EFFECT OF POST HARVEST LOSS REDUCTION OF IRISH POTATO ON FOOD SECURITY IN RWANDA

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Abstract

The study aimed to assess the ***effect of post-harvest loss reduction of Irish potato on food security in Rwanda****. Specifically the study aimed to map the key Irish potato value chain actors in Musanze district, to analyse determinants of post-harvest loss of Irish potato in Musanze district and to assess the effect of post-harvest loss reduction of Irish potato on farmers' revenues in Musanze District. The study was conducted in four high potential Irish potato production sectors of Musanze district namely Gataraga sector, Musanze, Busogo and Kinigi sectors. The study covered the total of 112 Irish potato producers including 92 Post Harvest Handling and Storage (PHHS) adopters and 30 non-adopters. The study used primary data collected through structured questionnaires containing quantitative and qualitative parameters. The study used descriptive statistics as well as econometric propensity score matching (PSM) to model and compare the effect of use of Irish potato post-harvest loss reduction interventions on food security among farmers from the study area.* *Data was analysed using Ms excel, SPSS and STATA and modelling. The study found that 11% of the total Irish potato production is lost at farm level with only 89% reaching the different markets outlets. The factors affecting Irish potato post-harvest losses in Musanze district were age of the farmer, farm size, land allocated for Irish potato farming, access to extension services, trainings on PHHS operations, materials used in Irish potato harvesting and storage duration of Irish potato production. For Irish potato production in 2018A, the average Irish potato production was 6.979tons/ha and the mean difference in terms of production ranged from 854.72 kg/ha to 1,039.97 kg/ha. While in season 2018B, the average Irish potato production was 4.3tons/ha and the mean difference in terms of production ranged from 1.18 to 1.19tons/ha the mean difference between treated and control increased from 16.80 Kg/ ha to 374.41 Kg/ha and the production parameter was not statistically significant at 5% level of significance (Insufficient production). For food storage, in season of 2018A, the average quantity of Irish potato stored was 57.69Kg per households while the mean difference was ranging from 56.07Kg to 57.69Kg .while in 2018B there was no farmer who stored any Irish potato. For food consumption, in 2018A the average quantity of Irish potato consumed was 825Kg while the mean difference was ranging from 254.18Kg to 511.54Kg of cooked Irish potato. During the next farming season of 2018B, the average mean quantity consumed was 748.08Kg while the mean difference of treated and control was ranging from 294.29Kg to 542.63Kg using the NNM, KM and RM and all parameters were statistically significant at 5% level of significance. The seasonal findings showed that Average Treatment effect on Treated (ATT) of farmers' revenues per hectare of Irish potato was 1,394,517 Frws/ha and 1,161,103 Frws/ha while the mean difference was ranged from 383,592Frws/ha to 411,854 Frws/ha in 2018A. While in season of 2018B, the mean difference was ranging from 171,816 Frws/ha to 211,577 Frws/ha. All parameters were evaluated based on three matching algorithms including using Nearest Neighbor Matching (NNM), Kernel Matching (KM) and Radius Matching (RM). The study findings also concluded that there is no food security due to price fluctuation and low farmers' revenues that may hamper producer's ability to participate in retail markets outlets and afford dietary needs for their households' members. A need for improve of extensions services to encourage farmers to adopt different physical layout of stores is recommended so as to minimize loss and increase the nutritional status of the Irish potato.*

Key words: Post harvest handling, Storage, Food security and Propensity Score Matching

1. Introduction

On a global scale, Irish potato (*Solanum tuberosum L.*) is the fourth most cultivated food crop after maize, wheat and rice. Globally, it is also the most important tuber crop with higher productivity among root and tuber crops, with an annual total world potato production estimated at 388,191,000 tonnes from an area of 19,302,600ha (FAOSTAT, 2017) . Globally, there are wide regional disparities in Irish potato production; Asia and Europe are the world's major Irish potato producing regions, accounting for more than 80% of global production. Irish potato produces considerably more energy, protein than cereals and it is the fastest growing staple food crop and source of cash income for smallholder farmers. Irish potato cultivation is expanding strongly in the developing world, where its ease of cultivation and nutritive content has made it a valuable food security and cash crop for millions of farmers [1].

