Ciência Rural, Santa Maria, v.54:10, e20230340, 2024
http://doi.org/10.1590/0103-8478cr202303470
ISSNe 1678-4596
RURAL EXTENSION

Adoption behavior of lemon growers towards essential oil extraction technology in the Pothwar region of Punjab, Pakistan

Fouzia Anjum[1] **Sher Muhammad**[1*] **Badar Naseem Siddiqui**[2] **Muhammad Yaseen**[3]

[1]Department of Agricultural Sciences, Faculty of Sciences, Allama Iqbal Open University, Islamabad, Pakisan. E mail: shermuhammadnioa@yahoo.com.
[*]Corresponding author.
[2]Department of Agricultural Extension, Faculty of Crop and Food Sciences, PMAS-Arid Agriculture University Rawalpindi, Pakistan.
[3]Department of Agricultural Extension & Rural Studies, College of Agriculture, University of Sargodha, Pakistan.

ABSTRACT: This study assessed the adoption level of essential oil extraction practices among lemon growers in the Pothwar region of Punjab, Pakistan. A well-structured questionnaire was used to collect data from 138 smallholders using the interview method by trained remunerators. Descriptive statistics and econometrics; logit and Poisson regression were employed for data analysis. Results of farmers' perceptions of adopting new practices indicated that 10.1% of the farmers are not adopting any one, 22.5% are adopting any three, and 26.8% are adopting all four practices. Moreover, farmers' age, farming experience, land holding, skill, training participation, and receptivity proved to be statistically significant determinants in improving the likelihood of adopting all four practices under the logit and Poisson models, respectively. Hence, it is recommended that the provision of an effective package in the form of literature concerning essential oil extraction practices to the doorsteps of smallholders during demonstration sessions, along with adequate professional training, could help in improving farmers' perceptions toward adoption and strengthening the essential oil sector.
Key words: adoption, aromatic plants, socio-economic characteristics, essential oil extraction, logit, and Poisson, Pakistan.

Comportamento de adoção de produtores de limão em relação à tecnologia de extração de óleo essencial na região de Pothwar em Punjab, Paquistão

RESUMO: Este estudo contemporâneo foi conduzido para avaliar o nível de adoção de práticas de extração de óleo essencial entre os produtores de limão na região de Pothwar, em Punjab, Paquistão. Um questionário bem estruturado foi utilizado para coletar dados de 138 pequenos agricultores utilizando o método de entrevista por remuneradores treinados. Estatística descritiva e econometria; logit e regressão de Poisson foram empregados para análise dos dados. Os resultados das percepções dos agricultores sobre a adoção de novas práticas indicaram que 10,1% dos agricultores não adotam nenhuma, 22,5% adotam quaisquer três e 26,8% adoptam as quatro práticas. Além disso, a idade dos agricultores, a experiência agrícola, a propriedade da terra, as competências, a participação na formação e a receptividade provaram ser determinantes estatisticamente significativos na melhoria da probabilidade de adoção de todas as quatro práticas no âmbito dos modelos logit e Poisson, respectivamente. Assim, recomenda-se que o fornecimento de um pacote eficaz sob a forma de literatura relativa às práticas de extracção de óleos essenciais às portas dos pequenos agricultores durante as sessões de demonstração, juntamente com formação profissional adequada, poderia ajudar a melhorar as percepções dos agricultores relativamente à adoção e ao reforço dos princípios essenciais.
Palavras-chave: adoção, plantas aromáticas, características socioeconômicas, extração de óleo essencial, logit e Poisson, Paquistão.

INTRODUCTION

Pakistan is an agrarian country blessed with varying resources of agro-climatic conditions favorable for growing a range of crops, including medicinal and aromatic plants, with a 22.7% share of the national GDP (AAQIL et al., 2023). Unlike other agro-based industries, the essential oil sector in Pakistan is highly disproportionate because of negligence, unawareness, lack of knowledge and skill in cultivation, post-production, and inefficient processing techniques, leading to low yield and productivity hampering the development of this sector. As novel agricultural technologies such as essential oil extraction (EOE) and production are rapidly promoted for smallholders in Asia to meet demand in the international market, their adoption and use must be well-known by the farming communities in the region (FRANZ, 2010; BAPTISTA-SILVA et al., 2020).

A wide range of essential oil-bearing crops notably, mint, citrus (lemon), and eucalyptus, produce high-value oil worldwide in leading European countries (SHER et al., 2017). On the contrary, the total value of exports of essential oils in Pakistan was worth $ 3.12 million in 2020, and over $ 9.2 million was spent for import purposes, indicating massive demand for these oils (KHALID, 2023). Globally, essential oils represent a valuable sector in agriculture, offering economic potential

Received 06.26.23 Approved 01.10.24 Returned by the author 04.17.24
CR-2023-0340.R1
Editors: Leandro Souza da Silva Ana Louise de Carvalho Fiúza

from extracting essential oils from a range of aromatic plants including citrus (lemon). Supporting this valuable sector not only strengthens the country's economic expansion but also contributes to higher production and marketing of farmers' high-value products and amplifies their profitability. However, meager literature is available on disseminating practical knowledge on cultivating these crops to end users. Likewise, research on the factors determining the participation and adoption of these crops along with the adoption process is lagging, leaving less technology adoption as a crucial challenge (YIGEZU et al., 2018). Citrus species, preferably lemon, are produced in four provinces of Pakistan, but Punjab holds above 95% of the total production with an annual output of 1.5 MMT (ALI et al., 2022). Hence, it is Pakistan's leading citrus (lemon) producing area. However, the awareness level of cultivating lemon for essential oil is minimal. The diffusion of improved agricultural technologies mainly depends on an effective extension setup, as most of them rely on public extension for the latest information on improved production practices. However, the desired outcomes have not been achieved because of the non-involvement of agricultural personnel, lack of knowledge, meager financial resources, and inadequate training, which have proved to be the critical barriers limiting the adoption of technologies (JABBAR et al., 2022). The existing socioeconomic conditions of farmers are crucial to understanding their participation in interventions, notably in novel agricultural technologies (NIGUSSIE et al., 2017; BALOCH &THAPA, 2019). For instance, lack of education causes unawareness, ultimately leading to a low literacy rate, and limiting people's access to information and services may add fuel to the fire (CARRER et al., 2017).

