The effect of intermediary market power on grain prices in India

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Abstract

Post-harvest loss is a major concern for global food security and the livelihoods of vulnerable small-holder farmers. Current research is largely limited to estimating physical losses, which ignores the many effects of quality loss on value, food supply, and health and safety. To prevent quality losses, one must understand the incentives that are causing or preventing their occurrence. We estimate the financial incentives to preserve grain quality, in the form of quality premia, in Bihar, India. In particular, we investigate the roleplayed by trader market power in price and quality premia facing farmers. We estimate a modified hedonic model with using measures of market power from a survey of agricultural traders and price and self-reported quality from a survey of farmers. We find that high trader market power decreases both the price and the premium a trader pays to households. Households who are unable to sell to another trader also receive lower prices than households who are flexible in their choice of trader. Further, we find that technology adoption is also not compensated in highly concentrated markets.

1   Introduction

Concern over global food security has caused resurgence in research on post-harvest loss. The Food and Agricultural Organization of the United Nations (FAO) reports that a third of all food is lost or wasted worldwide (Aulakh & Regmi, 2013). The potential impact of a reduction in post-harvest loss, or the loss of food from field to fork, is high. Not only would it increase the food available worldwide, but this increase would occur without putting further strain on the world's resources, making this an "easy win." A crucial question is why post-harvest loss is so high. If reducing losses is relatively inexpensive and if farmers are rewarded for their quantity and quality of production, then we would expect that losses would be relatively small. Thus, in this paper we explore the factors that affect the incentives facing farmers to reduce post harvest loss.

We investigate the incentives throughout the grain supply-chain to reduce post-harvest loss, which we define broadly as including either physical or quality losses that decrease the value of agricultural production. Fafchamps, Hill, and Minten (2008) show that a consumer will maximize utility by choosing a product for which the quality premium is equal to the marginal utility of that quality, which, under perfect competition, will equal the marginal cost of producing that quality. Thus, a low quality premium either reflects a low marginal utility of an attribute or the fact that the attribute is not properly identified by the buyer. They stipulate, however, that there must be full transfer of information throughout the entire value chain to achieve equilibrium premia (Fafchamps, Hill, & Minten, 2008). We test the effects of high levels of market power by intermediaries on achieving equilibrium quality premia and prices.

The existing literature on post-harvest loss, largely in India, focuses on physical losses. The studies find physical losses between 2 and 7 percent of total production in India (table 5), although these relatively low levels of losses are still large in nominal terms. Nanda et al. (2014) estimate 6.36% of paddy is lost, which is equal to 3.46 million kg when taken as a percent of Bihar's 2004 harvest. This loss would be sufficient to provide 44,422 individuals with a year's worth of rice at India's average per capita consumption levels (Mohanty, 2013). For wheat, a 7.32% loss is equivalent to 2.70 million kg, or a year's worth of wheat for 36,000 individuals (Indexmundi, 2015). By only considering physical losses, previous studies fail to account for the full impact of post-harvest loss on global food security.

To effectively address post-harvest loss, the definition of loss itself must be broadened, as only physical loss ignores the numerous ways quality loss affects small-holder farmers and the global food supply chain. First, loss in quality causes the grain to lose value, which directly results in a loss in income to producers. This lost income could result in lower capital investment and higher losses in future seasons. Second, although we divide the supply chain into distinct phases, quality losses early in the supply chain can lead to physical losses later on. For example, small fissures in grain during harvest can lead to large breaks during drying. Inadequate drying will result in spoilage during storage and higher losses during milling. Table 1 outlines the causes of post-harvest loss at each stage and how the stages relate to each other. Additionally, inconsistent levels of moisture changes the measure of the amount of grain present, as a loss in moisture makes the grain lighter and vice versa. Thus, even quantity losses will be masked without appropriate moisture measurements. Finally, some quality losses make food less nutritious or even toxic to the consumer, such as growth of mycotoxins or improper use of pesticide. If quality losses become too severe the food may no longer meet minimum marketing standards for human consumption, leading it to be used for animal feed.

This article demonstrates a method to quantitatively investigate the value of grain quality to small-holder farmers in a variety of situations. We focus on Bihar, a state in Northern India whose agricultural sector is an important source of employment and GDP. Sixty-five percent of total area is used for grain cultivation in Bihar, with more than ninety percent of land holdings less than two ha (BAMETI, 2015). Grain farmers primarily produce rice and wheat, with slightly larger farmers also producing maize. Agricultural intermediaries facilitate the sales of grain by small farmers to larger buyers. Grain markets in Bihar are informal and rarely use quality standards set forth by the Indian government.

Farmers in Bihar often can only sell to one local trader. We ask how trader market power and household's ability to choose another trader affects the premia paid for quality. Farmers with low market power relative to their trader would then choose to produce lower quality grain, as the marginal benefit of producing quality is lower when high power traders pay low premia.

We develop a theoretical framework that models the decisions of farmers and traders regarding quality premia. We represent the quality premia received by farmers as a function of the quality premia received by traders and a pass-through coefficient. The model suggests that the price the trader receives is positively related to the average price in the sale market and the trader's ability to differentiate his services, and negatively related to the number of traders in the market. Conversely, we find that the premium increases, meaning the trader passes a greater portion of the price he receives on to the farmer, when the number of traders increases or the trader becomes less differentiated.

We test these hypotheses using an adapted hedonic model which includes variables other than quality that determine price in informal markets where the assumptions of perfect information transfer and matching of buyers and sellers fail (Rosen, 1974). We test the effect of the relationship between trader and farmer on grain price and premia by including controls for an individual trader's village market power and the household's ability to switch traders. We find that high village market power by the trader and low flexibility for the household lead to both lower overall prices and low quality premia. This information can be used to identify situations in which farmers are unlikely to be compensated for high quality grain. We analyze the quality outcome of households for whom quality premia and low and find that they respond to the lack of financial incentive by not producing high quality grain.

The data for the adapted hedonic model comes from a survey of 3,200 households in Bihar, which was collected in January - April 2016, and the census of grain traders working in these villages which was collected in July - September 2015.

Previous studies estimate quality premia in informal markets and the dynamics of these incentives for small-holder farmers using adapted hedonic models. Kariuki, Loy, and Herzfeld (2012) find that farmers with Global Good Agricultural Practice (GGAP) certification for green beans in Kenya receive a 9.4% price premium overall throughout the year. They also do not experience a stark drop in price after harvest, so 3 weeks after harvest the premium for GGAP certification is 24%. Hueth and Jano (2014) find that, in the market for Ecuadorian cocoa, quality is rewarded via price premia for actions that affect quality; actions that are easily identifiable are more rewarded, but actions that affect lower-value characteristics receive a larger relative premium. Kadjo, Ricker-Gilbert, and Alexander (2015) find that, in Benin, discounts for insect damage to maize are high at harvest, but these discounts drop in the lean season when the supply of maize is low. Kvaløy (2006) develops a theoretical model for implicit price in informal markets, which is a useful foundation for our theoretical model. He shows that a farmer's bargaining power at the time of sale determines the incentive pay for high quality, as do his risk aversion and the variance in the distribution of quality in the region. Goldsmith, Martins, and de Moura (2015) address the question of why profit maximizing farmers may choose to allow some post-harvest losses. They find that soybean producers in Brazil accept a "suitable loss" of soy harvest in order to time the maize planting correctly.

First, we develop a theoretical model of price premia including producers, traders, and end users. Next, we estimate the premia received by households and received traders when selling grain in Bihar. Finally, we try to understand the mechanism underlying these premia through the main models and a series of robustness checks. We make three primary contributions to the literature. First, we identify the financial incentives, or the lack thereof, for producers and traders reduce quality loss. Rather than simply estimating the losses farmers are incurring or measuring the effects of an intervention, we ask why losses occur in the first place through an analysis of the supply chain and an estimation of financial incentives. The use of contextual evidence, data, and a theoretical model makes our findings more generally applicable.

Second, we empirically test whether and how trader market power affects the quality premia recevied by

traders. A high quality premium is a straightforward incentive to improve grain quality, but premia is not only determined by quality. We incorporate both the trader and farmer's market power, which allows us to anticipate variation in quality premia based on the number of grain buyers in the market. The unique primary data we use sets this work apart from the previous literature on premia. To our knowledge, this is the first study to match buyers and sellers to measure both the household and their buyer's market power in informal markets. This article also exceeds previous studies in sample size of households and villages. The large number of villages provides a better distribution of market power.

Finally, we seek to change the way researchers think about post-harvest loss. By broadening the scope of losses to include loss in quality, and thereby value, we address a vital and often overlooked component of post-harvest loss. Global food security, access to safe, sufficient, and nutritious food by all people at all times is hindered by losses in monetary or nutritional value, which result from quality loss.

2   Background and Supply Chain

Bihar is a state in Northwest India with an area of 9.4 million hectares. In 2011-2012, the net sown area was 5.4 million hectares, or 57.6% of total area. Of this area, 90% was planted in food grains, mostly rice and wheat (Government of Bihar Finance Department, 2015). In 2006 3.1 million ha were planted under paddy, 2.0 million under wheat, and 468 thousand under maize (BAMETI, 2007). The rain-fed crop, known as the kharif crop, is harvested in October and November. The second season crop, known as the rabi crop, must be irrigated, and is harvested in March. Rice is a kharif crop, wheat is a rabi crop, and maize is grown in both seasons. The gross net sown area aggregating the two (rabi and kharif) seasons is 7.9 million ha.

The 2011 national census recorded a population of 104.1 million living in Bihar, making it the 3rd most populous state in India (Indian National Census, 2011). It is also one of the poorest. The annual income per capita in 2013-2014 was only 39.2% of the national average, at US$ 235. While this is a marked improvement from 2009-2010, when income per capita was US$159, or 31.1% of the national average, 33.7% of the population remains below the poverty line. Nine out of ten people live in villages, and agriculture accounts for 19.4% of state GDP (Government of Bihar Finance Department, 2015). There are 10,432,417 land holdings in the state, of which 82.9% are less than one hectare. Another 9.6% are between one and two hectares (BAMETI, 2015). Only 1.8% of land holdings are greater than four hectares. In our sample, the mean landholding was 0.879 ha, of which 0.577 ha were planted in grains.