The land under Irish potato production in Rwanda rose from 130,000ha to 200,000ha and yield increases up to 846,184tons in 2017 (FAOSTAT, 2019). Irish potato has been cultivated in Rwanda for nearly a century, and most accounts trace introduction of the crop to the arrival of German missionaries in the late 19^{th} century [2]. Since its introduction, Irish potato production have been increasing and it is becoming an important cash and food crop in Rwanda which is currently largest producer in the East African Community countries (EAC) and third largest producer in sub-Saharan Africa (AGRA, 2016). Irish potato is the country's most important crop in income generation and food supply after plantains and one of the main staple crops in terms of growth and yield play of a major role in national food nutritional security (Habimana et al, 2015). In 2011, Irish potato productivity ranged from 12-30mt/ha with potential to reach 40mt/ha [3]

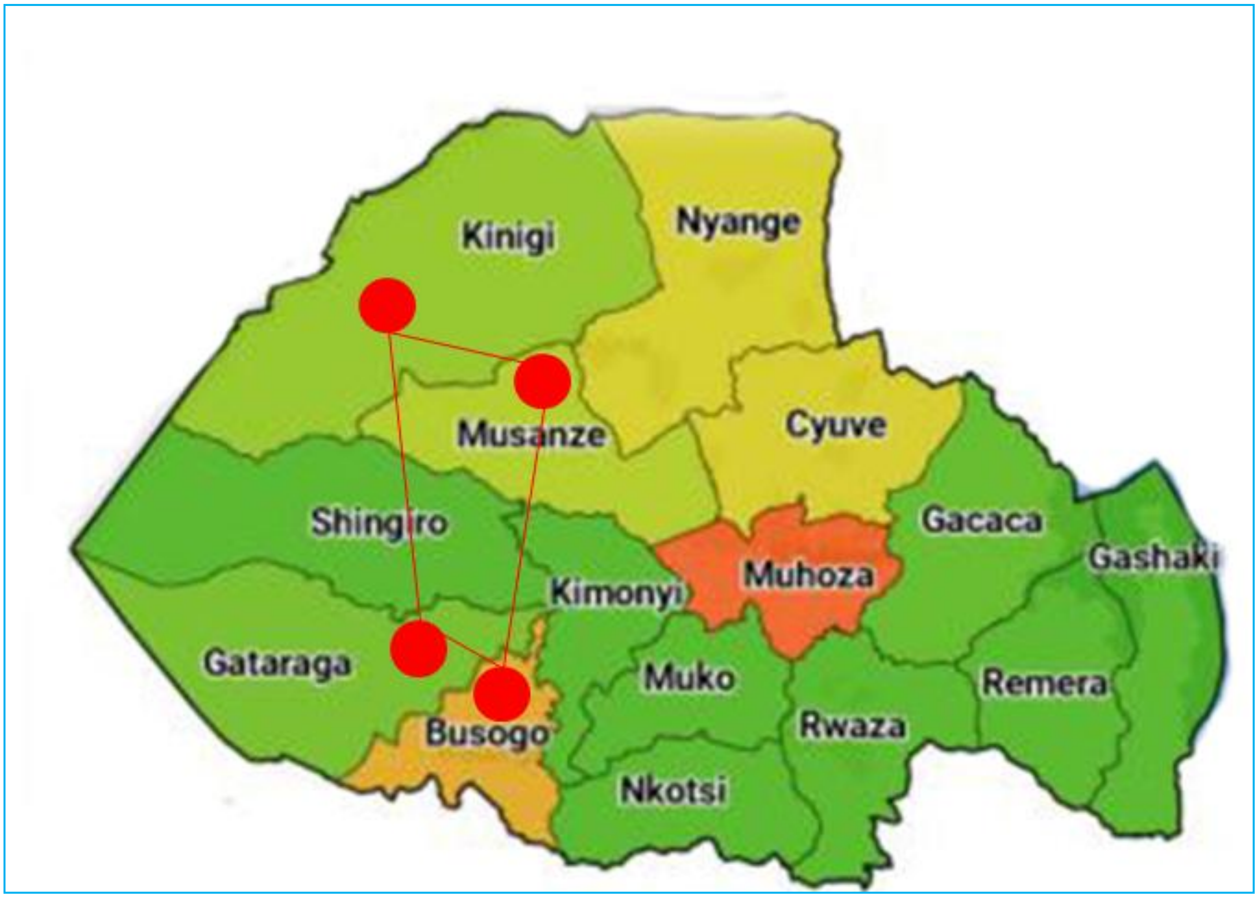
Irish potato is one of the Rwanda government’s six priority crops in its Crop Intensification Program (CIP). The country plans to increase production significantly through better expanding the area under production and increasing the yield per hectare (productivity). The role of Irish potato as a staple food in Rwanda has increased since the mid1960s. Annual per capita consumption rose from 8 kg in 1965 to 40 kg in 1985/86 and to 76 kg in 2000. In rural areas, average per capita annual consumption ranges from 20 kg to 216 kg. The variation in consumption reflects the distribution of production. Urban per capita demand is 141 kg per year, which is unusually high compared to other urban centres in Sub-Saharan Africa. During the period from 1985-2000, urban consumption of Irish potato, bread and rice rose sharply, while that of traditional food staples (sweet potatoes, beans, cassava, maize and sorghum) decreased[4]. In Rwanda, the low productivity of Irish potato is constrained primarily by use of low quality seeds. The districts of Musanze, Burera, Nyabihu, Rubavu and Gicumbi are net exporters of Irish potato to other parts of Rwanda [4]. Rwanda is the 6th largest producer of potatoes in East African Community Countries which is significant given the relative land size of the country for the Irish potato production. The country plans to increase production from the current (2013) 2,240,000 Mt per year to 6,000,000 Mt per year by 2019 by expanding the area under potato production from 130,000 in 2010 to 200,000ha and yield increases. The demand for potato chips (the main use of potatoes in the processing sector) is growing rapidly as a result of a change in eating habits as well as the increase in urbanization, fast food restaurants and tourism [5]. Lack of Post-harvest handling storage facilities for Irish potato y will make producers fail to only plan next farming season but also to eradicate hunger from homestead. To date Rwanda has storage facilities with the capacity to handle a total of 311, 295 tons of food crops grains and six cold storage facilities for fruits spread across the country, each handling 140 tons per day. To mitigate the challenges there is a need of effort to have storage facilities constructed for farmers as a solution to the problem of postharvest management. Improving the productivity and profitability of smallholder farmers is the main pathway out of poverty in agriculture development [6] and this can reduce poverty and improve household welfare through increased income[7]. Though smallholder farmers are increasingly being recognized as important contributors for global food security, smallholder's production is fraught with challenges, including low yields, low quality of crops, lack of access to markets and credit. Securing capital to purchase inputs, invest in post-harvest handling and storage equipment to increase the quality of produces to markets is a challenge that smallholder farmers face every harvest season [8]. TTo date no specific study has been conducted in Rwanda to assess the effect of Irish potato post-harvest losses reduction on food security in Rwanda. This study aimed to close that knowledge gap by focussing on mapping the key players of Irish potato value chain actors in Musanze district, to analyse determinants of Irish potato post-harvest losses and to assess the effect of Irish potato post-harvest losses on farmers' revenues.

