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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 estimate information efficiency of vegetable market, by using data collected from a representative sample of 360 farmers in Pakistani Punjab. Chromatography technique is employed to quantify pesticide residues in four common vegetables. Majority of the vegetable samples surpasses the maximum residues limits; hence, they are lemons (bad products). 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 labelling may help to provide safe vegetables to consumers.

Keywords: Vegetables, Information Asymmetry, Lemons Market, Gas Chromatography, Pesticide Residues, Food Safety, Pakistan.

1. INTRODUCTION

Food markets can play crucial role in ensuring food safety in developing countries [Clark and Hobbs (2018)]. Food safety[1] 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 product. 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. The market for vegetables, extensively sprayed with toxic pesticides, could be one of these lemons markets.

Pesticides are chemical compounds that are commonly used to eradicate pests such as insects, weeds, fungi and diseases in modern agriculture [Duong, *et al*. (2019); Guler, *et al*. (2010)]. 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 7,000 metric tons per annum in 1960 to 78,132 metric tons per annum in 2003 [Syed and Malik (2011)]. These pesticides were insecticides (74 percent), herbicides (14 percent), fungicides (9 percent) and others (3 percent) (Khan 1998). During 1984, the share of pesticide market was captured by several hazardous insecticides: pyrethroid (45 percent), phosphates (39 percent), chlorinated hydrocarbons (9 percent), and carbonates

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[1]Food safety means handling, preparing and storing food in such a way to minimise 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)].

(4 percent) [Khooharo, *et al*. (2008)]. 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 monitor pesticide residues to ensure safe vegetables.

Vegetables are integral parts of the daily diet of all Pakistanis. They are rich source of carbohydrate, protein, vitamins, minerals, fibre and antioxidants and contribute to preserve a healthy life. Nonetheless, in Pakistan, 11.9 percent of total pesticides are being applied on vegetables only [Khan (2010)]. 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 [Barr, *et al*. (2010); Schreinemachers (2003); Waller, *et al*. (2010); Bal, *et al*. (2012); Miligi, *et al*. (2006)]. 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 Agriculture Organisation (FAO) of the United Nations and the World Health Organisation (WHO) has set the maximum residue limits (MRLs) for each pesticide in all food items [FAO/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 food.

A growing body of literature confirms that more than 50 percent 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 measure 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 [Rosenman and Wilson (1991)], cherries [Chezum and Wimmer (1997)] 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 Ma, *et al*. (2014) and Hoffmann and Moser (2017) 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 and Moser (2017) 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 attribute 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 allows determining the true factors influencing pesticide residue in vegetables. Secondly, the study also measures the extent of market efficiency by analysing 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 impact 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 learning other similar markets.

The remainder of this research article is organised 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.

2. SURVEY DESIGNS AND DATA

Data used in this study collected through a farm survey and a biophysical survey conducted by the Institute of Agricultural and Resource Economics (IARE) and the National Institute of Food Science and Technology (NIFSAT), respectively, during 2012-14, under a multidisciplinary project supported by Punjab Agricultural Research Board (PARB) of Pakistan. Both surveys were conducted in the Punjab province, the largest contributor to total vegetable production (64 percent) [Pakistan (2010)] and pesticide consumption (88 percent) [Syed, *et al*. (2014)] in the country. A multistage sampling technique is employed for data collection. In the first stage, three major vegetable growing districts named Gujranwala, Faisalabad and Multan[2], representing east, central, and south parts of the 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 initially. Okra and cauliflower are kharif (summer) vegetable but brinjal and spinach are rabi (winter) vegetables. Then, 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 final harvest of the vegetables, face to face interview were conducted, with the help of trained enumerators, using a pretested and well-structured questionnaire. The questionnaire is 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 the biophysical survey, vegetable samples from each selected farmer were procured at three maturity levels in triplicate form. Thus, 3240 (=3*4*30*3*3) samples were analysed. Samples collected from Gujranwala and Multan districts were stored at -40^{o}C in cold storage and then transported to the laboratory of NIFSAT. However, samples collected from Faisalabad district were directly brought to the laboratory in polyethylene bags for immediate processing. In case of any delay, samples were stored at -40^{o}C to avoid degradation of pesticide residues. Residues of pesticides were extracted from the homogenised vegetable sample using the method propose 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 pesticides (Alpha HCH, Chlorpyrifos, Deltamethrin, Dimethoate, Gama HCH, Monocrotophos, Profenophos) commonly sprayed on vegetables 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

[2]Each district is producing the highest amount of vegetables in its region except Multan, which is the second largest supplier of vegetable after Khanewal [Pakistan (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)].