The supply chain of Bihar is outlined in figure 1. Farmers plant, tend, and harvest grains themselves. Grain is harvested mechanically, threshed, and dried on farm. Sun drying is nearly universal, with around a quarter of farmers sun drying on a sheet, but none of our sample had used a solar or diesel dryer. Households store grain on farm at least temporarily, during which time it is most likely to be stored in jute bags without plastic liners, although plastic liners and pesticide may be used in the jute bag. No households have used a moisture meter to monitor their crop's moisture content (table 6).

Some households then sell at least a portion of their crop, while others continue to store grain in the house or a shed until they consume it themselves. We find that only 18.22% of households sell grain in our sample and nearly all households who sell grain store at least a portion of their grain. Households typically store half of their crop for their own consumption. A third of households store grain to obtain a better price later in the season. These rates of storage and home consumption are consistent with the literature. The DMI survey finds that 45% of paddy is kept on-farm for consumption in Bihar, and nationwide producers keep 41.45% of maize and 39.67% of grain for on-farm consumption (Shroff & Kajale, 2013). Nanda et al. report that 33% of paddy and 37% of wheat are retained by farmers for their own use (Nanda et al., 2012).

Although prices are higher outside of harvest, many farmers who commercialize grain sell their product immediately after harvest, when prices are low. Lack of access to storage is one cause; households on average have storage capacity of 854.17 kg, but in the most recent harvest households in the sample sold 1326.16 kg of maize alone on average. Lack of a buyer also limits sales, as traders purchase intermittently throughout the year. Finally, households who have taken out loans are expected to repay those loans at the time of harvest, as creditors are aware that the household will have an increase in income. In our sample, 23.00% of households had standing loans at the time of the survey, and 11.6% of households had standing loans for agriculture.

Grains that are sold are commercialized through a local trader in the trader's shop or through the trader

buying at the farmer's field. Traders in Bihar are financially liable for any losses that occur after purchase, as they are then sole owners of the grain. In fact, traders go to efforts to improve quality by hiring employees to pick out broken grains and foreign matter after purchase. This practice can be viewed as a form of vertical integration. Rather than establishing an informal contract (in the form of quality premia) with farmers for quality preservation, traders perform the action themselves. It is likely less expensive to vertically integrate because labor costs are low while the cost of coordination is high, as binding contracts are difficult to establish in informal markets without regulatory agencies. The results of a farmer's efforts to improve quality may also have high variance in quality, which Hueth and Jano (2015) find reduces the compensation for quality.

Of households that do commercialize their grain, 60% report that they could not sell to another trader for a better price (table 7). Reasons given for this are collusion among traders and a lack of other traders. Data from the trader survey also show that village traders in Bihar enjoy extreme levels of market power. The sample has an average of 1.912 traders purchasing in each village, with a minimum of one trader and a maximum of four. Even more remarkably, the average village Herfindahl index (table 8) for each crop more than doubles the benchmark the US Department of Justice considers to be highly concentrated, 0.25 out of 1.00 (US Department of Justice, 2015). Economic theory shows that quantity will be lower and prices will be higher in monopoly and oligopoly settings compared to a perfectly competitive market. When buyers have high market power (monopsony or oligopsony), both quantity and price will be low. Intermediaries that act as both a monopsonist buyer and a monopolist seller may have the ability to buy grain below competitive equilibrium prices and sell it at high prices, garnering a large profit.

During sale traders do not adhere to formal quality standards that have been set forth by the government, and anecdotally neither do local government buyers. Some communication of quality preferences still occurs, however, as households and traders agree that moisture is one of the most important qualities for all three crops and that grain size is important for wheat and rice (table 4). Opinions differ with regards to the second and third most important qualities, however. This imperfect information transfer prevents quality being produced at the level where marginal benefit of quality matches the marginal cost of its production (Fafchamps, Hill, & Minten, 2008).

Traders store grain temporarily, but they claim they would not make a higher profit if they stored grain after harvest. Traders agree that prices do increase after harvest, but storage costs are too high to benefit. In practice, traders rarely have the option to store long term, as they need to sell immediately to repay farmers.

In our sample, most traders sell to another trader, with a much smaller number selling directly to a mill, retail, an animal feed producer, or directly to households (table **??**. Mechanical milling has been nearly universally adopted, which is likely due to the fact that milling is carried out by processors rather than farmers. After households sell grain to a local trader the grain continues being sold to progressively larger traders until it reaches a processor; grain sold to processors is then sold back to consumers.

Officially, the Food Corporation of India (FCI) procures grain from farmers at a Minimum Support Price to reach its mission of stabilizing grain prices in the country so that farmers can sell at a sufficiently high price while households purchase at a sufficiently low price. While the FCI is a federal entity and procurement occurs nationwide, 97% of paddy and 87% of wheat procurement is carried out by state agencies (FCI, 2016; FCI, 2016). As such, the system functions differently in each state. In Bihar, state procurement is carried out by Primariy Agricultural Credit Societies (PACS), local societies of farmers. Notably, however, none of the farmers in the sample sell to PACS. This is a nationwide phenomenon. Although small-holders are supposed to be able to sell grain to federal or state procurement organizations, only 10% of paddy and 16.2% of wheat farmers sold to a federal or state procurement agency between January and June 2013 (Rajawat, 2015).

Rajawat (2015) argues that shortage of government storage capacity makes it impossible for the government to procure the entire harvest; the only people who can sell to government procurers at the time of harvest are those who have greased enough palms. Farmers in the sample say that local officials cite incomplete paperwork or poor quality as justification to refuse a sale. Farmers also complain that officials prefer processing the paperwork of a few traders to that of dozens of farmers, and therefore impose an unofficial minimum purchase quantity. Official policy also requires that farmers be reimbursed for transportation costs to the PACS, but farmers report that is never paid. The FCI also has formal quality standards that they can use to refuse sale (tables 2 and 3), although it unlikely those standards are used consistently. Traders measure quality using their teeth and hands, and very few report refusing sale as their method of penalizing

low quality (7 wheat traders, 7 maize traders, and 1 rice trader from our sample of 107). Farmers also report that local officials demand between 5 and 10 percent of the grain as extra payment, and that payment from sales to PACS is delayed from two months to a year; traders pay within a month.

No traders in our sample report selling to PACS, however. One possible reason for this is that PACS were established to work directly with farmers; traders may be reluctant to report violating this system by selling to the government directly as a trader. If a trader also farms, this would constitute a farmer's selling to the government, but they would largely be selling someone else's crop. Anecdotally, only large farmers and traders sell to PACS, so traders in our sample may be too small to sell to PACS. This anecdotal evidence implies that market power is necessary to sell grain to the government for the established floor price, an irony given that the program was established to ensure that all farmers could receive fair prices.

The ineffectiveness of this program with respect to its intended purpose is clearly demonstrated in Table 10, which finds that the Minimum Support Price (MSP) does not hold for any crops. The average price which households received in the last harvest is at least 1.5 Rs. kg, or 11.03%, under the MSP, depending on crop. The traders confirm this, as their average purchases prices are well under the MSP. Notably, the average sale price of traders in our sample was also under the MSP, which supports the hypothesis that the traders in the sample are too small to sell directly the PACS themselves.

The data also confirm that grain is typically passed between at least two intermediaries before it reaches the end consumer. Since quality must be maintained during each stage of the supply chain to prevent losses from compounding, each additional intermediary introduces another potential agency problem, leading to possible careless or untrained handling.

3   Theory

We model a setting with a large number of farmers, each who produce a fixed quantity of grain (determined, say, by their farm size). Grain is purchased by n local traders who then sell the grain to local end users. All sales take place within the same market. Each individual farmer can directly choose the quality level ϕ per unit of grain, where ϕ is ordinal, and a higher value of ϕ represents higher grain quality. Quality is a function of price that is determined by the end user's demand function for quality.

Producing ϕ incurs a marginal cost c for the farmer. The trader pays the farmer $\beta p \phi$ per unit of grain, where p is the marginal value of quality that the trader receives when he resells the grain. The portion of the price that is passed on to the farmer is represented by $\beta \in (0, 1)$. The farmer's per unit profit takes the form

$$\pi_f = \beta p \phi - c \phi. \tag{1}$$

Maximizing this with respect to quality, we find that the farmer produces quality at such a level as

$$\beta p = c, \tag{2}$$

In other words, the farmer produces at the point that marginal revenue of quality is equal to the marginal cost of quality.

The n traders have the ability to differentiate their product, giving them a degree of power to set their price. The trader faces a final demand for quality:

$$\phi_d(p_i) = S * (\frac{1}{n} - b(p_i - \bar{p})) \tag{3}$$

where S is the preference for quality in the market. End users that need a higher quality grain to produce their product, such as millers, will have a higher value of S and a higher quality demanded, ϕ_d than a feed producer whose product does not depend on quality. As stated above, n is the number of traders buying and selling grain in the market.

The term b represents the trader's ability to differentiate and set prices above market prices; a higher value of b results in a larger decrease in quality demanded when p_i strays above the prevailing market price, $\bar{p}$. Imagine a setting with only high and low levels of quality, ϕ_{dh} and ϕ_{dl} and a trader setting the equilibrium price for high quality grain (determined by the levels of S, n, b, and $\bar{p}$). If the trader wishes to set price above his current level, he will no longer face demand for high quality grain, and will instead face demand for low quality grain by end-users. To increase price while still selling high quality grain, he must also lower

b, his sensitivity to market price. This can be achieved by differentiating his services from the other $n - 1$ traders in the market by changing the location or timing of his delivery. Traders which differentiate their product can set a higher price p_i while still selling the same quality of grain.

Given this, the trader will choose p_i and β that maximize profit.

$$\pi_t = p_i \phi_d(p_i) - \beta_i p_i \phi_s(p_i) - F \tag{4}$$

where F is a fixed cost of operation such as shop rent or employing assistants. The quality of grain that end users demand is represented by ϕ_d, and ϕ_s represents the quality of grain the trader buys from farmers. For the trader to successfully sell his grain, the quality he buys from the farmer must be of greater or equal than the quality demanded by the end user. For the sake of simplicity we assume that traders cannot change quality. We therefore assume that the trader will set p_i such that $\phi_s = \phi_d$, as this maximizes profit. Two practices in Bihar may violate this assumption. First, traders in Bihar practice grain mixing, which makes it possible that $\phi_s \neq \phi_d$ for small quantities, but it must be true that $\bar{\phi}_s = \bar{\phi}_d$ for the trader to mix the grain to achieve ϕ_d. The practice of traders hiring workers to manually improve quality, as discussed in section 4.2, is more problematic. We discuss the implications of that violation in the results section.

