

EVALUATING THE DETERMINANTS OF PESTICIDE RESIDUES IN VEGETABLES: A CASE OF LEMON MARKET IN PAKISTAN

Abedullah^{1*} and S. Kouser²

¹Pakistan Institute of Development Economics, Islamabad, Pakistan

²COMSATS Institute of Information Technology, Islamabad, Pakistan

*Corresponding author's e-mail: abedullah@pide.org.pk

ABSTRACT

In developing countries, vegetable markets are inefficient in terms of information exchanges between producers and consumers on food safety attributes. This study attempts to investigate the determinants of pesticide residues and estimates information efficiency of vegetable market, using socioeconomic and biophysical data collected from a representative sample of 360 farmers in Pakistani Punjab. Chromatography technique is employed to quantify pesticide residues in okra, brinjal, spinach and cauliflower. A large proportion of spinach samples (83%), followed by okra (72%), brinjal (60%) and cauliflower (50%) have surpassed the maximum residue limits of pesticides, implying that they are lemons. Results of pesticide residue model show that magnitudes of pesticide residues in vegetables vary with pesticide quantity and spray interval at the farm level. Results of information efficiency model reveal that vegetable prices are negatively but insignificantly correlated with pesticides residues, implying that vegetable market is a lemon market in Pakistan. Proper implementation of food safety standards and product labeling may help to provide safe vegetables to consumers.

Key words: Vegetables, information asymmetry, lemons market, gas chromatography, pesticide residues, food safety, Pakistan.

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INTRODUCTION

Food markets can play a crucial role in ensuring food safety in developing countries (Clark and Hobbs, 2018). Food safety¹ is a main public health risk. Ingestion of contaminated food causes food-borne illnesses among 600 million people and deaths of 420,000 individuals worldwide every year (WHO 2015). Food safety is an unobservable quality attribute to consumers at the time of purchase (Reiler *et al.* 2015). Product quality can be reflected by its price. Nevertheless, price can act as a signal for food safety only if markets are efficient in term of information exchanges between producers and consumers (Fama 1970). In case of vegetables, producers have complete information on hazardous chemicals used during production process but for consumers, it is difficult to identify safe/uncontaminated vegetables prior to purchase, resulting in market failures for food safety. Akerlof (1970) has called this information asymmetry between producers and consumers as a lemon dilemma, which likely results in adverse selection of poor-quality products. As safe vegetables are costly to produce; only high prices can enable such producers to survive in the market. Otherwise, low quality products, known as lemons by Akerlof, will occupy the market. In developing countries, the vegetable market, extensively sprayed with toxic pesticides, could be one of these lemon markets.

Pesticides are chemical compounds that are commonly used to eradicate pests such as insects, weeds, fungi and diseases in modern agriculture (Guler *et al.* 2010; Duong *et al.* 2019). Since green revolution, there is a substantial increase in pesticide consumption in Pakistan. The total amount of pesticides used in the country has increased from 38 thousand metric tons in 1997 to 206 thousand metric tons in 2017 (GoP 2019). Moreover, most of the pesticides used in the country are either highly hazardous (34.2%) or moderately hazardous (35.0%) (Damalas and Khan 2017). Currently, 108 types of hazardous insecticides are being used in Pakistan (Mehmood *et al.* 2017). Indiscriminate, excessive, and unintended use of toxic pesticides results in numerous negative externalities including development of pest resistance, annihilation of natural enemies, loss of biodiversity, poisoning of humans and animals, pollution of soil and water resources and contamination of food with pesticide residues (Desneux *et al.* 2007; Damalas and Eleftherohorinos 2011; Kouser and Qaim 2014; Syed *et al.* 2014; Abedullah *et al.* 2016; Wentz 2017). One of the important food safety risks for consumers is the prevalence of pesticide residues in food commodities (Henson and Traill 1993). Zhou and Jin (2009) have observed that food safety risk increases with pesticide residues in vegetables. Therefore, it is imperative to important food safety risks for consumers is the

¹Food safety means handling, preparing and storing food in such a way to minimize risk of food-borne illnesses (AIFS 2017). Unsafe food contains harmful bacteria, viruses, parasites or chemical substances including pesticide residues, heavy metals, food additives etc (WHO 2015).