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 for 360 farmers. Their mean values have been reported in Table 2 and discussed in section 3 below. Data on pesticide residues would help to test lemons and information efficiency in the vegetable market of Pakistan.

3. 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, we use linear regression model to show price-quality relationship (lemon market model) proposed by Akerlof (1970) as follows:

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

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 and Moser (2017)]. 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 vegetable contamination with injurious pesticides, which leave pesticide residues in harvested vegetables. These pesticide residues were measured by GC-ECD. We hypothesise 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 endogenity 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:

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

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)].

4. RESULTS AND DISCUSSIONS

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 have almost same age (42 years), education (6 schooling years) and vegetable growing experience (19 years). Likewise, pesticide quantity applied by these farmers is approximately similar (6 litter/acre). However, farmers in Multan are 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 is measured by residues of pesticides in vegetables using GC-ECD. Pesticide residues are 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 are also consistent with the earlier studies [Syed, *et al*. (2014); Amir, *et al*. (2015, 2017); Randhawa, *et al*. (2015)]. Figure 1 shows further comparison of pesticide residues across vegetables and districts. In Faisalabad, highly contaminated vegetables are spinach and brinjal, while in Gujranwala, okra and brinjal are highly contaminated. Multan has 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 is difficult to conclude the possible sources of contamination based on this simple comparison. This study would explore the possible determinants in the next section. The highest proportion of farmers in Faisalabad (75 percent) are using freshwater, followed by Multan (41 percent) and Gujranwala (29). In our sample, okra is the costlier vegetable compared to other vegetables at the farm gate and the same trend continues at the retail level.