For the model, however, we maintain the assumption that $\phi_s = \phi_d$, which allows us to rewrite trader profit with respect to quality as

$$\pi_t = (1 - \beta_i) \phi(p_i) * p_i - F \tag{5}$$

Substituting in the final demand function, we find

$$\pi_t = S\left(\frac{1}{n} - (p_i - \bar{p})\right)(1 - \beta_i)p_i - F. \tag{6}$$

The trader then chooses p_i and β that maximizes profit. The first order conditions are:

$$\frac{\partial \pi_t}{\partial p_i} = (1 - \beta_i)\left(\phi_i(p_i) + p\frac{\partial \phi}{\partial p}\right) = 0 \tag{7}$$

$$\frac{\partial \pi_t}{\partial \beta_i} = p_i \frac{\partial \phi_i}{\partial \beta_i} - \beta_i p_i \frac{\partial \phi_i}{\partial \beta_i} - p_i \phi_i = 0 \tag{8}$$

Plugging equation 3 into equation 7 yields

$$\frac{\partial \pi_t}{\partial p_i} = (1 - \beta_i)\left(S\left(\frac{1}{n} - 2bp_i + b\bar{p}\right) - \frac{-pbS}{n}\right) = 0 \tag{9}$$

Solving for price we find

$$p_i^* = \frac{1}{bn} + \frac{1}{bn^2} + \frac{\bar{p}}{n} + \bar{p}. \tag{10}$$

Similarly, plugging equation 3 into 8 shows

$$\frac{\partial \pi_t}{\partial \beta_i} = (1 - \beta)\frac{\partial \phi_i}{\partial \beta_i} - S\left(\frac{1}{n} - b(p_i + \bar{p})\right) = 0 \tag{11}$$

we solve this for β_i, which yields

$$\beta_i^* = 1 - \frac{-S(\frac{1}{n} - b(p_i - \bar{p}))}{\frac{\partial \phi_i}{\partial \beta_i}} \tag{12}$$

From equation 10, a trader will increase his price if the average market price increases. The FOC also show that p_i decreases when the number of traders in the market n increases. P_i decreases as the trader becomes more sensitive to the prevailing market price, or b increases. Although traders sell their product for a lower price when the number of competitors increases, we find that the share of the price that is passed on to the farmers, β, is increasing in n. This implies that traders must compete to purchase grain from farmers when there are more traders in the market. Equation 12 also indicates that β is increasing in b. As traders become less differentiated, the share price they pay to farmers increases.

6

To assess the effect of the number of traders on quality, we assume that quality is increasing in compensation, or $\frac{\partial \phi(p)}{\partial \beta p} > 0$. Because β is increasing in n but p is decreasing in n, the overall effect of a change in the number of traders on the compensation a farmer receives is ambiguous. The effect of a change in the number of traders on the quality produced cannot be determined without imposing more structure on $\phi(p)$ and β. When $|\frac{\partial p}{\partial n}|$ is greater than $|\frac{\partial \beta}{\partial n}|$, or an increase in n results in a decrease in the price that is higher in magnitude than the increase in the pass-through to the farmer, quality will decrease, and vice versa.

Similarly, the effect of trader differentiation on the price farmers receive, βp, is ambiguous. Traders who are not sensitive to the average market price, $\bar{p}$, will receive a higher price, p_i, but they will also pass less of that price on to farmers through β. Again, the net effect depends on the magnitudes of the partial derivatives. When $|\frac{\partial p}{\partial b}|$ is greater than $|\frac{\partial \beta}{\partial b}|$, the effect of the increase in price that a trader receives will dominate the decrease in pass-through, and the farmer will net gain.

In the following section we test the results of this model in practice by modeling the purchase effect of village and regional market power and differentiation traders' price and premia.

4   Data

Data for this study come from a baseline household survey and a trader survey in India. A total of 3,200 household surveys were collected in Bihar. The sampling strategy was as follows. Two districts were non-randomly selected in each of the regions surrounding Bihar Agricultural University and Rajendra Agricultural University for a total of four districts. Within each district two blocks were randomly selected, excluding blocks in which the crops of interest are not cultivated. Data from the 2011 census were used to create a list of villages in each block with less than 1,500 households, to ensure that villages are homogenous in size. Eight villages were randomly selected from each block using this list.

Once villages were selected, a village level survey was conducted by enumerators in June and July 2015. During this time enumerators gathered list of the households in each village from the local government register.

Enumerators also surveyed agricultural traders operating in the villages at this time. The sampling strategy was exhaustive; all traders working within sample villages were surveyed for a total of 107 over 49 villages. Of these, 105 trade wheat, 100 trade maize, and 70 trade rice. They work in an average of 3.85 villages, and buy grain from an average of 74.57 households. A full set of summary statistics is discussed in section 4.2 and is listed on table 9.

Fifty households were randomly selected in each village using the lists of households obtained during the village survey. The baseline household survey took place in from November 2015 - February 2016. All randomized selection was performed in Stata.

Of the 3,200 households surveyed, 346 commercialize wheat, 298 commercialize maize, and 298 commercialize rice. Their average land holding is 1.417 hectares. Households summary statistics are discussed in section 4.2 and reported in table 7.

Summary statistics for the data are in tables 6 - 10.

5   Estimation

We develop several testable hypotheses from the theoretical model of the effect of market power on grain quality premia. First, we hypothesize that grain intermediaries with higher market power are able to simultaneously offer lower quality premia to farmers and receive high premia from end users. Second, we hypothesize that traders who differentiate themselves so that households are unable to sell to another trader are able to pay lower prices to households beyond the level expected given their market power. This differentiation may be achieved by paying quickly after harvest, buying in a convenient location, or through social and familial ties. We test these hypotheses using primary data from India. Given that these hypotheses involves two transactions and three actors, the analysis includes several methods.

5.1 Trader Estimation

The pricing decisions of traders in Bihar are modeled using a linear regression with village fixed effects model. We use the following form to model a trader's purchase price and purchase discount:

$$P_{ijc} = \beta_{0c} + \beta_{1c}MP_{ijc} + \beta_{2c}B_{ij} + \beta_{3c}R_{ij} + \beta_{4c}T_{ijc} + V_{jc} + \epsilon_{ijc}. \tag{13}$$

Here the subscript i refers to an individual trader, j refers to the village in which he operates, and c refers to the crop the model represents. we estimate the model separately for wheat, maize, and rice. The market share of trader i in village j is written MP_{ijc}. It is calculated as $\left(\frac{Volume_i}{\sum_{j=1}^{n} Volume_j}\right)^2$, the square of the volume of trader i as a proportion of the total volume in village j. The type of client the trader buys grain from and sells grain to are represented by sets of indicator variables, B_{ij} and R_{ij}, respectively. A vector of demographic variables for the trader, T_{ij}, includes their years working as a trader and indicator variables for high caste traders and those with secondary education. The village fixed effects term is V_{jc}, and ϵ_{ijc} is the standard random error term.

To model the price at which the trader sells grain we use a similar village fixed effects model, but we omit the village market power term and include the number of villages in which the trader buys grain. Unlike in the theoretical model where purchases and sales took place in one market, traders may purchase grain in a small village and resell it at a larger market. Therefore, we want to control for regional market power in a model of sale price rather than village market power, MP_{ijc}. However, we are constrained from using explicit regional market power measures by our village sampling strategy. Since we selected a subset of villages per block, we do not have data on all traders within the market where they resell grain. The vector of trader attributes, T_{ij}, as well as the type of clients the trader buys from and sells to, R_{ij} and B_{ij}, are representative of the trader's power in the regional market. To understand the relationship between regional and village market power measures we estimate

$$MP_{ij} = \gamma_0 + \gamma_1 B_{ij} + \gamma_2 R_{ij} + \gamma_3 T_{ij} + V_j + C_{ij} + \epsilon_{ij}. \tag{14}$$

For this model, we pool all observations and control for the crop the market power corresponds with using indicator variables C_{ij}.

5.2 Household Estimation

5.2.1 Main Results

For the primary household model, we follow the method of Hueth and Jano (2014), Kariuki, Loy, and Herzefeld (2012), and Kadjo, Ricker-Gilbert, and Alexander (2015). we estimate the price of grain as a function of quality parameters as well as characteristics of the buyer and seller. This type of model is an extension of the traditional hedonic price model, which Rosen introduced in 1974 (Rosen, 1974). Rosen's original model represents a good as a bundle of attributes, whose respective prices compose the total price of the good. The coefficients of the model represent the implicit price of each individual attribute. The model takes the form

$$P = \alpha_0 + \alpha_1 \phi_1 + \alpha_2 \phi_2 + ... + \alpha_n \phi_n + \epsilon, \tag{15}$$

where $\phi_1, ..., \phi_n$ represent the quality level of n quality attributes and $\alpha_1, ..., \alpha_n$ are the marginal values of those attributes.

For this equation to provide an unbiased estimate of price, Rosen made two assumptions that do not hold in India. First, Rosen assumes that buyers and sellers are perfectly matched. As previously shown, farmers in Bihar are limited in their choice of buyer due to the limited number of traders in each village, collusion among traders, difficulty accessing large markets, and minimum purchase quantities imposed by larger intermediaries. Second, there must be full transfer of information regarding desired quality attributes. This allows producers to tailor their goods to meet the demands of consumers. We find that some information transfer occurs in Bihar despite the lack of formal quality standards, but there is still difference of opinion between households and traders regarding qualities that most determine price (Table 4).

To control for the first violation we include the village market share of the trader the household sold to in the most recent harvest and an indicator variable for whether the household reported it could sell to another

trader. These account for the trader's market power and price setting ability in the village as well as in their relationship with that particular household. Since the theoretical model represents price as a function of quality per unit of grain, we control for quantity.