prevalence of pesticide residues in food commodities (Henson and Traill 1993). Zhou and Jin (2009) have observed that food safety risk increases with pesticide residues in vegetables. Therefore, it is imperative to monitor pesticide residues to ensure safe vegetables in Pakistan. Vegetables are integral parts of the daily diet of all Pakistanis. They are rich source of carbohydrate, protein, vitamins, minerals, fiber and antioxidants and contribute to preserve a healthy life. However, vegetables are highly vulnerable to insect infestation because of their tenderness and better nutritive status. This motivates farmers to intensively use hazardous pesticide to protect their vegetable crops. As a result, vegetables have higher probability of traces of pesticides, termed as pesticide residues, than any other food crop (Syed *et al.* 2014). Ingestion of unprocessed vegetables contaminated with pesticide residues may cause short term (acute) health symptoms such as vomiting, stomachache, diarrhea etc (Jardim *et al.* 2014; Reiler *et al.* 2015) and long term (chronic) health effects such as birth defects, endocrine disruption and carcinogenic effects (Schreinemachers 2003; Miligiet *al.* 2006; Barret *al.* 2010; Waller *et al.* 2010; Bal *et al.* 2012). Hence, contaminated food creates vicious cycle of diseases and impedes socio-economic development. To avoid consumers' potential health hazards, the Codex Alimentarius Commission of the Food and Agriculture Organization (FAO) of the United Nations and the World Health Organization (WHO) has set the maximum residue limits (MRLs) for each pesticide in all food items (FAO and WHO 2004). MRL is the highest permissible level of pesticide residues that is legally tolerated when pesticides are applied under good agricultural practices. To protect consumers' health, pesticide residues should be below the permissible limits in vegetables. A growing body of literature confirms that more than 50% of fresh vegetables have residues of pyrethroid, organophosphate and organochlorines exceeding MRLs in Pakistan (Parveen *et al.* 2005; Tahir *et al.* 2009; Ahmed *et al.* 2011; Latif *et al.* 2011; Saqib *et al.* 2011; Syed *et al.* 2014; Amir *et al.* 2017). Using pesticide residue analysis and descriptive statistics, these studies have concluded that different agronomic and socio-economic factors like amount and toxicity of pesticides, spray duration, farmer's pesticide literacy, his farming experience, food processing technique etc could influence the level of pesticide residues in vegetables. Although without controlling for other confounding factors, it is difficult to conclude about the net impacts of these factors on the prevalence of pesticide residues. Previous studies on food safety have used indirect approach of farmer's/ consumer's perceptions to quantify food safety risk (Zhou and Jin 2009; Mercado *et al.* 2018). The earlier studies have also detected the

existence of lemons (bad product) in the market for used vehicles (Bond, 1982 1984; Genesove 1993), thoroughbred yearlings (Chezum and Wimmer 1997), cherries (Rosenman and Wilson 1991) and child care (Mocan 2007). These studies have measured the extent of market efficiency by investigating the relationship between product price and indirect measure of product quality (seller characteristics). Only Hoffmann *et al.* (2013) and Ma *et al.* (2014) have used the direct measure of product quality. Ma *et al.* (2014) have quantified the extent to which seed prices reflect Bt toxin concentration in genetically modified cotton crop to resist insects. Hoffmann *et al.* (2013) have related aflatoxin concentration in maize flour with its price. Nevertheless, to our best knowledge, no study has estimated vegetable market efficiency to investigate reflection of food safety attributes in its price. This study aims to detect lemons in the vegetable markets, to evaluate the determinants of pesticide residues in four common vegetables (okra, brinjal, cauliflower, and spinach) of Punjab province and to test the extent of information efficiency in the market using a precise measure of food safety. For this purpose, this study conducts regression analysis by implementing two unique surveys: farm survey to compile information on vegetable farm and farmer characteristics and biophysical survey to collect vegetable samples for pesticide residue analysis. The paper contributes to previous empirical literature on pesticide residue analysis, lemons market and information efficiency in three ways. Firstly, this study employs a unique and direct measure of food safety attribute (pesticide residues). By regressing pesticide residues on farm and farmer specific characteristics, this study allows determining the true factors influencing pesticide residue in vegetables. Secondly, the study also measures the extent of market efficiency by analyzing the association between pesticide residues and vegetable prices. This helps to investigate whether vegetable prices reflect signals of food safety. Dominance of contaminated vegetables could be the primary vehicle for lemons market and could lead to adverse selection by consumers. Lastly, the study estimates unbiased impacts of pesticide residues on vegetable prices by controlling for observed and unobserved heterogeneity. The investigation of these issues not only provides insights into food safety risk caused by information asymmetry-based market failure in this particular market, but it can also help exploring other similar markets. The remainder of this research article is organized as follows: the next section describes the data, measure of food safety and econometric model. Section 3 presents and discusses descriptive and econometric results. The last section concluded the study.