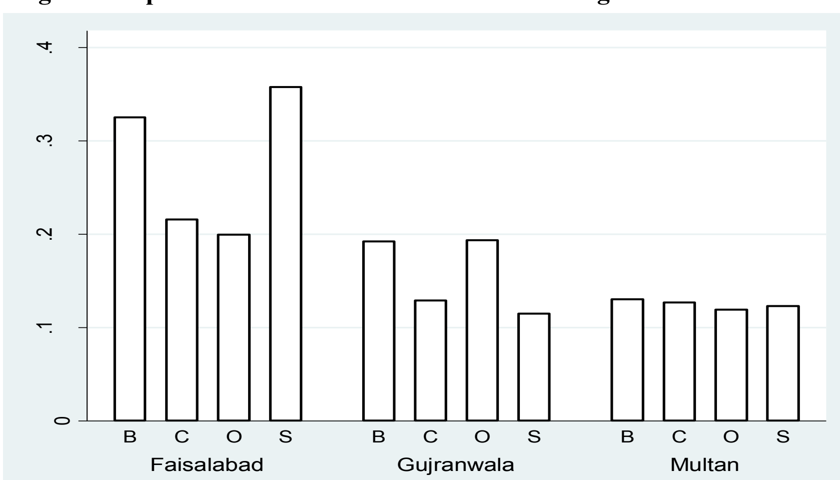
Table 1

Descriptive Statistics of Sample Farms and Farmers Across Districts

Variables	Faisalabad	Gujranwala	Multan
Farmers' age (years)	42.758	42.708	40.875
	(10.830)	(11.928)	(10.844)
Farmers' education (years)	6.008	5.525	5.925
	(4.328)	(4.161)	(3.893)
Farmers' vegetable experience (years)	17.908	19.308	19.808
	(9.960)	(11.510)	(8.854)
Pesticide quantity (liter/acre)	5.788	5.858	6.049
	(3.451)	(4.563)	(4.235)
Spray interval (days)	7.458	7.408	4.972
	(4.066)	(4.973)	(5.882)
Pesticide residues (mg/kg)	0.270	0.157	0.125
	(0.273)	(0.161)	(0.149)
Source of irrigation (%)	75	29	41
Price of brinjal (Rs/kg)	13.767	14.300	16.100
	(2.609)	(1.896)	(2.074)
Price of cauliflower (Rs/kg)	7.667	6.600	7.100
	(0.606)	(0.770)	(0.712)
Price of spinach (Rs/kg)	9.400	9.133	9.167
	(0.932)	(0.819)	(0.986)
Price of okra (Rs/kg)	15.800	20.200	20.867
	(4.452)	(1.627)	(1.776)
Observations	120	120	120

Note: Standard deviations have been reported in parentheses.

Fig. 1. Comparison of Pesticide Residues Across Vegetables and Districts



Source: Authors' own survey data.
Note: B stands for brinjal, C for cauliflower, O for okra and s for spinach.

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 percent) have surpassed the food safety standards (MRLs) set by FAO/WHO (2004), followed by okra (72 percent), brinjal (60 percent) and cauliflower (50 percent). The in-depth analysis explains 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 are lemons (bad quality product) in the vegetable market of Pakistan, implying that most of the vegetable market is occupied by lemons as mentioned by Akerlof (1970). This could be due to the absence of price incentive for producing expensive safe vegetables. This mean comparison helps to answer the first researchable question of the study.

Table 2

Summary of Vegetable Samples in Percentage Contaminated with Pesticide Residues Across Pesticides

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

The second objective of this study is to investigate the determinants of pesticide residues in vegetables. For this purpose, we conducted farm and biophysical surveys and estimated simple lemon model using ordinary least square (OLS) regression given in Equation 1.The results of this model is presented in column 1 of Table 3. The coefficient of pesticide residue has expected negative sign but it is insignificant, refuting our hypothesis of efficient vegetable market. This indicates that pesticide residues in vegetables are not reflecting into price signals in our vegetable market. However, as discussed in section 2, pesticide residue variable is endogenous and to correct its endogeneity, we have estimated IV regression. The results of the first stage (pesticide residue model) of IV as given in Eq. 2 are reported in column 2 of Table 3. Since pesticide quantity is expected to be highly correlated with the pesticide residues, we start investigation with this variable. Pesticide quantity is found to be positively and significantly contributing to determine their residues in vegetables. All other things equal, the coefficient indicates that 1 litter/acre increase in pesticide quantity increases vegetable contamination with 0.03 mg/kg of pesticide residues. Similar findings have 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 decrease significantly with increase in spray interval. Similarly, farmer's education and vegetable experience are 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.

Table 3

Determinants of Pesticide Residues

	OLS Regression	IV regression	
Variables	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	-	-1.953
	(0.578)		(1.540)
Okra (dummy) [a]	3.732***	-0.022	3.700***
	(0.337)	(0.038)	(0.454)
Cauliflower (dummy) [a]	-7.150***	-0.034	-7.288***
	(0.338)	(0.045)	(0.276)
Spinach (dummy) [a]	-4.517***	-0.019	-4.617***
	(0.390)	(0.043)	(0.330)
Irrigation (dummy)[b]	1.578***	-0.012	1.504***
	(0.360)	(0.028)	(0.347)
Education (years)	0.008	-0.007***	-0.009
	(0.029)	(0.002)	(0.035)
Vegetable experience (years)	0.015	-0.004***	-0.008
	(0.011)	(0.001)	(0.011)
Faisalabad (dummy) [c]	-1.580***	0.124***	-1.345***
	(0.330)	(0.030)	(0.425)
Multan (dummy) [c]	0.550**	-0.000	0.511**
	(0.280)	(0.020)	(0.207)
Constant	13.800	0.236***	14.375***
	(0.465)	(0.063)	(0.593)
R^2	0.835	0.31	0.83
Wald $chi^2(9)$	-	-	2699.63
Observations	360	360	360

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

Note: Coefficient estimates are shown with standard errors in parentheses. [a]The base vegetable crop is brinjal. [b]Source of irrigation is 1 for freshwater and 0 for wastewater. [c]The base district is Gujranwala.