The model takes the form

$$P_{ikc} = \omega_{0c} + \omega_{1c}\phi_{kc} + \omega_{2c}MP_{ic} + \omega_{3c}S_k + \omega_{4c}N_{ic} + \epsilon \tag{16}$$

where the subscript represents observations of household k selling crop c to trader i. The model is estimated separately for each grain, as the desired qualities and practices vary by grain. The quality of the grain, ϕ_{kc}, is measured by a set of self-reported indicator variablesthat signify whether the farmer states that they have better or worse quality than their neighbors. The trader's village market power, MP_{ic}, is measured using the same method as in equation 13. The indicator variable S_k takes the value of 1 if household k could not sell grain to another trader. The variable N_{kc} controls for the quantity sold, so that ω_{1c} is a per unit premium for quality.

In the full specification model, we include a set of indicator variables for the month of sale and household demographic variables in equation 16. The inclusion of the proportion of the farmer's income that comes from non-farm activities accounts for the farmer's reliance on the grain sale, and thereby their trader, for their livelihood. The total area that a household owns represents the household's wealth. Finally, we include the standard demographic variables, household head age, gender, and education level. The household head's education and age as well as their involvement in agriculture, measured as the size of their land holding and the proportion of income coming from agriculture, control for their likelihood of receiving information regarding quality.

While the previous models demonstrate that traders with high market power pay lower prices overall, they do not specifically address the effect of village market power on quality premia. To answer this question, we include an interaction term between quality and village market power for each quality, l one at a time. The model mimics the form of equation 16, but rather than including the full vector ϕ, we include one quality, and the interaction term between that quality and village market power. Due to limitation of sample size, we estimate the model for each quality separately, so each crop has five models with the form

$$P_c = \omega_{0cl} + \omega_{1cl}\phi_{ikcl} + \omega_{2icl}MP_{ic} + \omega_{3cl}(\phi_{ikcl} * MP_{ic}) + \epsilon. \tag{17}$$

We additionally estimate equation 16 using an alternative specification for ϕ_{kc}. Farmers were asked to compare their grain quality to their neighbors' as well as to the quality they produced in the previous harvest. One might be concerned that farmers overstate their quality compared to their neighbor, whereas they would not be as compelled to boast when comparing to their own quality. For robustness, we re-estimate the model using the comparison to the past harvest in place of the comparison to the neighbor. We also validate the results by using block fixed effects, which includes a constant term for each block (containing eight villages), B in equation 16.

For robustness, we also test whether there are clusters of poor quality in regions of the sample. These clusters of poor quality grain could attract traders which are systematically different from the sample. For example, low quality regions might only attract traders with high enough market power to hire labor to improve grain quality or mix grain manually; low quality regions would then have fewer traders with inherently higher market power. To investigate this relationship, we estimate the average Herfindahl index in a block and tabulate the instances of low, medium, and high quality in that village. We use the χ^2 value to test whether the distribution of grain quality is statistically significant between blocks using both measures of grain quality.

5.2.2   Secondary Analyses

To understand whether quality incentives are sufficient to encourage farmers to adopt quality-augmenting technologies and whether these technologies do indeed improve quality, we compare the quality outcomes of households who do and do not use technologies which are not universally adopted: a sheet during solar drying, manual harvesting, a lined bag during storage, and pesticide during storage. Again, we use the χ^2 value to test whether households who use the technologies have statistically different grain quality than those who do not.

Further, we estimate mean price received by households that do and do not use all of the surveyed technologies. We then estimate the price a household receives as a function of non-universally adopted technologies. In this model, technology, τ, is used as a measure of grain quality, and signals quality to traders (Hueth & Jano, 2015). We also include market power in a second model, which is structured similarly to equation 16.

$$P_{ikc} = \omega_{0c} + \omega_{1c}\tau_{kc} + \omega_{2c}MP_{ic} + \omega_{3c}S_k + \omega_{4c}N_{ic} + \epsilon \tag{18}$$

The effect of selling on-farm on price is not immediately clear; traders usually charge a premium if they must travel to the farm, but they are better able to identify the steps a farmer took to improve quality (Hueth & Jano, 2015). Furthermore, the sale must hold a degree of importance to the trader to compel them to travel to the farm for the sale. This places more of the power in the hands of the farmer than one would find in a typical off-farm sale. First, we include an indicator variable for whether or not a household sold on-farm in the hedonic model with market power, equation 16. This will demonstrate whether location results in a premium or a discount once quality is controlled for. We also estimate equation 18 separately for households who sold on-farm and those who did not to discern whether traders are more responsive to technology usage when they are able to identify it on-farm at the time of sale.

Finally, the traders in the sample are heterogeneous in terms of who they can sell to. Less than 30% of the sample sells to a mill, a retailer, or a feed producer, whereas 83% sell to another trader. Traders which sell directly to end-users are subject to more rigorous quality measurements, and may offer different prices and premia to the households they buy from. We first estimate the price a household receives as a function of the type of they sell to (sells directly to end-users or only sells to traders); next we control for the grain quality, and finally we also include market power in the model. The final model takes the form:

$$P_{ikc} = \omega_{0c} + \omega_{1c}\phi_{kc} + \omega_{2c}MP_{ic} + \omega_{3c}S_k + \omega_{4c}N_{ic} + \omega_{5c}L_{ic} + \epsilon. \tag{19}$$

6 Results

6.1 Household Models

6.1.1 Main Results

Next, we use the household data to confirm whether traders with high market power price grain differently than those with low market power. Table 13 presents the coefficients on trader market power and a household being stuck with their trader, as described in equation 16. Importantly, both MP_{ic} and S_k have negative and significant coefficients in the main hedonic specification (column 1), with the exception of the coefficients of market power for maize and wheat which is negative but insignificant. If a trader's village market power increases or the household loses the ability to sell to another trader, the price they receive per unit of grain will decrease, all else equal. Relating this to the theoretical model, the negative terms suggest that $|\frac{\partial \tilde{\beta}}{\partial n}|$ is greater than $|\frac{\partial p_i}{\partial n}|$, causing the overall price the farmer receives to decrease as their trader's market power increases. This result is robust to an alternative definition of quality, in which households define their quality in comparison to their own previous harvest (column 3). The inclusion of block and household fixed effects results in fewer of the coefficients on trader market power and a household being stuck with a trader (columns 4-6). They remain consistently negative, however. It is likely that household controls in the model determine are correlated with whether a household is stuck with their trader. There also may be regional patterns of market power which absorb much of the explanatory power of the individual trader. This spatial clustering of market power should be explored in future work.

Using equation 17, we estimate the effect of market power on the premium received by a farmer by reporting the main effect of the quality premium and the interaction term of quality and market power. We find that the interaction term of quality and market power works in the opposite direction of the quality premium in every case where the premium is significant. Moreover, the main effect and market power interaction have opposite sign in twenty-seven out of thirty cases, and they only take the same sign when the premia are already small and insignificant. Farmers selling to high market power traders, therefore face a very unchanging price schedule, and have little incentive to produce high quality grain.

Translating these results into monetary terms, we use equation 16 to estimate the average price for a household who is stuck with their trader and a household who is able to seek a different trader, holding all else constant. Households who are able to seek another trader sell to traders with market shares of 0.54 for wheat, 0.55 for maize, and 0.67 for rice, on average. In contrast, households who are stuck with their trader on average face traders with lower market shares of 0.53 for wheat, 0.47 for maize, and 0.51 for rice. Holding quality and household characteristics equal, a household who is stuck with their trader receives 0.64 fewer Rs. per kg of wheat, 0.90 fewer Rs. per kg of maize, and 0.12 fewer Rs. per kg of rice. In practical terms, the prices a household who is stuck with their trader receives are 4.94% lower for wheat, 5.57% lower for maize, and 1.20% lower for rice. At the sample average quantities, this results in a total loss of income of 252.37 Rs. for wheat, 1,193.55 Rs. for maize, and 53.72 Rs. for rice.

A household who sells to a monopsonist trader ($MP = 1.00$) compared to a household who sells to a trader with a competitive market share according to the US Department of Justice ($MP = 0.25$) will receive 0.15Rs./kg less for wheat, 0.36Rs./kg less for maize, and 0.22Rs./kg less for rice. At the sample average quantities, this translates to a total loss of income of 54.86Rs. for wheat, 477.42Rs. for maize, and 98.49Rs. for rice.

The household models support the conclusion that traders with high village market power buy grain for low and unvarying prices. When village and regional market power overlap, a trader may be able to buy at a low price and sell for a high price, making a much larger profit than he would in the absence of market power. In other cases, small traders with local market power purchase from households at a low price and sell to a larger trader for a higher price. This larger trader has regional market power, and is able to sell grain for an even higher price. This long supply chain results in a large disparity between the price and incentives the farmer receives and the price and incentives the end user gives, and it is driven by market power.

6.1.2   Secondary Analyses

These results, which point to high power traders in Bihar receiving incentives for high quality grain but those incentives never reaching households, seem at odds with the predictions of Fafchamps. Fafchamps predicts that quality premia in a competitive market will settle at the level where the marginal utility of the quality is equal to the marginal cost of producing that quality. High power traders in Bihar, however, may be under-compensating farmers for quality by paying less than the marginal utility (or the premia traders receive when they sell the grain). It is therefore important to understand whether grain quality is suffering as a result of market power or whether farmers continue to produce high quality grain regardless.

Table 15 reports the average village market power of the traders households sell to by the quality of their crop. It suggests that for qualities that can be altered after harvest, impurities, broken grains, and moisture content, households who produce low quality grain sell to high power traders. This pattern is not present for color or size. First, households have little control over grain color or size post-harvest, so whether a household produces grain with good color or quality is less influenced by incentives. Second, traders are also not able to alter color or size after the sale takes place.

Given preliminary evidence that high power traders receive lower grain quality, offering such low premia seems to be an irrational behavior, as traders themselves receive higher prices for higher quality grain. In practice, however, traders are able to improve grain quality after sale. When traders have high market power, they are able to purchase grain at such low prices that the marginal cost of improving quality themselves is lower than the premia necessary to motivate farmers to improve quality. Lower power traders must offer competitive prices and premia to complete sales. The marginal cost of motivating farmers to produce high quality grain is in effect lower, as the trader would not be able to make a sale without offering a premium. Therefore it is less costly to buy high quality grain from households than to manually improve quality. Households who are offered premia respond by producing higher quality grain. When traders are unable to change quality after purchase (as is the case for color and size), however, market power has no effect on the quality households produce.