²Each district is producing the highest amount of vegetables in its region except Multan, which is the second largest supplier of vegetable after Khanewal (GoP 2010). Multan was selected because of high pesticide consumption and large negative health externalities reported in the literature (Masud and Baig 1991; Syed *et al.* 2014).

MATERIALS AND METHODS

A multistage sampling technique was employed for data collection. In the first stage, three major vegetable growing districts (Gujranwala, Faisalabad and Multan²) representing east, central, and south parts of the Punjab province, were purposively selected. These districts cover all vegetable producing agro-ecological zones of the province. In the second stage, four most pesticide ridden vegetables (Okra, Brinjal, Spinach and Cauliflower) were identified. Okra and cauliflower are kharif (summer) vegetables, while brinjal and spinach are rabi (winter) vegetables. Thirty farmers of each vegetable were randomly selected from the peri-urban farming system of each district. This generates a sample of 360 (=3*4*30) farmers. Before *the last* harvest of the vegetables, farm survey was conducted with the help of trained enumerators *and* using a pretested and well-structured questionnaire. The questionnaire was used to collect information on farmers' socio-economic characteristics and input-output details particularly about frequency, type and quantities of pesticide use, duration between consecutive sprays etc. In addition to the farm survey, vegetable samples from each selected farmer were procured at three maturity levels in triplicate form during the biophysical survey. Thus, 3240 (=3*4*30*3*3) samples were analyzed. Samples were stored at -40° C to avoid degradation of pesticide residues. Residues of pesticides were extracted from the homogenized vegetable sample using the method proposed by Kadenezki *et al.* (1992), with some modifications illustrated by Khan *et al.* (2009). Further, pesticide residue analysis was conducted to measure pesticide residues of seven commonly sprayed pesticides (Alpha HCH, Chlorpyrifos, Deltamethrin, Dimethoate, Gama HCH, Monocrotophos, Profenophos) using Gas Chromatography equipped with Electron Capture Detector (GC-ECD), as illustrated by Chandra *et al.* (2010). Pesticide residues of three samples of same vegetable procured at one maturity level from the same farm were averaged to obtain its single value, implying that there are three mean values of pesticide residues for each pesticide for one vegetable for each farmer. Thus, we have total 1080 vegetable samples from 360 farmers.

Econometric Model: This study models the lemon dilemma in the vegetable market of Pakistan. To investigate the extent to which vegetable prices reflect vegetable safety information and how consumers use different price signals to infer vegetable safety, linear regression model was used to show price-quality relationship (lemon market model) proposed by Akerlof (1970) as follows:

$$P_i = \alpha x_i + \mu_i \quad (1)$$

Where P_i is the vegetable specific farm gate price received by the i^{th} farmer. x_i is a vector of

covariates included to incorporate variations in the P_i . Based on extant lemon literature, this study uses pesticide residues measured in mg/kg by GC-ECD technique, vegetable dummies, district dummies, source of irrigation (freshwater or wastewater), farmer's education and vegetable experience (Bond 1982, 1984; Rosenman and Wilson 1991; Genesove 1993; Chezum and Wimmer 1997; Mocan 2007; Ma *et al.* 2014; Hoffmann *et al.* 2013). α is vector of parameters to be estimated, while μ_i is random error term. This lemon model is estimated using ordinary least square (OLS) regression technique.

As mentioned above, this study quantifies food safety in terms of vegetable contamination with injurious pesticides, which leave pesticide residues in harvested vegetables. These pesticide residues were measured by GC-ECD. We hypothesize negative relationship between vegetable prices and pesticide residues, which refers to an efficient vegetable market. Efficient market helps allocating appropriate prices to products by exchanging information on its desirable and undesirable quality attributes between producers and consumers. Alternative to this hypothesis is a lemons market, which offers either same or higher prices for poor quality product (lemons) because of information failures in markets resisting consumers in differentiating product food safety attribute. Pesticide residues may be an endogenous covariate because it varies with observed and unobserved farm and farmer characteristics. However, observed characteristics can be incorporated as control variables but if unobserved characteristics are also playing a significant role, the estimated coefficients for pesticide residues may still be biased. Instrumental variable (IV) regression is used to test and control for observed and unobserved heterogeneity (Smith and Blundell 1986; Rivers and Vuong 1988; Wooldridge 2002). IV approach comprises two steps: the first step estimates residuals (ε) from pesticide residue equation using appropriate instruments and the second step tests the significance of predicted residuals in the lemon market model. A significant coefficient of the residuals confirms the endogeneity and controls for resulting bias in the estimates (Wooldridge 2002). In the first step of IV, pesticide residues (PR) is treated as dependent variable and proposed linear model is estimated by OLS as:

$$PR_i = \beta w_i + \varepsilon_i \quad (2)$$

Where w is a vector of covariates. For proper model identification, w should have at least one instrumental variable besides variables in x vector. β is a vector of parameters to be estimated and ε is an error term. In the second step, predicted values of PR is used in Eq. (1) if endogeneity proves. Following the past literature, we used pesticide quantity and interval between sprays as instruments for pesticide residues (Parveen *et al.* 2005; Latif *et al.* 2011; Saqib *et al.* 2011; Syed *et al.* 2014).

RESULTS AND DISCUSSION

Descriptive Analysis: Table 1 presents descriptive comparison of the farm and farmer characteristics across three districts: Faisalabad, Gujranwala and Multan. Vegetable farmers living in peri-urban areas of these districts had almost same age (42 years), education (6 schooling years) and vegetable growing experience (19 years). The highest proportions of farmers in Faisalabad (75%) were using freshwater, followed by Multan (41%) and Gujranwala (29%). Likewise, pesticide quantity

applied by these farmers was approximately same (6 litter/acre). However, farmers in Multan were applying pesticides at the shortest interval (5 days) compared to their counterparts in Gujranwala (7 days) and Faisalabad (8 days). Food safety attribute in this study was measured by residues of pesticides in vegetables using GC-ECD. Pesticide residues were observed highest in Faisalabad (0.270 mg/kg), followed by Gujranwala (0.157 mg/kg) and Multan (0.125 mg/kg). Findings of pesticide residues were also consistent with the earlier studies (Syed *et al.* 2014; Amir *et al.* 2015, 2017; Randhawa *et al.* 2015).

Table 1. Descriptive statistics of sample farms and farmers across districts.

Variables	Faisalabad	Gujranwala	Multan
Farmers' age (years)	42.8±10.8	42.7± 11.92	40.9±10.8
Farmers' education (years)	6.0±4.3	5.5±4.2	5.9±3.9
Farmers' vegetable experience (years)	17.9± 9.9	19.3±11.5	19.8± 8.8
Source of irrigation (%)	75	29	41
Pesticide quantity (liter/acre)	5.8± 3.5	5.9±4.6	6.1±4.2
Spray interval (days)	7.5±4.1	7.4±4.9	4.8±5.9
Pesticide residues (mg/kg)	0.3±0.3	0.2±0.2	0.1±0.2
Price of brinjal (Rs/kg)	13.8±2.6	14.3±2.0	16.1±2.1
Price of cauliflower (Rs/kg)	7.7±0.6	6.6±0.8	7.1±0.7
Price of spinach (Rs/kg)	9.4±0.9	9.1±0.8	9.2±1.0
Price of okra (Rs/kg)	15.8±4.5	20.2±1.7	20.9±1.8
Observations	120	120	120

Note: Standard deviations have been reported in parentheses.