This study presented practical insights into the relationship between socioeconomic factors and personal and farming characteristics that may influence the adoption behavior of smallholders concerning essential oil extraction. The findings of this study will help growers understand the economic potential associated with cultivating these high-value crops, including lemon, to boost farm productivity and profitability. Furthermore, this research will assist the Government of Punjab in promoting the significance, value, and demand of these high-value products in both domestic and international markets. This can be achieved by targeting farmer nationwide and reinforcing extension and adaptive research. In addition, this study examined the following research questions:

Do these determinants affect the adoption behavior of the smallholders regarding recommended EOE practices?

Is there any significant relationship among socio-economic, farming, and personal factors that influence the perception of smallholders regarding EOE technology?

The present study has the following key contributions. (i) Previous research studies examined the impact of several determinants affecting the adoption of diverse innovative agricultural technologies among cultivators of agricultural crops (MARIANO et al., 2012; WU, 2022). However, they overlooked the novelty associated with adopting EOE technology among aromatic crop growers, particularly in developing countries. Hence, the present study addressed a gap by analyzing the effects of fundamental factors influencing the perception of lemon growers toward the adoption of EOE technology, (ii) disseminating field-based knowledge about EOE technology among aromatic crop growers through four innovative practices before analysis, and (iii) finally two econometric models (logit and Poisson) are employed to assess and forecast the potential effects of interconnected variables, allowing the producers to make informed decisions about their potential outcomes.

The current study is formulated as follows. The first section presents the background, significance, research questions, and key contributions of the study. The second section provides a detailed description of the research methodology comprising research design, theoretical framework, empirical approach, formulation of variables and hypotheses, data collection, and analysis. The third section presents the estimation results and discussion, and the concluding section summarizes the study.

MATERIALS AND METHODS

Research design and data collection

This study revealed data from a well-structured questionnaire administered in two districts namely Chakwal and Rawalpindi of *Pothwar* Punjab, Pakistan in 2022. A sample size of 138 lemon growers was obtained by using the table developed by (KREJCIE & MORGAN, 1970). Thereafter; a proportionated sampling technique was applied through simple random sampling.

This study highlighted the technology transfer process by introducing innovative practices. At first, master trainers were selected from the postgraduate students of the Department of Agricultural Extension, PMAS-AAUR. Second,

hands-on training was provided to them on recommended practices by the researcher, one of the senior faculty members of the University, and at the farm of a progressive farmer in Kallar Kahar Tehsil Chakwal, Punjab. Thereafter, the master trainers trained the respondents at their farms. Lastly, the data was collected from trained respondents via master trainers to record their perception of the adoption decision of practices.

Variables, and Hypothesis

The applied model intended to reveal the adoption behavior of lemon growers towardessential oil extraction practices. Finally, the data were concluded with 12 variables as key determinants based on the researcher & master trainers' field experience. As the propensity index is not directly observable in the models, it may be treated as a latent variable that explains the probability that a farmer is likely to adopt the said practices (1= yes, adoption of an essential oil extraction practice, 0=no, non-adoption of an essential oil extraction practice).

The analysis of the results presents the adoption rate of practices by the individual in three different levels: low, medium, and high (adoption of any one, two or three, and all four practices), respectively. Furthermore, a description of all the estimated parameters of the independent variables (Table 1), descriptive statistics related to the key determinants, and the application of econometrics to analyze the influence of the variables on the farmer' adoption decision is presented. Data were analyzed using R- statistics and Microsoft Excel.

The Empirical Approach

The current study used two econometrics models to analyze farmers' adoption decisions on practices: the logit and Poisson regression models (JARA-ROJAS et al., 2012).

Logit regression model

The following model helps to test the determinants of adoption, observing the decision for "adopters" or "non-adopters" as an outcome of binary variables, which express the values as 1

and 0, respectively (CARRER et al., 2017). The model can mathematically be specified as;

$P\,[yi = 1] = (e > -Xi\beta) =$

$$1 - F\,(-Xi\beta) = F\,(Xi\beta) = \frac{1}{(1 + e)^{(-\mathrm{Xi}\beta)}}$$

Where,

Y_i = *1 if the farmer adopts essential oil extraction practices*

0 if the farmer does not adopt essential oil extraction practices

F is the cumulative distribution function, β and βi are coefficients, i = 1, 2…n are the coefficients of the independent variables to be estimated. While e = error term.

After acquiring the maximum likelihood estimates of Xi variables for adopting recommended techniques, the marginal effect of each variable requires the following procedure for estimation. This means that the small effects of a unit change in X_i with all the other factors remaining constant.

$$\frac{\Delta pi - \partial p}{\Delta xi \partial xi} = \left[\frac{\beta_i e^{(-Xi\beta)}}{1 + e^{(-Xi\beta)}}\right]$$

Poisson regression model

The adoption of technology decision is modeled as count data variables in Poisson regression, which ranges from 1 for adopters of only one practice to 4 for adopters of four practices (Y_i);

1 if the farmer adopts one practice
2 if the farmer adopts two practices
3 if the farmer adopts three practices
4 if the farmer adopts four practices

For the random Poisson variable y, the function can mathematically be expressed as follows $(Y = y_i|x_i) = (y|\mu) = \underline{e}^{-\mu}\underline{\mu}^{y}$, $y = 0,1,2, \ldots, 0 \leq \mu < \infty, y!$

yi = sum of the total number of practices used for adoption, xi = independent variables to be estimated, and μ = expected mean parameter.