Some grain quality may be recovered manually by traders, but the trader never returns the grain to its full potential quality. The trader combats high percentages of broken or damaged grains by discarding the individual grains; that physical loss would not have occurred had farmers prevented quality from deteriorating to begin with. The household knows they will receive the same compensation whether they sell 100kg of

perfect grains or grain of which 10kg must be thrown away. They therefore do not take action to prevent breakage during threshing or pest infestation that damages grain further. They may not dry the grain properly, and while the grain remains at high moisture content for longer than necessary, it can acquire must or mold that requires it to be discarded.

The disconnect between quality and prices may also be caused by the available technology. The relationship between adoption of sheet drying, manual threshing, lined gunny sacks, and pesticide tablets in storage is not obvious. Tables 19, 20, and 21 find that technology usage significantly affects the quality distribution twenty-one out of thirty-six tests, but no obvious or intuitive pattern emerges.

The nebulous results of technology "improvements" may be another reason that traders are less likely to enter informal contracts with farmers. Tables 16 and 17, which estimate the price received by the full sample based on the technology used during and after harvest, confirm that farmers are almost never compensated for technology. The exception to this result is pesticide usage, as the reduction of insects in grain bags can be easily detected and compensated. When we split the sample into sales which take place on and off-field, pesticide usage is only significant in sales taking place off-field, as the pesticide is more useful the longer the grain remains in storage, and on-field sales are likely immediately after harvest. Laying grain on a sheet also significantly increases the price of wheat which is sold on-field, although it decreases price when rice is sold off-field, holding all else equal. Laying grain on a sheet may deliver a signal of quality improvement which traders respond to during on-farm sales, but which does not improve quality enough to result in a higher price when the sale takes place off farm.

If technology use alone is not a strong signal of grain quality (although proper use of technology may improve quality), then traders are still left without a simple predictor or measure of grain quality. Rather than investing in technology to accurately predict quality, they choose to employ low-wage labor to improve quality post-sale.

Sale location is also related to both price and market power; we also investigate it as an explanation for the lack of compensation for quality. Sales which take place on-field are significantly larger in quantity than those which take place in a trader's shop. Traders are willing to travel for an important client with large amounts of grain. These large clients receive significantly higher prices of wheat and rice, holding quality constant. For maize, the effect is opposite, and on-field sales receive a statistically lower price (table 13, column 2). For wheat and rice, a very small percentage of the sample sells grain on-field, whereas half of maize sales take place on-field (table 7). Wheat and rice producers which sell on-field are important enough that traders pay a premium for the grain, even after building the cost of transportation into the purchase price. For maize, however, traders lower price to cover their own transportation costs without offering farmers a premium, since maize is sold on farm for more than just the most important clients.

It may also be that traders in the sample lack the regional market power to receive quality premia themselves. Just as it is increasingly difficult to maintain quality as the number of actors handling the grain increases, incentives can become diluted with each transaction. In the theoretical model, an intermediary only passes β of the premia he receives on to farmers. If the trader instead sells the grain to another trader, who then passes $\delta \in (0,1)$ of the price he received, βp, on to a farmer, the farmer only receives $\delta \beta p$. As the number of sales taking place before the grain reaches the end user becomes infinitely large, the premia the households receive goes to zero. In practice, we find that the premia become statistically indistinguishable from zero far with only a three or four traders, far before the number of traders reaches infinity.

The sample contains both traders who purchase directly from households and those who purchase from other traders, allowing us to identify that traders can obtain premia by selling to differentiated end users. Households, for the most part, sell to the lowest level traders, who are themselves receiving only a portion of the premia. Therefore, each trader in the supply chain is behaving rationally by passing on a portion of the premia he received, but at the end of the supply chain, the premia the households receive are insignificant. we expect that, as the incentives to preserve quality are lost with each transaction, so is quality itself.

Households who sell to traders who sell directly to mills and retailers will receive a lower price overall, holding quality equal (table 13, column 7). This is because traders which sell to end users directly have high regional market power, which is shown to decrease overall price. For wheat, where the effect of selling to a mill or retailer is the strongest, the coefficient on market power is insignificant, whereas the coefficient on selling to a mill or retailer is insignificant for rice but market power is significant.

The relationship between who the trader sells to and household price should be further developed. The current survey of traders does not distinguish who a trader sells to separately for each grain. Therefore,

a trader may have a value of one in the wheat for the variable indicating that they sell to feed producers, when in fact that trader only sells their maize to feed producers. This increases the risk that the end-user indicator variables are merely reflecting the trader's market power. In addition to overall price, the relationship between the seller a trader sells to and the premia a household receives should also be explored. To avoid splitting the sample even further, we leave this relationship to further work.

7   Conclusion

Reducing post-harvest loss is crucial to the effort to achieve global food security, but the causes of those post-harvest losses must be addressed. Farmers and intermediaries must be incentivized to prevent physical and quality losses, as the two are inextricably related. The structure of the supply chain determines whether actors are properly incentivized. High buyer or seller market power in grain markets and poor communication of quality standards prevent a market from reaching optimal levels of quality and premia.

In Bihar, farmers face traders with high market power, and in many cases cannot sell to another trader. Traders with high regional power are able to pay households low prices as well as low quality premia. More often, however, multiple intermediaries handle the grain, and each exerts market power by passing only a portion, β, of the price they receive on to the sellers. By the time premia reach households, they are no longer significant. Preferences of traders and end users are not clearly communicated with households, which drives the quality premia further from the equilibrium level, where the marginal value of quality equals its marginal cost. This problem is only exacerbated as the number of transactions increases, as in a game of telephone for grain quality. Households who sell to high power traders produce lower quality grain.

Traders may prefer to improve quality manually by discarding broken grains and impurities because the effect of technology on quality is inconsistent in Bihar. As a result, the premium for adopting technology such as drying grain on a sheet rather than on the ground is statistically insignificant. For traders, the least costly method of ensuring their grain is of high quality is hire low-wage workers and improve grain quality themselves. This causes higher post-harvest losses, as the grain that traders discard could have been saved had farmers been compensated to maintain grain quality before problems occurred. Additionally, farmers are not incentivized to adopt technology which could improve grain quality when used properly. This result is critical for introduction of technology, as the market is currently structured such that farmers may be hesitant to adopt new technology for fear they would not receive higher prices at harvest.

We find evidence that the effect of market power on price can be present for farmers as well as traders. Farmers who sell large quantities of wheat and rice on-field receive a per-unit premium rather than penalty. These grains are rarely sold on-field, so traders are only willing to travel to purchase on-field for farmers who have a higher degree of market power. Since maize is frequently sold on-field, selling on-field is a weak signal of the farmer's market power, and farmers receive a penalty for selling on-field.

This article has a number of limitations. Future work should explicitly control for information transfer and trust in the relationship between farmers and intermediaries in India. While traders were surveyed on their caste, households will not be surveyed regarding their caste until a future module. That could allow us to include a term denoting whether the farmer and trader are from the same caste. We also wish to obtain a more reliable measure of grain quality by observing the grain at time of sale or using pre-determined levels of quality to elicit prices from traders. Finally, the spatial clustering of quality should be analyzed, as trader market power may be clustered based on regional grain quality.

Policies to reduce post-harvest loss could establish and publicize quality standards and encourage competition among intermediaries. Where quality standards already exist, they could be hung in markets to help hold traders accountable. The internet has fostered the dissemination of information regarding quality standards and premia on international markets, and this system could be adopted to developing contexts as well. Quality standards could be disseminated via text message; farmers who knew what their grain was worth based on its quality could better negotiate prices with traders. Improving household access to larger markets through transportation infrastructure improvement would allow households to sell directly to traders higher in the supply chain and prevent the loss of information and incentives throughout a long and convoluted supply chain.

Where government grain programs exist, smallholder participation should be encouraged. Bihar has the structure in place to combat high market power thanks to the Food Corporation of India. There are

already organizations across the country who are meant to purchase from farmers at fair prices. Bihar could remove corrupt PACS officials or motivate officials to purchase from farmers. A disruption to the status quo would force traders to compete to sell grain. Trader competition can also be increased by offering training or education so that new traders could enter the market. Bihar's concerted effort to end corruption in the FCI's work supplying grain to households lowered grain leakage in the state by 73% in only seven years (Dreze & Khera, 2015); anti-corruption efforts in the procurement system could have similarly extraordinary results.

High market power by grain intermediaries prevents farmers from being compensated for quality and technology adoption. The implications of these lack of incentives on grain quality on post-harvest loss outcomes are troubling. When quality is incentivized throughout the supply chain, however, farmers, intermediaries, and end users will ensure that grain is preserved. Efforts to reduce post-harvest loss are best served by establishing supply chains where high quality grain is compensated financially at all levels. A reduction in quality loss will lead to a reduction in post-harvest loss and an increase in the world's available food supply.

8   Tables and Figures

Table 1: Post-Harvest Techniques and Causes of Loss

Stage	Actors	Methods	Types of Loss
Harvest	Farmer, contracted labor	Combine harvester, lathe	Harvesting outside optimal time, breakage due to improper technique, animals and pests when grain left in field
Threshing	Farmer, contracted labor	Combine harvester, manual thresher	Breakage or loss due to improper technique
Drying	Farmer, intermediary	Sun drying (In Field), solar dryer, fan dryer	Breakage (over-drying), burning (fast drying), damp grain (under-drying)
Transport	Farmer, contracted labor	Truck, bicycle, cart, intermediary	Falling out of vehicle
Storage	Farmer, intermediary	Jute bag, plastic bag, hermetic bag, small metal silo, large metal silo	Rotting/spoilage (damp grain), pests/rodents, disease
Processing	Farmer, miller		Processing losses

(Parfit, Barthel & Macnaughton, 2010)

Table 2: Food Corporation of India wheat grading standards

	Grade we	Grade II
Maximum percents		
Moisture	12.0	12.0
Foreign Matter	0.75	0.75
Other foodgrains	3.0	2.0
Damaged grains	3.0	2.0
Slightly damaged	6.0	6.0
Shriveled broken	8.0	7.0

Table 3: Food Corporation of India rice grading standards

	Grade A Raw	Grade A Parboiled
Maximum percents		P
Moisture content	14.0	14.0
Broken grains	25.0	16.0
Foreign matter	0.5	0.5
Damaged	2.0	4.0
Discolored grains	3.0	5.0
Chalky grains	5.0	
Red grains	3.0	3.0
Admixture of lower class	10.0	0.0
Dehusked grains	12.0	12.0

