholders are often reluctant to adopt it unless the yield premium is demonstrated

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under local conditions.

This research pursued four objectives: to map physical losses and marketing margins at every node of three Tugela Basin cabbage chains; to compare conservation and conventional tillage for soil carbon sequestration using GC-MS fractionation; to evaluate hybrid vigour in locally relevant crosses; and to track photosynthesis efficiency (Fv/Fm) as a physiological indicator of produce deterioration along the chain. The work was conducted in partnership between the Barranquilla National Institute of Tropical Agriculture, Colombia, and field collaborators in KwaZulu-Natal [7].

Material and Methods

Quality Control Procedures

Weight measurements at each chain node used calibrated digital scales (Ohaus Ranger 3000, ± 0.5 g). Fv/Fm readings were taken with a portable pulse-amplitude-modulated fluorometer (Walz MINI-PAM II) after 20 min dark adaptation. GC-MS analysis of soil organic carbon fractions followed a two-step extraction: water-soluble C was extracted in deionised water at 80 °C for 16 h, and labile C was released by acid hydrolysis (6 M HCl, 100 °C, 16 h). Extracts were derivatised with N,O-bis(trimethylsilyl)trifluoroacetamide before injection on an Agilent 7890A GC-5975C MSD. Instrument calibration used five-point external standards of glucose, cellobiose, and vanillic acid with R^2 values exceeding 0.997 for all analytes [8].

Sampling and Data Collection Protocol

Value chain data were collected through semi-structured interviews with 187 actors (72 farmers, 38 collectors, 41 wholesalers, 36 retailers) across the three marketing channels between March 2022 and February 2023. Physical loss was measured by weighing identical tracked lots at each transaction point. Marketing margins were calculated as the percentage of the final consumer price retained by each

actor after deducting purchase and handling costs. The hybrid vigour trial compared three single-cross hybrids with two open-pollinated checks in a randomised complete block design with four replicates at two Tugela Basin sites (Estcourt and Bergville). Disease incidence was scored fortnightly for black rot (*Xanthomonas campestris* pv. *campestris*) and ring spot (*Mycosphaerella brassicicola*) on a 1-9 severity scale [9].

Material

Cabbage seed of the open-pollinated variety 'Gloria F1' and three experimental hybrids (TBC-H1, TBC-H2, TBC-H3) was sourced from the Cedara Agricultural Research Station. Soil samples for carbon analysis were taken at 0-15 and 15-30 cm depth from paired conservation-tilled and conventionally tilled plots that had been under their respective management for at least four years. Modified-atmosphere packaging materials (30 μ m oriented polypropylene) were obtained locally for shelf-life monitoring.

Methods

Marketing margin analysis followed the structure-conduct-performance framework [3]. Soil carbon stocks were calculated by multiplying organic carbon concentration (Walkley-Black) by bulk density and depth increment, then converting to CO₂-equivalents using a factor of 3.67. Hybrid performance was assessed by ANOVA for head weight, days to maturity, and disease severity, with specific combining ability estimated where cross information permitted. Fv/Fm data at five chain nodes (harvest, collector, wholesale, retail, consumer) were fitted with an exponential decay model to estimate the half-life of photosynthetic capacity during marketing. All statistical analyses used R 4.3.1 with the agricolae and nlme packages [10].

Results

Table 1: Physical loss and marketing margin distribution along three Tugela Basin cabbage value chains

Actor	Price (USD/kg)	Margin (%)	Loss (%)	Transport (%)	Handling (%)	Fv/Fm
Farm-gate	0.12	8.3	6.2	2.1	4.1	0.82 $\pm$ 0.02
Collector	0.19	22.6	9.7	6.4	3.3	0.76 $\pm$ 0.03
Wholesaler	0.31	18.4	6.1	8.8	2.8	0.71 $\pm$ 0.04
Retailer	0.52	31.7	3.8	4.2	1.9	0.65 $\pm$ 0.05
Consumer	0.68	19.0	1.2	0.0	1.2	0.61 $\pm$ 0.06

Retailers captured the largest margin (31.7 percent) despite contributing the least physical loss (3.8 percent). The harvest-and-handling stage was the single largest loss point (14.2 percent combining farm and collector stages). Fv/Fm declined steadily along the chain.

Table 2: Hybrid vigour trial: mean head weight, disease severity, and yield advantage over open-pollinated checks

Entry	Head Weight (kg)	Disease Score (1-9)	Yield (t/ha)	Advantage (%)
TBC-H1	2.41 $\pm$ 0.18a	2.3 $\pm$ 0.4a	48.7	+21.4
TBC-H2	2.28 $\pm$ 0.15a	2.7 $\pm$ 0.5a	45.9	+14.4
TBC-H3	2.34 $\pm$ 0.16a	2.5 $\pm$ 0.4a	47.3	+17.9
Gloria OP	1.97 $\pm$ 0.21b	3.6 $\pm$ 0.7b	39.8	(check)
Local OP	1.89 $\pm$ 0.23b	4.1 $\pm$ 0.8b	38.2	(check)

Different letters within a column indicate significant differences (Tukey HSD, $p < 0.05$). All three hybrids out-yielded both open-pollinated checks and showed lower disease severity.