The following logarithmic likelihood function presents PRM, in which β could be estimated using maximum likelihood procedures (CROWTHER et al., 2012).

$Ln\mathrm{L}(\beta) = \mathrm{In}\ \ \underline{e}^{\Lambda}\underline{\mu}^{y} = -\Lambda + yi\ \ln(\Lambda) - \ln(yi!) = \Sigma_{i=1}^{N} = (-\exp(\mathrm{xi}\,\beta) + \mathrm{yi}(\mathrm{xi}\beta) - lnyi!))$

Hypothesis testing;

H_1 = Positive relationship exists between the recommended practices and farmers' perception towards adoption.

The study focused on four innovative practices in lemon essential oil extraction: best horticultural practices, use of steam distillation unit, byproducts preparation, and economic training. These practices are chosen because they involved a range of production parameters, functions, and applications.

RESULTS AND DISCUSSION

Summary statistics for key variables

Regarding the key variables' statistics, most respondents fell between the ages of 31-40 (47.83%), illiterate having no formal education

Table 1 - Description of explanatory variables and their measurement.

Variable	Type	Measurement
Y_1 = Adoption of horticultural practices for essential oil extraction of aromatic plants	Dummy	1 if the farmer uses horticultural practices for lemon growing and essential oil extraction, 0 otherwise
Y_2 = Adoption of using a distillation unit for essential oil extraction	Dummy	1 if the farmer uses a distillation unit for lemon essential oil extraction, 0 otherwise
Y_3= Adoption of preparation methods of byproducts	Dummy	1 if the farmer uses byproducts preparation methods, 0 otherwise
Y_4= Adoption of economic training	Dummy	1 if the farmer prefers to grow lemon crop over traditional farming on an economic basis, 0 otherwise
Y: Poisson model	Categorical	values ranging from 0 to 4, where lemon essential oil extraction technology is the sum of four dummy (0,1) variables for the adoption of four practices: (1) horticultural practices for lemon growing; (2) using distillation unit for essential oil extraction; (3) preparation methods of byproducts; and (4) economic training
X_1 = Age (year)	Continuous	Age in years
X_2 = Education	Categorical	1. Illiterate, 2. Up to primary 3. Matric 4. Middle 5. Intermediate and 6. Graduate and above
X_3=Farming experience (year)	Continuous	Farm experience in years
X_4 = Farm size	Continuous	Land size (kanal)
X_5= Participation in training by master trainers	Dummy	1 if the farmer has participated in the training, 0 otherwise
X_6 =Land ownership	Dummy	1 for own land; 0 for tenant land
X_7= Knowledge level improvement	Dummy	1 if knowledge improves, 0 otherwise
X_8= Skill development	Dummy	1 if skill improves, 0 otherwise
X_9=Low operational cost	Dummy	1 if low operational cost, 0 otherwise
X_{10}=Positive opinion from a fellow farmer	Dummy	1 if positive opinion from a fellow farmer, 0 otherwise
X_{11} = Profit orientation	Dummy	1 if the practice is profit-oriented, 0 otherwise
X_{12}= Receptivity to the practices	Likert scale	values ranging from 1: poor, to 5: excellent with the following statement: 'Concerning lemon essential oil extraction practices for smallholders, I prefer to acquire it with all the available technological options

Source: Authors' calculation from primary research data.

(39.13%), holding 11 to 15 years of farming experience (39.13%), and farm size of 9 to 24 *kanal* (33.34%). Regarding the recommended practices, the majority of the farmers responded positively towards improvement in knowledge, followed by participation in training via master trainers, profit-oriented, positive opinion from fellow farmers, skill, low operational costs, and receptivity by 70.30, 65.20, 61.60, 59.42, 57.20, 44.93, and 42.75% respectively (Table 2). Finally, the frequency of the adoption of essential oil practices by lemon growers was measured as the dependent variable of the study. The most adopted practice was the use of a distillation unit for oil extraction by most respondents (63.8%), followed by best horticultural practices and byproduct preparatory methods (57.2%), and economic training (46.4%). In addition, the aggregate adoption of practices was also displayed. It was observed that 10.1% of the respondents did not adopt any recommended practice as non-adopters. 18.1% adopted only one practice that presented a low level of technology

Table 2 -Summary of key variables in the model.

----------Variable (N-138)----------					
Variable	Options	Frequency	Percentage	Mean	Standard deviation
----------Age (year)----------				34.5	24.28
	Less than 30	18	13.04		
	31-40	66	47.83		
	41-50	41	29.71		
	Above 50	13	9.42		
----------Education (year)----------				23	19.70
	Illiterate	54	39.13		
	Up to primary	12	8.70		
	Matric	28	20.29		
	Middle	35	25.36		
	Intermediate	06	4.35		
	Graduate and above	03	2.17		
----------Farming experience (year)----------				27.6	21.24
	No experience	02	1.45		
	Less than 05	13	9.42		
	05-10	26	18.84		
	11-15	54	39.13		
	16 and above	43	31.16		
----------Farm Size(*kanal*)----------				34.5	11.85
	01-08	32	23.19		
	09-24	46	33.34		
	25-40	41	29.71		
	41 and above	19	13.76		
Participation in training via master trainers	No	48	34.80	0.65	0.48
	Yes	90	65.20		
Land ownership	No	88	63.77	0.64	0.58
	Yes	50	36.23		
Knowledge level improvement	No	41	29.70	0.70	0.46
	Yes	97	70.30		
Skill development	No	59	42.80	0.57	0.50
	Yes	79	57.20		
Low operational cost	No	76	55.07	0.45	0.50
	Yes	62	44.93		
The positive opinion from a fellow farmer	No	56	40.58	0.63	0.48
	Yes	82	59.42		
Profit orientation	No	53	38.40	0.62	0.49
	Yes	85	61.60		
Receptivity to the practices	1= Poor	10	07.25	3.66	1.14
	2= Fair	12	08.70		
	3= Satisfactory	25	18.11		
	4= Good	59	42.75		
	5= Excellent	32	23.19		

Source: Authors' calculation from primary research data.

adoption. Likewise, respondents with medium and high levels of adoption accounted for 45 and 26.8%, respectively (Table 3).