Table 4: Desired attributes for maize, wheat, and rice of surveyed farmers and traders in Bihar

	Wheat		**Maize**		**Rice**	
	Farmers	Traders	Farmers	Traders	Farmers	Traders
Top Attribute	Moisture	Moisture	Moisture	Moisture	Moisture	Moisture
Second Attribute	Size	Broken	Size	Impurities	Size	Size
Third Attribute	Color	Size				

Table 5: Previous post-harvest loss studies in India

Source	Year	Location	Crop	Households	On-farm losses (% of total production)	Definition of on-farm activities
Indian Ministry of Agriculture	2002	India	Paddy	15,000	2.72	harvest, threshing, winnowing, on-farm transport, on-farm storage
			Maize	15,000	2.45	
			Wheat	15,000	1.79	
ICAR	2012	India	Paddy	12,000	6.36	harvest, threshing, winnowing/cleaning, drying, on-farm storage
			Wheat	12,000	7.32	
	2015		Paddy	12,400	4.67	
			Wheat	12,400	4.07	
			Maize	12,400	3.90	
Basavaraja et al.	2007	Karnataka	Rice	100	3.82	harvest, threshing, cleaning, drying
			Wheat	100	3.28	
Shroff and Kajale	2013	Maharashtra	Maize	100	1.69 (<1 ha) 2.00 (1-2ha) 2.10 (2-4ha)	harvest, threshing, winnowing, storage

Figure 1: The Grain Supply Chain of Bihar
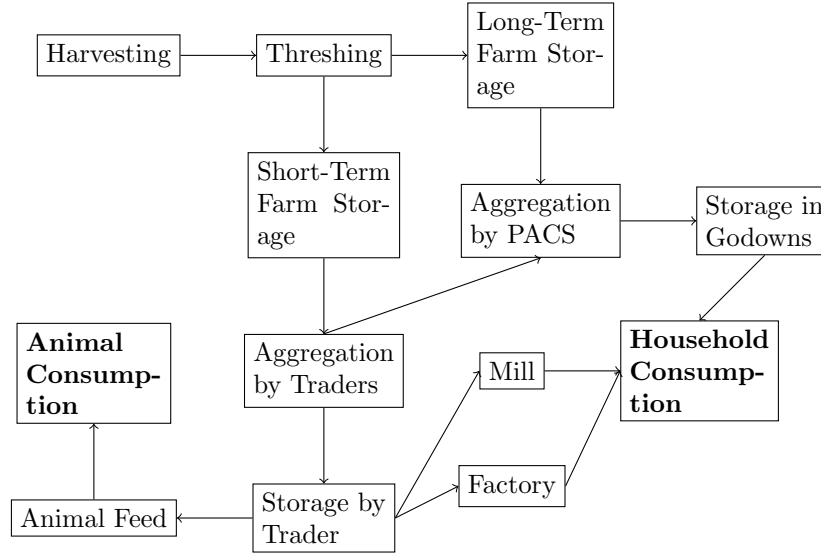
Table 6: Usage rates of post-harvest technologies of surveyed households commercializing grain in Bihar

Variable	Mean	Std. Dev.
Sun drying	0.983	0.13
Lay grain on sheet	0.278	0.448
Solar dryer	0.002	0.041
Diesel dryer	0.003	0.059
Manual threshing	0.616	0.487
Mechanical threshing	0.962	0.191
Mechanical milling	0.991	0.092
Unlined gunny sack	0.688	0.464
Lined gunny sack	0.249	0.433
Pesticide in the storage bag	0.305	0.461
Moisture meter	0	0
N		**583**

Table 7: Summary statistics of surveyed grain commercializing households in Bihar

Variable	Mean	Std. Dev.
Household size	4.443	2.434
Age	49.333	14.805
Proportion of income from non-agriculture sources	62.957	28.791
Proportion of income from wheat	9.276	12.951
Proportion of income from maize	10.835	15.557
Proportion of income from rice	8.148	13.242
Total landholding (ha)	1.417	9.725
Total area cultivating grains (ha)	1.143	13.517
Proportion who currently has a loan	0.23	
Proportion who could borrow 5,000Rs.	0.998	
Proportion who could borrow 20,000Rs.	0.957	
Proportion who could borrow 100,000Rs.	0.425	
Number selling wheat	346	
Proportion of wheat farmers selling in trader's shop	0.821	
Proportion of wheat farmers selling on field	0.136	
Quantity wheat Sold This Harvest (kg)	365.757	289.367
Number selling maize	298	
Proportion of maize farmers selling in trader's shop	0.513	
Proportion of maize farmers selling on field	0.45	
Quantity maize Sold This Harvest (kg)	1326.163	1560.725
Number selling rice	289	
Proportion of rice farmers selling in trader's shop	0.826	
Proportion of rice farmers selling on field	0.097	
Quantity rice Sold This Harvest (kg)	447.688	467.471
N	**583**	

Table 8: Village market concentration in Bihar, based on survey of grain traders

	Wheat	Maize	Rice
Number of traders	105	100	68
Average volume (100kg/month)	42.38	37.30	62.94
Traders per village	2.035	1.952	1.206
Village herfindahl	0.688	0.687	0.620
Villages with one trader	25	25	42

Table 9: Summary statistics of agricultural traders in Bihar, India, 2015

Variable	Mean	Std. Dev.
Demographics		
Age of Trader in Years	44.617	10.029
Years working as a trader	15.047	7.941
Proportion attended some secondary education	0.579	0.496
Proprtion high caste	0.075	0.264
Supply chain		
Proportion who farm	0.766	0.425
Proportion who purchase wheat	0.981	0.136
Proportion who purchase maize	0.935	0.248
Proportion who purchase rice	0.654	0.478
Proportion who buy grain from other traders	0.159	0.367
Proportion only wheat trader in village	0.131	0.339
Proportion only maize trader in village	0.159	0.367
Proportion only rice trader in village	0.318	0.468
Number of villages trader works in	3.85	2.145
Number of farmers trader buys from	74.570	51.983
Number of traders trader buys from	1.243	3.997
Market share wheat	0.467	0.279
Market share maize	0.48	0.313
Market share rice	0.565	0.301
Storage		
Proportion who sell to trader	0.832	0.376
Proportion who sell to mill	0.224	0.419
Proportion who sell to retail	0.29	0.456
Proportion who sell to feed	0.178	0.384
Proportion who store in jute bag	0.991	0.097
Proportion who store in woven plastic bag	0.075	0.264
Proportion who store in hermetic bag	0.056	0.231
Proportion who store in metal silo	0.028	0.166
Proportion who could get a higher profit storing	0.159	0.367
Reasons for not storing (Proportion responding)		
It costs too much	0.925	0.264
Need to sell immediately to repay farmers	0.925	0.264
Lose grain to moisture, rotting during storage	0.879	0.328
Prices don't go up after harvest	0.15	0.358
Volume too large to find storage	0.065	0.248
Credit		
Proportion who could get 50,000 rupees credit	0.86	0.349
Proportion who could get 100,000 rupees credit	0.598	0.493
N	**107**	

Table 10: Post-Harvest Average Prices in Bihar (2015-2016), Rupees per kg

	Wheat	Maize	Rice
Household price at harvest	12.90	11.53	10.35
Trader purchase price at harvest	11.7	10.1	9.49
Trader sale price at harvest	12.6	11.2	10.7
Government price floor (MSP)	14.5	13.25	14.5/14.1*

1

Table 11: Village fixed effects model of the purchase price of surveyed traders

VARIABLES	(1) Price wheat	(2) Discount wheat	(3) Price maize	(4) Discount maize	(5) Price rice	(6) Discount rice
Market share	-34.93**	-16.96*	5.247	-15.34*	-96.43**	-16.32
	(15.72)	(9.852)	(19.75)	(9.088)	(37.99)	(20.85)
Buys grain from other traders	21.53***	21.41***	-0.121	0.454	79.31***	4.098
	(6.684)	(6.696)	(10.58)	(10.13)	(20.95)	(6.946)
Sells to mills or retailers	12.06	-0.0606	4.983	5.610	-7.039	-4.021
	(7.357)	(6.421)	(5.503)	(15.46)	(13.58)	(5.535)
Sell to feed	-18.55**	-12.36*	-28.25	-5.780	-2.184	1.877
	(7.169)	(7.192)	(21.56)	(9.378)	(15.18)	(6.105)
High caste	33.53**	18.02*	14.89	21.36	81.41	9.742
	(16.13)	(9.793)	(11.43)	(14.42)	(73.24)	(12.08)
Attended some secondary education	-2.757	-14.46	-4.021	-2.202	29.53*	11.41**
	(9.334)	(8.621)	(6.281)	(7.694)	(15.24)	(5.232)
Years working as a trader	-0.613	-1.602*	0.717	-0.629	0.717	-0.0766
	(0.534)	(0.880)	(1.069)	(0.683)	(0.708)	(0.587)
Observations	105	98	100	93	69	68
R-squared	0.218	0.219	0.066	0.152	0.572	0.221
Number of Villages	49	48	48	47	39	39

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 12: Village fixed effects model of the sale price of surveyed traders

VARIABLES	(1) Price wheat	(2) Price maize	(3) Price rice	(4) Market Power
Buys grain from other traders	-8.795	98.19***	-27.47	0.309***
	(12.35)	(27.28)	(55.96)	(0.0772)
Sell to mill	41.26**	24.93	15.14	0.0266
	(16.50)	(23.75)	(26.11)	(0.0496)
Sell to retail	-21.64	37.77	16.89	0.00404
	(18.01)	(31.66)	(20.74)	(0.0925)
Sell to feed	-63.19**	-49.38*	-83.67	0.0995
	(26.98)	(25.47)	(58.16)	(0.0719)
Number of villages trader works in	0.433	6.283	1.291	0.0161
	(2.011)	(5.223)	(3.948)	(0.0125)
High caste	59.09**	27.85	95.47*	-0.0648
	(22.51)	(23.72)	(56.07)	(0.0779)
Attended some secondary education	25.22*	-11.46	8.046	0.0987*
	(14.21)	(10.35)	(17.58)	(0.0554)
Years working as a trader	3.297**	0.227	1.223	-0.00378
	(1.373)	(1.299)	(1.195)	(0.00477)
Maize observation				-0.00944
				(0.00799)
Rice observation				0.0886***
				(0.0295)
Observations	105	100	70	332
R-squared	0.387	0.397	0.404	0.168
Number of Villages	49	48	40	49