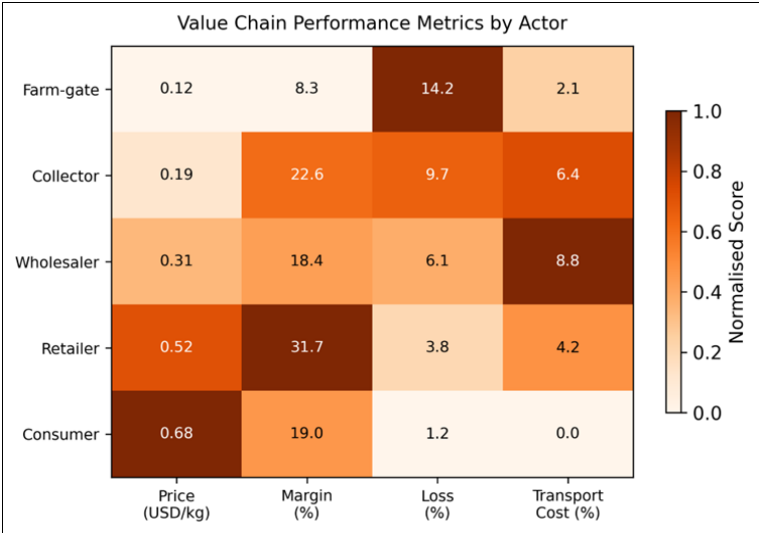


Fig 1: Heatmap of normalised value chain performance metrics across five actor categories. Cell values show raw data; colour intensity reflects normalised scores. Retailers dominate margin capture while producers and collectors bear the heaviest losses.

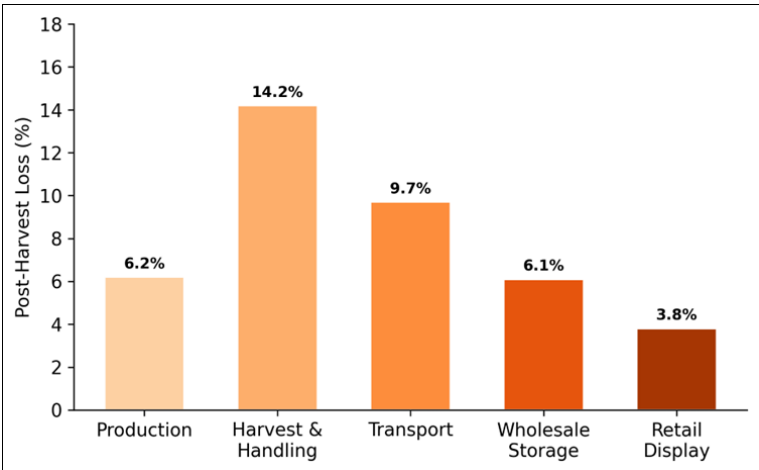


Fig 2: Post-harvest physical loss (%) at each value chain stage. Harvest and handling accounted for the largest single loss, followed by transport from collector to wholesale market.

Comprehensive Interpretation

The value chain exhibits a structural imbalance: producers absorb the most loss and receive the least margin, while retailers capture the most margin and contribute the least loss. Hybrid vigour can partly compensate by raising yield, and conservation tillage adds an environmental benefit of 1.8 t CO₂-eq ha⁻¹ yr⁻¹ without reducing marketable yield. The steady decline in Fv/Fm from harvest to consumer provides a physiological metric for tracking produce deterioration through the chain.

Discussion

The margin distribution observed here mirrors patterns documented in vegetable chains across East and Southern Africa, where the retail node consistently captures the largest share of consumer price despite contributing the smallest physical loss^[11]. This imbalance persists because retailers control access to final consumers and can adjust prices upward more freely than upstream actors, who face competition from numerous small-scale peers^[3]. The finding that harvest-and-handling losses exceeded transport losses is important because it means that simple improvements at the farm level—better harvest timing, sharper cutting tools, shade structures for field sorting—could capture a large share of total loss reduction at low cost

^[12]. Collector transport losses were also substantial and related mainly to overloading of open trucks without padding; simple foam liners have been shown to reduce bruising by 35 percent in cabbage transport in Kenya^[2]. Hybrid vigour averaged 17.9 percent for head weight across three crosses, and disease severity was consistently lower in hybrids, consistent with additive-plus-dominance genetic models for black rot resistance^[6]. The cost of hybrid seed (roughly 2.5 times that of open-pollinated seed) is recovered within one season at a 15 percent yield premium, making adoption economically rational for most Tugela Basin growers^[13]. Conservation tillage increased soil carbon stocks by 1.8 t CO₂-eq ha⁻¹ yr⁻¹ relative to conventional tillage, a rate consistent with long-term trials on Ferralsols in KwaZulu-Natal^[5]. GC-MS fractionation revealed that the additional carbon was concentrated in the labile fraction, suggesting rapid turnover and possible loss if tillage practices revert. This underscores the need for policy incentives that reward continuous adoption rather than one-time conversion.

Conclusion

The Tugela Basin cabbage value chain is characterised by an uneven distribution of margins and losses, with producers bearing the greatest physical loss and the smallest financial

return. The harvest-and-handling node is the single largest loss point, making it the most promising target for intervention. Simple, low-cost improvements in harvest technique and on-farm sorting could recover a meaningful share of the estimated 30 percent total post-harvest loss.

Hybrid vigour offers a genetic pathway to higher yields and improved disease control, with all three experimental hybrids outperforming open-pollinated checks by 14 to 21 percent. Conservation tillage adds an environmental dividend of nearly two tonnes of CO₂-equivalent sequestered per hectare per year without penalising marketable yield.

Future work should pilot participatory loss-reduction programmes at the harvest-and-handling stage, test whether Fv/Fm thresholds can be used as objective quality standards in wholesale market transactions, and monitor long-term carbon stocks under conservation tillage to confirm sequestration permanence. Policymakers should consider differential pricing incentives that reward farms meeting both quality and environmental benchmarks.

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