Correlation between the selected variables

Pearson correlation ranging from 0 to 1 was done to estimate the magnitude, direction, and strength of the relationship between the variables of the study presenting the numeric presentation of values at the upper half and the graphical presentation at the lower half (Figure 1). It clearly showed that the variable 'receptivity to the practices' had a strong positive relationship with other variables such as participation in training (0.59) followed by positive opinion from fellow farmers (0.56), lower operational cost (0.54), knowledge improvement (0.42), skill development (0.36) and profit orientation (0.20).

Factors influencing the adoption of essential oil extraction practices

The study findings of our empirical models are as follows.

Farmers' age (X_1) had a statistically significant effect on the likelihood of adoption of the use of steam distillation unit (Y_2) and byproduct preparation (Y_3). The estimated marginal effect indicated that a unit increase in age led to a 26 and 22% increase in the adoption of both practices by lemon growers. The estimated marginal effect narrated that a unit increase in the variables such as low operational cost (X_9), and farmers' participation in training statistically improved their adoption decision toward using a steam distillation unit (Y_2), and byproducts preparatory methods (Y_3) by 20%, respectively (Table 4).

The fourth practice analyzed, economic training (Y_4) to grow aromatic crops having economic potential over others. The main influencer was receptivity to the practices (X_{12}), which proved to be a significant independent variable likely to increase their decision toward adoption by 52% at a 5% level of significance. Hence, the same (X_{12}) also proved significant on each of the dependent variables (Yi) of the study under the logit model. The calculated marginal effect indicated that with a unit increase in this variable, the probability of adopting these practices increased by 81% (Y_1), 67% (Y_2), and 73% (Y_3) respectively (Table 5).

Farmers who had participated in training by master trainers (X_5), followed by the variables such as large farm size (X_4), farming experience (X_3), and skill development (X_8), had a strong positive association with the likelihood of adopting best horticultural practices (Y_1). In addition, the marginal effect indicated that a unit increase in each parameter was likely to improve their adoption decision by 26, 24,16, and 13%, respectively (Table 5 and Table 6).

Finally, analyzing practices in an aggregate way through the Poisson count model, the most significant variable receptivity to the practices (X_{12}) indicated that the probability of adopting the novel practices increased by 88 times with a one unit increase in the respective factor assuming, that other factors remain constant. Moreover, the overall model(s) of the study elucidated adoption moderately well (R^2 = 0.47, 0.51, 0.50, 0.27 & 0.20), and the P-values are less than 0.05 along with statistically significant coefficients help to reject the null and accept the alternative hypotheses support to the above findings of the study (Table 6).

DISCUSSION

Table 3 - Adoption of Essential oil practices by lemon growers in Pothwar Punjab, Pakistan.

Practices	Adopters	Frequency of adoption (%)	Observations
Adoption of best horticultural practices of growing lemon for essential oil	79	57.2	138
Use of a distillation unit for oil extraction	88	63.8	138
Byproducts preparatory methods	79	57.2	138
Economic training	64	46.4	138
Non-adopters	14	10.1	138
Adoption of any one practice (low-level)	25	18.1	138
Adoption of any two practices (medium level)	31	22.5	138
Adoption of any three practices (medium level)	31	22.5	138
Adoption of four practices (high level)	37	26.8	138

Source: Authors' calculation from primary research data.

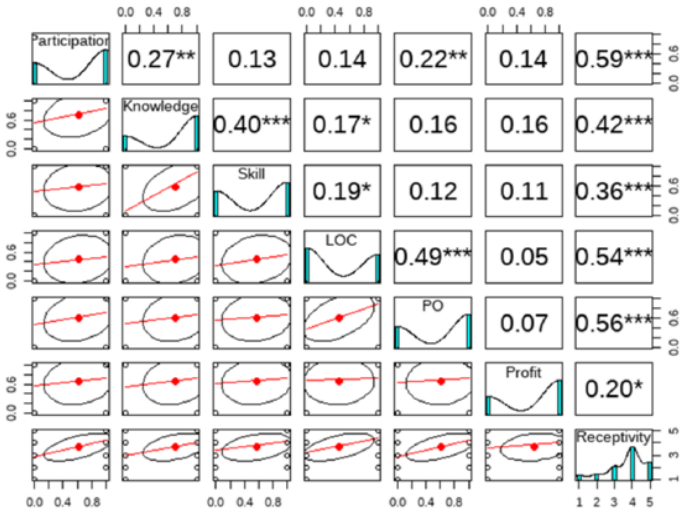

Figure 1 - Correlation matrix between the variables of the econometric models.

Note: LOC = Lower Operational Cost, PO = Positive opinion from fellow farmers.

Key factors that determine smallholder participation in lemon essential oil extraction

Emerging technologies have the potential to transform farming beyond recognition, thus enabling a smooth transition to modern agriculture for farming communities in the developing world. Essential oil extraction is a leading technology because it is simple, rapid, and cost-effective among smallholders. Producing lemon crops in terms of production and profit is highly demanding in our country because of highly conducive agro-climate conditions. Certainly, our farmers could not attain its potential economic benefits because of lack of awareness, knowledge, and skills in producing lemon for essential oil. Lemon fruit peel is usually discarded as food waste but enriched with a range of secondary metabolites, and antioxidants HOJJATI & BARZEGAR (2017); HEYDARI KOOCHI et al. (2022) that could be utilized effectively in cosmetics, and pharmaceutics industries.