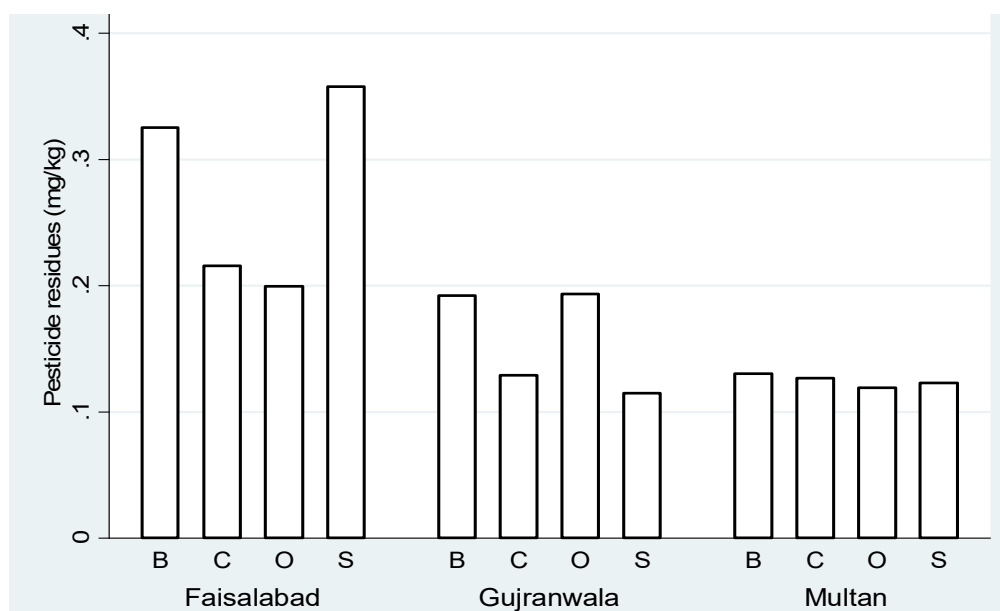


Figure 1. Comparison of pesticide residues across vegetables and districts

Note: B stands for brinjal, C for cauliflower, O for okra and s for spinach.

Source: Authors' own survey data

Figure 1 showed further comparison of pesticide residues across vegetables and districts. In Faisalabad, highly contaminated vegetables were spinach and brinjal,

while in Gujranwala, okra and brinjal were highly contaminated. Multan had almost same level of contamination in all four vegetables. Besides pesticide

quantity, other factors like farmers' education, vegetable growing experience, duration between sprays etc. could influence the contamination of vegetables with pesticide. But it was difficult to conclude the possible sources of contamination based on this simple comparison. This study explores the possible determinants in the next section. In Table 1, okra was the costlier vegetable compared to other vegetables at the farm gate and the same trend continued at the retail level.

The detailed summary of residues of seven common pesticides quantified at three maturity levels of four vegetables have been reported in Table 2. The highest proportion of spinach samples (83%) had

surpassed maximum residue limits (MRLs) set by FAO and WHO (2004), followed by okra (72%), brinjal (60%) and cauliflower (50%). The in-depth analysis explained that profenophos, deltamethrin, dimethoate, and chlorpyrifos are the main culprits of unsafe vegetables. These toxic pesticides are known to be carcinogen and banned in the country of origin. The contaminated vegetable samples exceeding MRLs were lemons (bad quality products) in the vegetable market of Pakistan, implying that most of the vegetable market was occupied by lemons as mentioned by Akerlof (1970). This could be due to the absence of price incentive for producing expensive but safe vegetables.

Table 2. Summary of vegetable samples in percentage contaminated with pesticide residues across pesticides.

Pesticides	Brinjal	Cauliflower	Spinach	Okra
Deltamethrin	43.70 (8.52)	49.26 (15.19)	38.15 (15.19)	27.04 (16.67)
Profenophos	37.78 (25.56)	52.22 (33.33)	32.96 (20.37)	30.37 (15.19)
Dimethoate	29.63 (23.33)	27.78 (20.37)	10.37 (3.73)	18.89 (13.33)
Chlorpyrifos	19.63 (1.85)	6.67 (0.00)	10.74 (6.30)	31.48 (25.93)
Monocrotophos	0.00 (0.00)	0.00 (0.00)	14.82 (0.37)	8.15 (4.81)
Alpha HCH	10.00 (0.00)	9.63 (3.33)	7.41 (2.22)	22.22 (5.19)
Gama HCH	5.56 (1.11)	0.00 (0.00)	4.82 (1.48)	0.74 (0.00)
Lemons (PR> MRLs)	(60.37)	(49.63)	(82.59)	(72.22)
Total samples	270	270	270	270

Note: Percentage of vegetable samples surpass maximum residue limits (MRLs) are reported in parentheses

Econometric Analysis: Results for determinants of pesticide residues in vegetables were presented in column 1 of Table 3. The coefficient of pesticide residues had expected negative sign but it was insignificant, refuting our hypothesis of efficient vegetable market. This indicated that pesticide residues in vegetables were not reflecting into price signals in our vegetable market. However, as discussed in section 2, pesticide residue variable was endogenous and to correct its endogeneity, we had estimated instrumental variable (IV) regression. The results of the first stage (pesticide residue model) of IV as given in Eq. 2 were reported in column 2 of Table 3. Since pesticide quantity was expected to be highly correlated with the pesticide residues, we start investigation with this variable. Pesticide quantity was found to be positively and significantly contributing to determine their residues in vegetables. All other things equal, the coefficient indicated that 1 liter/acre increase in pesticide quantity increased vegetable contamination with 0.03 mg/kg of pesticide residues. Similar findings had been reported by earlier studies using simple

descriptive analysis (Syed *et al.* 2014; Amir *et al.* 2015, 2017; Randhawa *et al.* 2015). Nonetheless, pesticide residues decreased significantly with increased in spray interval. Similarly, farmer's education and vegetable experience were negatively affecting prevalence of pesticide residues. As reported in previous studies (Zhou and Jin 2009), farmer's education contributes to enhance pesticide literacy, which could help to ensure the supply of safe vegetables.