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 13: Hedonic models of grain price received by surveyed households

	Dependent variable: price this harvest						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Wheat							
Trader's market power	-0.194	-0.0490	-0.157	-0.427	-0.190	-0.347	0.428
	(0.309)	(0.316)	(0.294)	(0.274)	(0.317)	(0.303)	(0.260)
Cannot sell to another trader	-0.640***	-0.707***	-0.487***	-0.0506	-0.543	-0.301	-0.268*
	(0.168)	(0.170)	(0.175)	(0.169)	(0.385)	(0.240)	(0.146)
Farmer sold on field		0.462**					
		(0.232)					
Trader sells to mill or retail							-1.570***
							(0.134)
Observations	296	296	296	296	296	296	296
Maize							
Trader's market power	-0.448	-0.569*	-0.298	-0.318	-0.161	-0.0344	-0.756**
	(0.317)	(0.316)	(0.322)	(0.300)	(0.140)	(0.183)	(0.319)
Cannot sell to another trader	-0.675***	-0.541***	-0.569***	-0.330	0.0113	-0.0441	-0.696***
	(0.199)	(0.203)	(0.192)	(0.206)	(0.112)	(0.0527)	(0.194)
Farmer sold on field		-0.613***					
		(0.230)					
Trader sells to mill or retail							-0.777***
							(0.220)
Observations	255	255	255	255	255	255	255
Rice							
Trader's market power	-0.302*	-0.273*	-0.387**	-0.403**	-0.112	-0.202	-0.466***
	(0.160)	(0.157)	(0.177)	(0.171)	(0.234)	(0.294)	(0.172)
Cannot sell to another trader	-0.173*	-0.206**	-0.194*	-0.168	0.0218	0.0382	-0.0449
	(0.0918)	(0.0905)	(0.105)	(0.109)	(0.0822)	(0.107)	(0.109)
Sells on field		0.526***					
		(0.159)					
Sells to mill or retail							0.0921
							(0.112)
Observations	248	248	248	248	248	248	248
HH Control	NO	NO	NO	YES	NO	YES	NO
Block FE	NO	NO	NO	NO	YES	YES	NO
Quality comparison	neighbor	neighbor	past	neighbor	neighbor	neighbor	neighbor
Number of blocknum					7	7	

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 14: Estimations of quality premia and the coefficient on the interaction of quality and market power

Crop	(1) Wheat	(2) Maize	(3) Rice
More impurities	-11.74**	-1.793	0.567
	(5.377)	(2.395)	(0.629)
Interaction	13.60**	2.922	-1.900**
	(6.505)	(3.228)	(0.784)
Fewer impurities	-1.252***	-0.696	0.167
	(0.386)	(0.669)	(0.291)
Interaction	2.750***	0.838	-0.266
	(0.670)	(1.095)	(0.507)
More broken grains	0.853	-2.433	0.198
	(2.821)	(3.360)	(0.617)
Interaction	-0.184	3.303	1.116
	(4.014)	(4.482)	(0.965)
Fewer broken grains	-0.161	-0.580	0.572*
	(0.373)	(0.667)	(0.308)
Interaction	0.529	1.127	-1.518***
	(0.627)	(1.119)	(0.481)
Bigger grains	0.928	0.864	-0.212
	(1.011)	(1.374)	(0.502)
Interaction	-0.452	-2.170	-0.344
	(1.921)	(2.321)	(1.043)
Smaller grains	-0.310	-1.075	0.233
	(0.383)	(0.720)	(0.416)
Interaction	0.0594	1.183	-0.442
	(0.668)	(1.130)	(0.676)
Better color	0.975	-1.288	-0.618
	(1.588)	(1.163)	(0.471)
Interaction	-0.219	2.042	1.301
	(2.001)	(1.619)	(0.826)
Worse color	-0.652*	0.183	0.602**
	(0.362)	(0.682)	(0.284)
Interaction	0.725	-0.0792	-1.425***
	(0.618)	(1.190)	(0.470)
More moisture	2.823	-1.484	0.106
	(5.713)	(3.636)	(0.564)
Interaction	-3.903	3.061	-1.457
	(6.803)	(4.059)	(0.939)
Less moisture	-0.161	-0.395	0.455
	(0.490)	(0.778)	(0.329)
Interaction	0.0572	-0.407	-1.074*
	(0.946)	(1.321)	(0.610)
Observations	296	256	249

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 15: Average market power of households producing high, average, and low quality grain

Crop	Wheat			Maize			Rice		
Quality level	Low	Average	High	Low	Average	High	Low	Average	High
Number of households									
impurities	5	211	80	8	154	94	16	126	107
brokens	5	164	127	5	135	116	14	165	70
color	100	186	10	88	139	29	77	152	20
size	108	175	13	71	151	34	32	206	11
moisture	4	240	52	11	180	65	8	190	51
Average market share									
impurities	0.823	0.531	0.514	0.693	0.472	0.573	0.762	0.626	0.475
brokens	0.688	0.503	0.563	0.709	0.480	0.550	0.587	0.558	0.595
color	0.514	0.529	0.770	0.431	0.537	0.669	0.525	0.601	0.501
size	0.512	0.547	0.489	0.592	0.471	0.556	0.555	0.582	0.386
moisture	0.835	0.543	0.455	0.882	0.490	0.525	0.483	0.603	0.460

Table 16: Mean grain prices received by surveyed households in Bihar with and without technology

	Maize	Crop Rice	Wheat
	Mean price	Mean price	Mean price
Sun drying			
Has never used	11.767	10.460	13.171
Has used	11.837	10.398	13.054
Lay grain on sheet			
Has never used	11.647	10.405	12.604
Has used	12.244	10.384	13.716
Manual threshing			
Has never used	11.524	10.532	13.467
Has used	12.055	10.349	12.800
Mechanical threshing			
Has never used	12.000	10.286	15.500
Has used	11.831	10.405	13.042
Unlined gunny sack			
Has never used	11.930	10.363	13.738
Has used	11.764	10.409	12.784
Lined gunny sack			
Has never used	11.655	10.328	12.783
Has used	12.320	10.532	13.569
Pesticide in the storage bag			
Has never used	11.571	10.339	12.530
Has used	12.250	10.526	13.731

Table 17: Grain price received by households selling on and off-farm in Bihar as a function of technology usage and market power

	(1) Pooled	(2) On field	(3) Off field
Wheat			
Trader's market power	-0.234	0.291	-0.0650
	(0.309)	(0.956)	(0.322)
Cannot sell to another trader	-0.418**	0.646*	-0.398**
	(0.180)	(0.330)	(0.200)
Quantity sold	-0.000349	0.000113	-0.00157***
	(0.000252)	(0.000263)	(0.000339)
Lay grain on sheet	0.178	2.871**	0.244
	(0.204)	(1.161)	(0.199)
Manual threshing	-0.0601	-0.126	-0.0740
	(0.158)	(0.305)	(0.169)
Lined gunny sack	0.0612	-3.508***	0.272
	(0.175)	(0.925)	(0.174)
Pesticide in the storage bag	0.125	-1.315	0.410*
	(0.225)	(0.907)	(0.227)
Observations	296	42	254
Maize			
Trader's market power	-0.460	-0.405	-0.528
	(0.318)	(0.380)	(0.472)
Cannot sell to another trader	-0.0421	0.0682	-0.145
	(0.203)	(0.186)	(0.366)
Quantity sold	2.25e-06	3.35e-05	-0.000160
	(6.76e-05)	(5.36e-05)	(0.000211)
Lay grain on sheet	0.188		0.167
	(0.238)		(0.298)
Manual threshing	0.0127	0.0813	-0.0978
	(0.178)	(0.179)	(0.299)
Lined gunny sack	0.406*		0.387
	(0.228)		(0.291)
Pesticide in the storage bag	0.682**	1.066	0.565
	(0.264)	(0.911)	(0.362)
Observations	255	114	141
Rice			
Trader's market power	-0.308*	0.188	-0.301
	(0.182)	(0.860)	(0.188)
Cannot sell to another trader	-0.261**	0.251	-0.302***
	(0.109)	(0.375)	(0.113)
Quantity sold	-8.62e-05	-8.74e-06	-0.000176
	(9.00e-05)	(7.81e-05)	(0.000114)
Lay grain on sheet	-0.442***	0.465	-0.470***
	(0.130)	(0.279)	(0.133)
Manual threshing	-0.0183	0.521*	-0.0796
	(0.0967)	(0.265)	(0.100)
Lined gunny sack	0.0104		0.0377
	(0.116)		(0.120)
Pesticide in the storage bag	0.334**		0.347**
	(0.139)		(0.144)
Observations	248	18	230

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Ommitted (no obs): Lay grain on sheet(maize), lined gunny sack (maize and rice) and pesticide (rice)

Table 18: Sale quantity (kg) in Bihar India as a function of whether the sale took place on-field

| | Dependent variable: quantity sold | | |
Crop	Wheat	Maize	Rice
Sells on field	177.2***	1,688***	391.1***
	(44.40)	(153.4)	(88.65)
Observations	354	298	298
R-squared	0.043	0.290	0.062