The most significant factor that determining the adoption of the respondents was their receptivity to the practices. Receptivity refers to individuals' beliefs and attitudes that can change and explain behavior toward rejecting and accepting innovations (MOTTALEB, 2018). Farmers who are more open to novel technologies are more likely to adopt them based on their individual beliefs. The results are more consistent with the findings of DIAZ et al. (2022) who claimed that individuals' willingness to perceive positive aspects of any innovation is entirely based on the assumptions that support their well-being in terms of economically profitable returns.

The second and third significant factors were farm area and higher farming experience. Although, the small-to medium-sized essential oil distillation unit requires a minimum area for oil extraction, it is necessary to prepare byproduct such as bio-compost after using the leftover lemon essential oil extraction waste. Hence, the large land area factor had a greater influence on the adoption of a distillation unit and byproduct preparation. The results are in support the findings of NAVEED & HASSAN (2021), which stated that the large farm size is a significant economic factor that influences the decisions of farm households to adopt novel agricultural technologies. However, an increase in years of farming experience is highly useful in the adoption of any technology when farmers can test its potential benefit by themselves, which later determines its adoption or non-adoption over time (PIERPAOLI et al., 2013). Hence, farmers with a large area of cultivated land and high farming experience are more willing to significantly adapt to new techniques.

Participation in training was found to be another statistically significant factor in the adoption of practices. The motivation of the farmers towards the adoption decision process significantly

Table 4 - Results of the Logit and Poisson models: Socioeconomic determinants of the adoption of essential oil extraction practices by lemon growers.

Variables (Independents)	(Dependents)	Logit				Poisson Y (1,2,3,4)
		Adoption of best horticultural practices (Y_1)	Use of distillation unit for oil extraction(Y_2)	Byproducts preparatory methods(Y_3)	Economic training (Y_4)	
Intercept	ß	-6.03 **	1.62	-2.39	-5.03	-1.38
	(Std-error)	(2.26)	(2.26)	(3.47)	(2.69)	(0.62)
	P-values	0.01**	0.47	(0.49)	0.06	(0.02) *
----------Age (X_1)----------						
Less than 30	ß	-0.81	-1.13	-1.13	-1.09	0.07
	(Std-error)	(1.02)	(0.86)	(0.82)	(0.66)	(0.19)
	Marginal effect	-0.11	-0.10	-0.01	-0.18	0.16
	P-values	0.34	-0.11	0.88	0.10	0.73
41-50	ß	-3.21 *	2.95 *	2.28*	-0.66	-0.09
	(Std-error)	(1.43)	(1.29)	(1.15)	(0.75)	(0.17)
	Marginal effect	-0.42 *	0.26**	0.22*	-0.11	-0.20
	P-values	0.01**	0.02*	0.04*	0.38	0.62
Above 50	ß	-0.48	-1.49	-0.05	-0.18	-0.13
	(Std-error)	(0.90)	(1.35)	(1.53)	(1.26)	(0.30)
	Marginal effect	-0.05	-0.15	-0.01	-0.03	-0.29
	P-values	0.54	0.27	0.97	0.89	0.66
----------Education (X_2)----------						
Illiterate	ß	2.57	-2.79	0.16	-0.23	-0.12
	(Std-error)	(1.53)	(1.76)	(2.86)	(1.66)	(0.50)
	Marginal effect	0.27	-0.24	0.02	-0.04	-0.28
	P-values	0.09	0.17	0.96	0.89	0.81
Up to Primary	ß	0.48	-2.37	-0.89	0.28	-0.31
	(Std-error)	(1.72)	(2.00)	(2.95)	(1.78)	(0.54)
	Marginal effect	0.06	-0.25	-0.10	0.05	-0.69
	P-values	0.78	0.24	0.76	0.87	0.56
Matric	ß	-3.25		-1.45	0.61	-0.16
	(Std-error)	(3.38)		(2.88)	(1.69)	(0.50)
	Marginal effect	-0.08		-0.16	0.10	-0.37
	P-values	0.99		0.61	0.72	0.76
Middle	ß	0.10	-2.41	-0.21	0.43	0.04
	(Std-error)	(1.55)	(1.85)	(1.83)	(1.65)	(0.50)
	Marginal effect	0.01	-0.24	-0.02	0.07	0.11
	P-values	0.95	0.19	0.94	0.80	0.93
Intermediate	ß	0.68	-1.69	-0.79	2.32	-0.01
	(Std-error)	(2.07)	(2.27)	(3.11)	(2.00)	(0.54)
	Marginal effect	0.08	-0.17	-0.09	0.35	-0.01
	P-values	0.74	0.45	0.80	0.24	0.99
Low operational cost (X_9)	ß	1.44	1.70 *	0.85	0.35	0.16
	(Std-error)	(0.85)	(0.80)	(0.70)	(0.57)	(0.16)
	Marginal effect	0.16	0.20 *	0.10	0.06	0.38
	P-values	0.09	0.03*	0.22	0.54	0.32
Profit orientation (X_{11})	ß	0.15	-1.46	-1.32	0.79	0.08
	(Std-error)	(0.62)	(0.92)	(0.83)	(0.58)	(0.17)
	Marginal effect	0.02	-0.13	-0.13	0.14	0.18
	P-values	0.81	0.11	0.11	0.17	0.66

Table 5 - Results of the Logit and Poisson models: Personal determinants of the adoption of essential oil extraction practices by lemon growers.