To control for potential endogeneity of pesticide residues in Equation 1, we use two instruments i.e., pesticide quantity and spray interval. We tested the validity of these instruments. Empirical tests indicate that pesticide quantity and spray intervals are highly correlated with pesticide residues but they do not affect the vegetable prices. Pesticide quantity and spray interval have strong impacts on the expression of pesticide residues in vegetables. The predicted residual from first stage is significant in the second stage of IV approach, implying that it rejects the null hypothesis regarding the exogeneity of pesticide residues. Endogeneity tests also confirm that selected instruments have helped to address the endogeneity problem of pesticide residues.

Columns 3 of Table 3 reveal the results of lemon model (second stage of the IV approach) after controlling for the endogeneity problem. The coefficient of predicted pesticide residue is 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 does not help consumers to differentiate between contaminated and uncontaminated vegetables. Therefore, consumers are paying same prices for contaminated vegetables as for safe vegetables. This concludes that vegetable market in Pakistan is a lemon market. Other control variables significantly affecting vegetable prices are types of vegetables, source of irrigation and district dummies.

5. CONCLUSIONS

Food safety is a main public concern in developing countries. Efficient food markets can play substantial role to ensure safe food for consumers. In efficient markets, prices fully reflect information on desirable and undesirable product quality attributes. However, in developing countries, information asymmetry between producers and consumers leads to market failure for food safety. Akerlof (1970) called such markets as lemons market. In Pakistan, the market for vegetables contaminated with pesticides could be one of these markets. This study attempts to test lemons in the vegetable market, investigate determinants of pesticide residues and estimate information efficiency in reflecting vegetable safety signals. For this purpose, the study conducted farm survey in major vegetable producing districts of Punjab province to compile information on farm and farmer characteristics by using a well-structured questionnaire. Biophysical survey is also conducted to collect vegetable samples from same farmers to quantify residues of seven pesticides—a quality trait that is generally unobservable by the consumers—in four major vegetables i.e., okra, spinach, cauliflower and brinjal using GC-ECD. We have a representative sample of 360 farmers. Pesticide residue model is estimated to explore the determinants of pesticide residues, while lemon model is estimated to test market efficiency in the vegetable market. Majority of all the vegetable samples are found to be contaminated with pesticide residues exceeding the maximum residues limits set by FAO/WHO. We call contaminated vegetables as lemons, which could negatively influence consumers' health and impede economic development.

The results of pesticide residue model indicate that pesticide quantity is significantly determining the prevalence of residues in vegetables. Ceteris paribus, its coefficient demonstrates that 1 litter/acre increase in pesticide quantity increases vegetable contamination by 0.03 mg/kg. However, pesticide residues decrease with increase in spray interval, farmer's education and vegetable experience.

The results of the lemon model demonstrate that pesticide residue has 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 attribute. This concludes that vegetable market in Pakistan is a lemon market.

Based on our empirical findings, this study suggests that farmer' education, improved extension services and consumer information on vegetable quality traits can play a significant role to mitigate the pesticide residues in vegetable production. A variety of institutional tools including labelling, branding, promotion of contract farming and certification and alternative food networks are useful to mitigate the persistent problem of information asymmetry (market inefficiency) for food safety attributes [Ma, *et al*. (2014); Hoffmann and Moser (2017)]. Further, proper monitoring and implementation of good agricultural practices (GAP) to comply with food safety standards could help to provide safe vegetables to consumers. Several studies have concluded that GAP help to reduce the use of toxic pesticide and their residues in crops [Schreinemachers, *et al*. (2012)]. Extension department through awareness campaign about effective pest control strategies and optimal level of pesticide use could help to prevent food from becoming contaminated with hazardous chemicals [Kouser and Qaim (2014)]. On the other hand, enhancing awareness among consumers about risk of synthetic pesticides and the role of washing vegetables may help to promote food safety [Zhou and Jin (2009); Wanwimolruk, *et al.* (2017)]. Replacing most toxic pesticides with low-toxic or biological pesticides could also help to reduce food safety risk [Zhang, *et al*. (2004)].

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