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

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A Tables

Table 19: Distribution of wheat quality with and without technology

	More		Less		Same		Total	
	No.	%	No.	%	No.	%	No.	%
Impurities of wheat								
Lay grain on sheet								
Has never used (n=207)	3.0	42.9	70.0	70.0	134.0	55.1	207.0	59.1
Has used (n=143)	4.0	57.1	30.0	30.0	109.0	44.9	143.0	40.9
Pearson chi2(2) =	7.2546	Pr =	0.027					
Manual threshing								
Has never used (n=133)	5.0	71.4	28.0	28.0	100.0	41.2	133.0	38.0
Has used (n=217)	2.0	28.6	72.0	72.0	143.0	58.8	217.0	62.0
Pearson chi2(2) =	8.5895	Pr =	0.014					
Lined gunny sack								
Has never used (n=227)	4.0	57.1	65.0	65.0	158.0	65.0	227.0	64.9
Has used (n=123)	3.0	42.9	35.0	35.0	85.0	35.0	123.0	35.1
Pearson chi2(2) =	0.1865	Pr =	0.911					
Pesticide in the storage bag								
Has never used (n=198)	4.0	57.1	73.0	73.0	121.0	49.8	198.0	56.6
Has used (n=152)	3.0	42.9	27.0	27.0	122.0	50.2	152.0	43.4
Pearson chi2(2) =	15.5295	Pr =	0.000					
Brokens of wheat								
Lay grain on sheet								
Has never used (n=207)	5.0	71.4	80.0	51.3	122.0	65.2	207.0	59.1
Has used (n=143)	2.0	28.6	76.0	48.7	65.0	34.8	143.0	40.9
Pearson chi2(2) =	7.3040	Pr =	0.026					
Manual threshing								
Has never used (n=133)	2.0	28.6	57.0	36.5	74.0	39.6	133.0	38.0
Has used (n=217)	5.0	71.4	99.0	63.5	113.0	60.4	217.0	62.0
Pearson chi2(2) =	0.6018	Pr =	0.740					
Lined gunny sack								
Has never used (n=227)	2.0	28.6	95.0	60.9	130.0	69.5	227.0	64.9
Has used (n=123)	5.0	71.4	61.0	39.1	57.0	30.5	123.0	35.1
Pearson chi2(2) =	6.8996	Pr =	0.032					
Pesticide in the storage bag								
Has never used (n=198)	4.0	57.1	83.0	53.2	111.0	59.4	198.0	56.6
Has used (n=152)	3.0	42.9	73.0	46.8	76.0	40.6	152.0	43.4
Pearson chi2(2) =	1.3116	Pr =	0.519					
Moisture of wheat								
Lay grain on sheet								
Has never used (n=207)	3.0	50.0	59.0	86.8	145.0	52.5	207.0	59.1
Has used (n=143)	3.0	50.0	9.0	13.2	131.0	47.5	143.0	40.9
Pearson chi2(2) =	26.6635	Pr =	0.000					
Manual threshing								
Has never used (n=133)	2.0	33.3	22.0	32.4	109.0	39.5	133.0	38.0
Has used (n=217)	4.0	66.7	46.0	67.6	167.0	60.5	217.0	62.0
Pearson chi2(2) =	1.2369	Pr =	0.539					
Lined gunny sack								
Has never used (n=227)	3.0	50.0	47.0	69.1	177.0	64.1	227.0	64.9
Has used (n=123)	3.0	50.0	21.0	30.9	99.0	35.9	123.0	35.1
Pearson chi2(2) =	1.1866	Pr =	0.553					
Pesticide in the storage bag								
Has never used (n=198)	3.0	50.0	54.0	79.4	141.0	51.1	198.0	56.6
Has used (n=152)	3.0	50.0	14.0	20.6	135.0	48.9	152.0	43.4
Pearson chi2(2) =	17.9237	Pr =	0.000					

Table 20: Distribution of maize quality with and without technology

	More		Less		Same		Total	
	No.	%	No.	%	No.	%	No.	%
Impurities of maize								
Lay grain on sheet								
Has never used (n=209)	5.0	55.6	85.0	75.9	119.0	65.4	209.0	69.0
Has used (n=94)	4.0	44.4	27.0	24.1	63.0	34.6	94.0	31.0
Pearson chi2(2) =	4.3586	Pr =	0.113					
Manual threshing								
Has never used (n=123)	4.0	44.4	59.0	52.7	60.0	33.0	123.0	40.6
Has used (n=180)	5.0	55.6	53.0	47.3	122.0	67.0	180.0	59.4
Pearson chi2(2) =	11.2280	Pr =	0.004					
Lined gunny sack								
Has never used (n=219)	4.0	44.4	80.0	71.4	135.0	74.2	219.0	72.3
Has used (n=84)	5.0	55.6	32.0	28.6	47.0	25.8	84.0	27.7
Pearson chi2(2) =	3.8472	Pr =	0.146					
Pesticide in the storage bag								
Has never used (n=185)	6.0	66.7	70.0	62.5	109.0	59.9	185.0	61.1
Has used (n=118)	3.0	33.3	42.0	37.5	73.0	40.1	118.0	38.9
Pearson chi2(2) =	0.3214	Pr =	0.852					
Brokens of maize								
Lay grain on sheet								
Has never used (n=209)	6.0	100.0	85.0	61.6	118.0	74.2	209.0	69.0
Has used (n=94)	0.0	0.0	53.0	38.4	41.0	25.8	94.0	31.0
Pearson chi2(2) =	8.2513	Pr =	0.016					
Manual threshing								
Has never used (n=123)	3.0	50.0	63.0	45.7	57.0	35.8	123.0	40.6
Has used (n=180)	3.0	50.0	75.0	54.3	102.0	64.2	180.0	59.4
Pearson chi2(2) =	3.1687	Pr =	0.205					
Lined gunny sack								
Has never used (n=219)	4.0	66.7	89.0	64.5	126.0	79.2	219.0	72.3
Has used (n=84)	2.0	33.3	49.0	35.5	33.0	20.8	84.0	27.7
Pearson chi2(2) =	8.1206	Pr =	0.017					
Pesticide in the storage bag								
Has never used (n=185)	4.0	66.7	78.0	56.5	103.0	64.8	185.0	61.1
Has used (n=118)	2.0	33.3	60.0	43.5	56.0	35.2	118.0	38.9
Pearson chi2(2) =	2.2000	Pr =	0.333					
Moisture of maize								
Lay grain on sheet								
Has never used (n=209)	3.0	23.1	64.0	88.9	142.0	65.1	209.0	69.0
Has used (n=94)	10.0	76.9	8.0	11.1	76.0	34.9	94.0	31.0
Pearson chi2(2) =	27.6413	Pr =	0.000					
Manual threshing								
Has never used (n=123)	11.0	84.6	34.0	47.2	78.0	35.8	123.0	40.6
Has used (n=180)	2.0	15.4	38.0	52.8	140.0	64.2	180.0	59.4
Pearson chi2(2) =	13.8535	Pr =	0.001					
Lined gunny sack								
Has never used (n=219)	6.0	46.2	62.0	86.1	151.0	69.3	219.0	72.3
Has used (n=84)	7.0	53.8	10.0	13.9	67.0	30.7	84.0	27.7
Pearson chi2(2) =	12.2908	Pr =	0.002					
Pesticide in the storage bag								
Has never used (n=185)	7.0	53.8	62.0	86.1	116.0	53.2	185.0	61.1
Has used (n=118)	6.0	46.2	10.0	13.9	102.0	46.8	118.0	38.9
Pearson chi2(2) =	24.9356	Pr =	0.000					

Table 21: Distribution of rice quality with and without technology

	More		Less		Same		Total	
	No.	%	No.	%	No.	%	No.	%
Impurities of rice								
Lay grain on sheet								
Has never used (n=218)	9.0	47.4	99.0	81.1	110.0	64.0	218.0	69.6
Has used (n=95)	10.0	52.6	23.0	18.9	62.0	36.0	95.0	30.4
Pearson chi2(2) =	14.7318	Pr =	0.001					
Manual threshing								
Has never used (n=91)	9.0	47.4	44.0	36.1	38.0	22.1	91.0	29.1
Has used (n=222)	10.0	52.6	78.0	63.9	134.0	77.9	222.0	70.9
Pearson chi2(2) =	10.0408	Pr =	0.007					
Lined gunny sack								
Has never used (n=202)	8.0	42.1	94.0	77.0	100.0	58.1	202.0	64.5
Has used (n=111)	11.0	57.9	28.0	23.0	72.0	41.9	111.0	35.5
Pearson chi2(2) =	15.5984	Pr =	0.000					
Pesticide in the storage bag								
Has never used (n=210)	12.0	63.2	100.0	82.0	98.0	57.0	210.0	67.1
Has used (n=103)	7.0	36.8	22.0	18.0	74.0	43.0	103.0	32.9
Pearson chi2(2) =	20.3312	Pr =	0.000					
Brokens of rice								
Lay grain on sheet								
Has never used (n=218)	15.0	83.3	56.0	65.9	147.0	70.0	218.0	69.6
Has used (n=95)	3.0	16.7	29.0	34.1	63.0	30.0	95.0	30.4
Pearson chi2(2) =	2.1772	Pr =	0.337					
Manual threshing								
Has never used (n=91)	6.0	33.3	26.0	30.6	59.0	28.1	91.0	29.1
Has used (n=222)	12.0	66.7	59.0	69.4	151.0	71.9	222.0	70.9
Pearson chi2(2) =	0.3504	Pr =	0.839					
Lined gunny sack								
Has never used (n=202)	9.0	50.0	58.0	68.2	135.0	64.3	202.0	64.5
Has used (n=111)	9.0	50.0	27.0	31.8	75.0	35.7	111.0	35.5
Pearson chi2(2) =	2.1758	Pr =	0.337					
Pesticide in the storage bag								
Has never used (n=210)	10.0	55.6	60.0	70.6	140.0	66.7	210.0	67.1
Has used (n=103)	8.0	44.4	25.0	29.4	70.0	33.3	103.0	32.9
Pearson chi2(2) =	1.5729	Pr =	0.455					
Moisture of rice								
Lay grain on sheet								
Has never used (n=218)	8.0	88.9	53.0	80.3	157.0	66.0	218.0	69.6
Has used (n=95)	1.0	11.1	13.0	19.7	81.0	34.0	95.0	30.4
Pearson chi2(2) =	6.6467	Pr =	0.036					
Manual threshing								
Has never used (n=91)	2.0	22.2	20.0	30.3	69.0	29.0	91.0	29.1
Has used (n=222)	7.0	77.8	46.0	69.7	169.0	71.0	222.0	70.9
Pearson chi2(2) =	0.2540	Pr =	0.881					
Lined gunny sack								
Has never used (n=202)	7.0	77.8	52.0	78.8	143.0	60.1	202.0	64.5
Has used (n=111)	2.0	22.2	14.0	21.2	95.0	39.9	111.0	35.5
Pearson chi2(2) =	8.6080	Pr =	0.014					
Pesticide in the storage bag								
Has never used (n=210)	7.0	77.8	53.0	80.3	150.0	63.0	210.0	67.1
Has used (n=103)	2.0	22.2	13.0	19.7	88.0	37.0	103.0	32.9
Pearson chi2(2) =	7.4656	Pr =	0.024					