Variables (Independents)	(Dependents)	Logit				Poisson Y (1,2,3,4)
		Best horticultural practices (Y_1)	Distillation unit for oil extraction(Y_2)	Byproducts preparatory methods(Y_3)	Economic training (Y_4)	
Participation in training by master trainers (X_6)	ß	2.02**	-0.12	1.61*	-0.17	0.25
	(Std-error)	(0.77)	(0.63)	(0.77)	(0.59)	(0.14)
	Marginal effect	0.26 **	-0.01	0.20*	-0.03	0.58
	P-values	0.01 **	0.85	0.04*	0.77	0.08
Knowledge improvement (X_7)	ß	0.35	0.18	1.06	0.29	0.29
	(Std-error)	(0.73)	(0.67)	(0.87)	(0.70)	(0.19)
	Marginal effect	0.04	0.02	0.11	0.05	0.69
	P-values	0.63	0.79	0.22	0.68	0.13
Skill development (X_8)	ß	-1.23	-1.17	-0.29	1.40 *	0.04
	(Std-error)	(0.69)	(0.66)	(0.76)	(0.64)	(0.15)
	Marginal effect	-0.13*	-0.12	-0.03	0.24*	0.10
	P-values	0.08	0.07	0.70	0.03*	0.76
Positive opinion from a fellow farmer (X_{10})	ß	-2.06	0.69	-0.64	0.98	0.09
	(Std-error)	(0.91)	(0.69)	(1.18)	(0.97)	(0.16)
	Marginal effect	-0.17**	0.08	-0.07	0.17	0.20
	P-values	0.02*	0.32	0.59	0.31	0.59
----------Receptivity to the practices (X_{12})----------						
2 = Fair	ß	0.60	-0.57	-0.45	1.64	
	(Std-error)	(1.69)	(1.47)	(1.78)	(0.53)	
	Marginal effect	0.05	-0.07	-0.05	0.27	
	P-values	0.72	0.70	0.80	0.28	
3 = Satisfactory	ß	3.65 *	-0.34	0.62	1.27	
	(Std-error)	(1.51)	(1.25)	(1.53)	(1.47)	
	Marginal effect	0.48 ***	-0.04	0.08	0.20	
	P-values	0.02*	0.79	0.69	0.39	
4 = Good	ß	5.07 **	3.06*	3.42 *	1.75	
	(Std-error)	(1.81)	(1.47)	(1.60)	(1.47)	
	Marginal effect	0.68 ***	0.45 *	0.52**	0.29	
	P-values	0.01**	0.04*	0.03*	0.24	
5 = Excellent	ß	6.52 **	5.84 **	5.61**	3.03	0.38
	(Std-error)	(2.27)	(1.97)	(1.93)	(1.63)	(0.11)
	Marginal effect	0.81 ***	0.67 ***	0.73 ***	0.52*	0.88**
	P-values	0.00**	0.00**	0.00**	0.06	0.00***

increased due to training from experts, fellow farmers' success and inherited knowledge. The results also support similar findings by RAMIREZ (2013) who asserted that association with farmer groups in terms of field-based knowledge is known to speed up the adoption processes.

The fifth most important factor predicted in our model that affects the likelihood ofadoption was skill development. Particularly, access to participation improved the skill development of the respondents in growing aromatic crops over traditional farming in their farmlands, not only for crop production but also for essential oil extraction. Farmers who had attained practical skills to run steam distillation units and preparation of bio-compost recorded their perception positively towards adoption. Notably, the findings

Table 6 - Results of the Logit and Poisson models: Farming determinants of the adoption of essential oil extraction practices by lemon growers.

Variables (Independents)	(Dependents)	Logit				Poisson Y (1,2,3,4)
		Adoption of best horticultural practices (Y_1)	Use of distillation unit for oil extraction(Y_2)	Byproducts preparatory methods(Y_3)	Economic training (Y_4)	
----------Farming experience (X_3)----------						
No experience	ß	-0.35	-1.88	-1.28	0.39	0.24
	(Std-error)	(2.33)	(1.90)	(1.49)	(1.45)	(0.41)
	Marginal effect	-0.04	-0.19	-0.14	0.06	0.65
	P-values	0.88	0.32	0.39	0.79	0.56
Less than 5	ß	0.36	-1.80	-1.05	1.20	0.06
	(Std-error)	(1.30)	(1.78)	(1.11)	(0.92)	(0.23)
	Marginal effect	0.04	-0.19	-0.12	0.20	0.14
	P-values	0.78	0.13	0.34	0.19	0.80
5-10	ß	1.58	-3.19**	-2.17*	0.73	-0.01
	(Std-error)	(0.89)	(1.00)	(0.85)	(0.63)	(0.17)
	Marginal effect	0.13	-0.33***	-0.25*	0.12	-0.02
	P-values	0.20	0.00**	0.01*	0.25	0.95
Above 16	ß	1.47	0.19	0.15	0.93	-0.08
	(Std-error)	(0.80)	(0.85)	(0.91)	(0.68)	(0.18)
	Marginal effect	0.16 *	0.02	0.02	0.16	-0.18
	P-values	0.07	0.83	0.87	0.17	0.65
----------Farm size(kanal)(X_4)----------						
9-24	ß	1.63	1.55	1.20	0.33	0.22
	(Std-error)	(0.85)	(0.90)	(0.84)	(0.61)	(0.16)
	Marginal effect	0.17	0.16	0.13	0.05	0.46
	P-values	*0.05	0.09	0.15	0.59	0.19
25-40	ß	0.58	0.83	1.01	-0.08	0.22
	(Std-error)	(0.79)	(0.84)	(0.86)	(0.65)	(0.17)
	Marginal effect	0.06	0.09	0.11	-0.01	0.47
	P-values	0.47	0.32	0.24	0.90	0.20
Above 40	ß	2.52	0.33	2.28*	0.14	0.74
	(Std-error)	(1.37)	(1.12)	(1.13)	(1.34)	(0.28)
	Marginal effect	0.24 *	0.03	0.33**	0.01	2.11*
	P-values	0.07	0.77	0.04*	0.92	0.01**
Land ownership (X_5)	ß	0.28	-0.95	-0.85	-0.53	0.06
	(Std-error)	(1.70)	(0.69)	(0.69)	(0.53)	(0.14)
	Marginal effect	-0.03	-0.10	-0.09	-0.09	0.13
	P-values	0.70	0.17	0.18	0.32	0.69
----------Model fitting information----------						
logLik		-46.62	-46.24	-50.41	-69.89	-193.48
AIC		146.06	144.48	148.65	193.77	434.97
Pseudo R^2		0.63	0.67	0.66	0.41	
Pr (>Chi)		0.000 ***	0.000***	0.000 ***	0.002 **	0.000***
R^2McFadden		0.47	0.51	0.50	0.27	0.20