To control for potential endogeneity of pesticide residues in Equation 1, we used two instruments i.e., pesticide quantity and spray interval. We tested the validity of these instruments. Empirical tests indicated that pesticide quantity and spray intervals were highly correlated with pesticide residues but they did not affect the vegetable prices. Pesticide quantity and spray interval had strong impacts on the expression of pesticide residues in vegetables. The predicted residual from first stage was significant in the second stage of IV regression, implying that it rejected the null hypothesis regarding the exogeneity of pesticide residues. Endogeneity tests also

confirmed that selected instruments had helped to address the endogeneity problem of pesticide residues.

Column 3 of Table 3 revealed the results of lemon model (second stage of the IV approach) after controlling for the endogeneity problem. The coefficient of predicted pesticide residue was still negative and insignificant, confirming the existence of lemon market, implying vegetable prices do not reflect vegetable quality trait like pesticide residues. Hence, prevailing information asymmetry in the vegetable market did not help consumers to differentiate between contaminated and uncontaminated vegetables. Therefore, consumers were paying same prices for contaminated vegetables as for safe vegetables. This concludes that vegetable market in Pakistan was a lemon market. Other control variables significantly affecting vegetable prices were types of vegetables, source of irrigation and district dummies.

Table 3. Determinants of pesticide residues.

Variables	OLS regression	IV regression	
	Vegetable price	Stage I Pesticide residues	Stage II Vegetable price
Pesticide quantity (liter/acre)	-	0.026*** (0.003)	-
Spray interval (days)	-	-0.013*** (0.003)	-
Pesticide residues (mg/kg)	-0.249 (0.578)	-	-1.953 (1.540)
Okra(dummy) ^a	3.732*** (0.337)	-0.022 (0.038)	3.700*** (0.454)
Cauliflower(dummy) ^a	-7.150*** (0.338)	-0.034 (0.045)	-7.288*** (0.276)
Spinach(dummy) ^a	-4.517*** (0.390)	-0.019 (0.043)	-4.617*** (0.330)
Irrigation (dummy) ^b	1.578*** (0.360)	-0.012 (0.028)	1.504*** (0.347)
Education (years)	0.008 (0.029)	-0.007*** (0.002)	-0.009 (0.035)
Vegetable experience (years)	0.015 (0.011)	-0.004*** (0.001)	-0.008 (0.011)
Faisalabad(dummy) ^c	-1.580*** (0.330)	0.124*** (0.030)	-1.345*** (0.425)
Multan(dummy) ^c	0.550** (0.280)	-0.000 (0.020)	0.511** (0.207)
Constant	13.800 (0.465)	0.236*** (0.063)	14.375*** (0.593)
R ²	0.835	0.31	0.83
Wald chi ² (9)	-	-	2699.63
Observations	360	360	360

***, **, * Significant at the 1%, 5%, and 10% level of significance, respectively.

Note: Standard errors are reported in parentheses. ^aThe base vegetable crop is brinjal. ^bSource of irrigation is 1 for freshwater and 0 for wastewater. ^cThe base district is Gujranwala.

Conclusion: The findings of this study revealed that large proportion of samples of spanich (83%) followed by okra (72%), brinjal (60%) and cauliflower (50%) have surpassed the maximum residue limits (MRLs) of safe vegetables. Our econometric model indicated that 1 litter/acre increase in pesticide quantity increased pesticide residues by 0.03 mg/kg. However, pesticide residues decreased with increase in spray interval, farmer’s education and vegetable growing experience. The results of the lemon model demonstrated that pesticide residue had negative but insignificant relation with vegetable price, rejecting our null hypothesis of efficient vegetable market. This suggests that pesticide residues are not reflecting into market prices of vegetables due to information asymmetry between producers and consumers for vegetables’ safety attributes. This concludes that vegetable market in Pakistan is a lemon market.

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