Note: Signif. codes: *** P < 0.001; ** P < 0.01; * P < 0.05.

underscore the essence of skilled farmers' competencies in promoting lemon essential oil production at a commercial scale. WHITE et al. (2005)confirmed the challenges of low-skilled farmers hinder the use and benefit of producing and selling farm commodities. Hence, skill factors are likely to impact the adoption processes that may help accelerate the adoption decision.

CONCLUSION

In a nutshell, farmers' age, farming experience, farm area, participation in training by master trainers, skill, lower operational cost, and receptivity to the practices proved to be the strong determinants that primarily increased the likelihood of adoption decisions of lemon growers in *Pothwar* region of Punjab, Pakistan. Hence, the study findings affirmatively supported the research questions. Moreover, by rejecting the null hypothesis and accepting the alternative, a positive relationship exists between the recommended practices and farmers' perception of adoption. Thus a localized perception of factors that derive adoption decisions, and boosting of the essential oil sector is essential. Despite employing twelve external drivers to predict adoption behavior using econometrics, the study has a few limitations. For instance, the research overlooked socio-psychological factors such as attitude, self-efficacy, and external resources affecting farmers' adoption behavior within the theoretical context. Hence, future studies may expand the current research incorporating these factors offers an improved understanding of the variables. Furthermore, it could be highly fruitful to replicate the existing model framework by adding a larger representative sample to provide further evidence in predicting its strengths and weaknesses. Finally, the implications of this study can be further extended to other regions within the country comprising similar agro-climatic conditions for cultivating aromatic crops specifically and to Asiatic regions in general.

ACKNOWLEDGMENTS

The author(s) acknowledge the technical support of Ms. Gule-e lala, Plant Pathology Department, PMAS-AAUR, and Mr. Hamid Khurshid (horticulturist) for providing hands-ontraining to the master trainers in operating field-based essential oil distillation unit.

DECLARATION OF CONFLICT OF INTEREST

The author(s) declared no potential conflicts of interest concerning the research, authorship, and or publication of this paper.

AUTHORS' CONTRIBUTION

The authors contributed equally to the manuscript.

REFERENCES

AAQIL, A. et al. Evaluation in Pakistan. In: R. Stockmann, W. Meyer, et al (Ed.). The Institutionalisation of Evaluation in Asia-Pacific. **Cham: Springer International Publishing**, v.10.1007/978-3-031-36918-6_9, 2023. Evaluation in Pakistan, p.273-321. Available from: <https://doi.org/10.1007/978-3-031-36918-6_9>. Accessed: Nov. 22, 2023. doi: 10.1007/978-3-031-36918-6_9.

ALI, A. et al. Identification and primary distribution of Citrus viroid V in citrus in Punjab, Pakistan. **Molecular Biology Reports**, v.49, n.12, p.11433-11441. 2022. Available from: <https://doi.org/10.1007/s11033-022-07677-7>. Accessed: Dec. 12, 2022. doi: 10.1007/s11033-022-07677-7.

BALOCH, M. A.; THAPA, G. B. Review of the agricultural extension modes and services with the focus to Balochistan, Pakistan. **Journal of the Saudi Society of Agricultural Sciences**, v.18, n.2, p.188-194. 2019. Available from:<https://www.sciencedirect.com/science/article/pii/S1658077X16302168>. Accessed: Apr. 02, 2019. Epub 19-May-2017. doi: 10.1016/j.jssas.2017.05.001.

BAPTISTA-SILVA, S. et al. The progress of essential oils as potential therapeutic agents: a review. **Journal of Essential Oil Research**, v.32, n.4, p.279-295. 2020. Available from: <https://doi.org/10.1080/10412905.2020.1746698>. Accessed: Jul. 03, 2020. doi: 10.1080/10412905.2020.1746698.

CARRER, M. J. et al. Factors influencing the adoption of Farm Management Information Systems (FMIS) by Brazilian citrus farmers. **Computers and Electronics in Agriculture**, v.138, p.11-19. 2017. Available from: <https://www.sciencedirect.com/science/article/pii/S0168169916302629>. Accessed: Jun. 01, 2017. doi: 10.1016/j.compag.2017.04.004.

CROWTHER, M. J. et al. Individual patient data meta-analysis of survival data using Poisson regression models. **BMC Medical Research Methodology**, v.12, n.1, p.34. 2012. Available from: <https://doi.org/10.1186/1471-2288-12-34>. Accessed: Mar. 23, 2012. doi: 10.1186/1471-2288-12-34.

DIAZ, T. R., et al. Socioeconomic determinants that influence the agricultural practices of small farm families in northern Colombia. **Journal of the Saudi Society of Agricultural Sciences**, v.21, n.7, p.440-451. 2022. Available from: <https://www.sciencedirect.com/science/article/pii/S1658077X21001648>. Accessed: Oct. 01, 2022. doi: 10.1016/j.jssas.2021.12.001.

FRANZ, C. M. Essential oil research: past, present and future. **Flavour and Fragrance Journal**, v.25, n.3, p.112-113. 2010. Available from: <https://onlinelibrary.wiley.com/doi/abs/10.1002/ffj.1983>. Accessed: Feb. 09, 2010. doi: 10.1002/ffj.1983.

HEYDARI KOOCHI, Z., et al. Citrus peel waste essential oil: Chemical composition along with anti-amylase and anti-glucosidase potential. **International Journal of Food Science & Technology**, v.57, n.10, p.6795-6804. 2022. Available from: <https://ifst.onlinelibrary.wiley.com/doi/abs/10.1111/ijfs.16031>. Accessed: Aug. 17, 2022. doi: 10.1111/ijfs.16031.

HOJJATI, M.;H. BARZEGAR. Chemical Composition and

Biological Activities of Lemon (Citrus limon) Leaf Essential Oil. **Nutrition and Food Sciences Research**, v.4, n.4, p.15-24. 2017. Available from: <http://nfsr.sbmu.ac.ir/article-1-244-en.html>. Accessed: Oct. 14, 2017. doi: 10.29252/nfsr.4.4.3.

JABBAR, A., et al. Exploring the Impact of Farmer Field Schools on the Adoption of Sustainable Agricultural Practices and Farm Production: A Case of Pakistani Citrus Growers. **Agronomy**, v.12, n.9, p.2054. 2022. Available from: <https://www.mdpi.com/2073-4395/12/9/2054>. Accessed: Aug. 29, 2022. doi: https://www.mdpi.com/2073-4395/12/9/2054.

JARA-ROJAS, R., et al. Adoption of water conservation practices: A socioeconomic analysis of small-scale farmers in Central Chile. **Agricultural Systems**, v.110, p.54-62. 2012. Available from: <https://www.sciencedirect.com/science/article/pii/S0308521X12000510>. Accessed: Jul. 01, 2012. doi: 10.1016/j.agsy.2012.03.008.

KHALID, P. Factors influencing Pakistan essential oil import. . **Agrobiological Records**, v.13, p.53-60. 2023. Available from: <https://doi.org/10.47278/journal.abr/2023.025>. Accessed: Sept. 20, 2023. doi: 10.47278.

KREJCIE, R. V.; D. W. MORGAN. Determining Sample Size for Research Activities. **Educational and Psychological Measurement**, v.30, n.3, p.607-610. 1970. Available from: <https://journals.sagepub.com/doi/abs/10.1177/001316447003000308>. Accessed: Sep. 01, 1970. doi: 10.1177/001316447003000308.

MOTTALEB, K. A. Perception and adoption of a new agricultural technology: Evidence from a developing country. **Technology in society**, v.55, p.126-135. 2018. Available from: <https://www.sciencedirect.com/science/article/pii/S0160791X18300769>. Accessed: Nov. 01, 2018. doi: 10.1016/j.techsoc.2018.07.007.

NAVEED, M. A.; A. HASSAN. Sustaining agriculture with information: An assessment of rural citrus farmers' information behaviour. **Information Development**, v.37, n.3, p.496-510. 2021. Available from: <https://journals.sagepub.com/doi/abs/10.1177/0266666920932994>. Accessed: Sept. 2021. doi: 10.1177/0266666920932994.

NIGUSSIE, Z. et al. Factors influencing small-scale farmers' adoption of sustainable land management technologies in north-western Ethiopia. **Land Use Policy**, v.67, p.57-64. 2017. Available from: <https://www.sciencedirect.com/science/article/pii/S0264837716305099>. Accessed: Sept. 01, 2017. doi: 10.1016/j.landusepol.2017.05.024.

PIERPAOLI, E. et al. Drivers of Precision Agriculture Technologies Adoption: A Literature Review. **Procedia Technology**, v.8, p.61-69. 2013. Available from: <https://www.sciencedirect.com/science/article/pii/S2212017313000728>. Accessed: Jan. 01, 2013. doi: 10.1016/j.protcy.2013.11.010.

RAMIREZ, A. The Influence of Social Networks on Agricultural Technology Adoption. **Procedia - Social and Behavioral Sciences**, v.79, p.101-116. 2013. Available from: <https://www.sciencedirect.com/science/article/pii/S1877042813010288>. Accessed: Jun. 06, 2013. doi: 10.1016/j.sbspro.2013.05.059.

SHER, H., et al. Promoting Sustainable Use of Medicinal and Aromatic Plants for Livelihood Improvement and Biodiversity Conservation under Global Climate Change, through Capacity Building in the Himalaya Mountains, Swat District, Pakistan. **Annals of the Missouri Botanical Garden**, v.102, n.2, p.309-315. 2017. Available from:<https://bioone.org/journals/Annals-of-the-Missouri-Botanical-Garden>. Accessed: Aug. 11, 2017. doi: 10.3417/D-16-00001A.

WHITE, D. S. et al. Technology adoption by resource-poor farmers: considering the implications of peak-season labor costs. **Agricultural Systems**, v.85, n.2, p.183-201. 2005. Available from: <https://www.sciencedirect.com/science/article/pii/S0308521X04001507>. Accessed: Aug. 01, 2005. doi: 10.1016/j.agsy.2004.07.018.

YIGEZU, Y. A. et al. Enhancing adoption of agricultural technologies requiring high initial investment among smallholders. **Technological Forecasting and Social Change**, v.134, p.199-206. 2018. Available from: <https://www.sciencedirect.com/science/article/pii/S0040162517315391>. Accessed: Sept. 01, 2018. doi: 10.1016/j.techfore.2018.06.006.