2. Materials and methods

2.1 Description of the study area

Musanze district is located in the Northern Province of Rwanda with geographical coordinates of 1°29'59.4" S 29°38'5.9" E respectively. The district has a population of 398,986 and is divided into 15 sectors; Busogo, Cyuve, Gacaca, Gashaki, Gataraga, Kimonyi, Kinigi, Muhoza, Muko, Musanze, Nkotsi, Nyange, Remera, Rwaza and Shingiro. The study was conducted in four sectors of Musanze district namely Gataraga, Busogo, Musanze and Kinigi sectors which are high potential in Irish potato production where in the study area as a whole.

Figure: Map of Musanze district showing sampled sectors



Legend: ⬤= Sampled sites

2.2 Methodology used

The study aimed to assess the effect of Irish potato post-harvest loss reduction on food security in Rwanda. For simplicity, the researchers selected four sectors with high potential for Irish potato production (Gataraga, Busogo, Musanze and Kinigi sectors). Multistage sampling techniques were used to select 112 individuals using a structured questionnaire. Descriptive statistics were used to characterize farmers and T-tests were also used to compare means of households' characteristics. Econometric methods were employed to analyse data using STATA version 13. Propensity score matching model was used to determine the effect of Irish potato post-harvest losses reduction on food security in Rwanda.

2.3 Statistical data analysis

2.3.1 Descriptive statistics analysis

Descriptive statistics such as means, standard deviation and percentages were used during the analysis of the study.

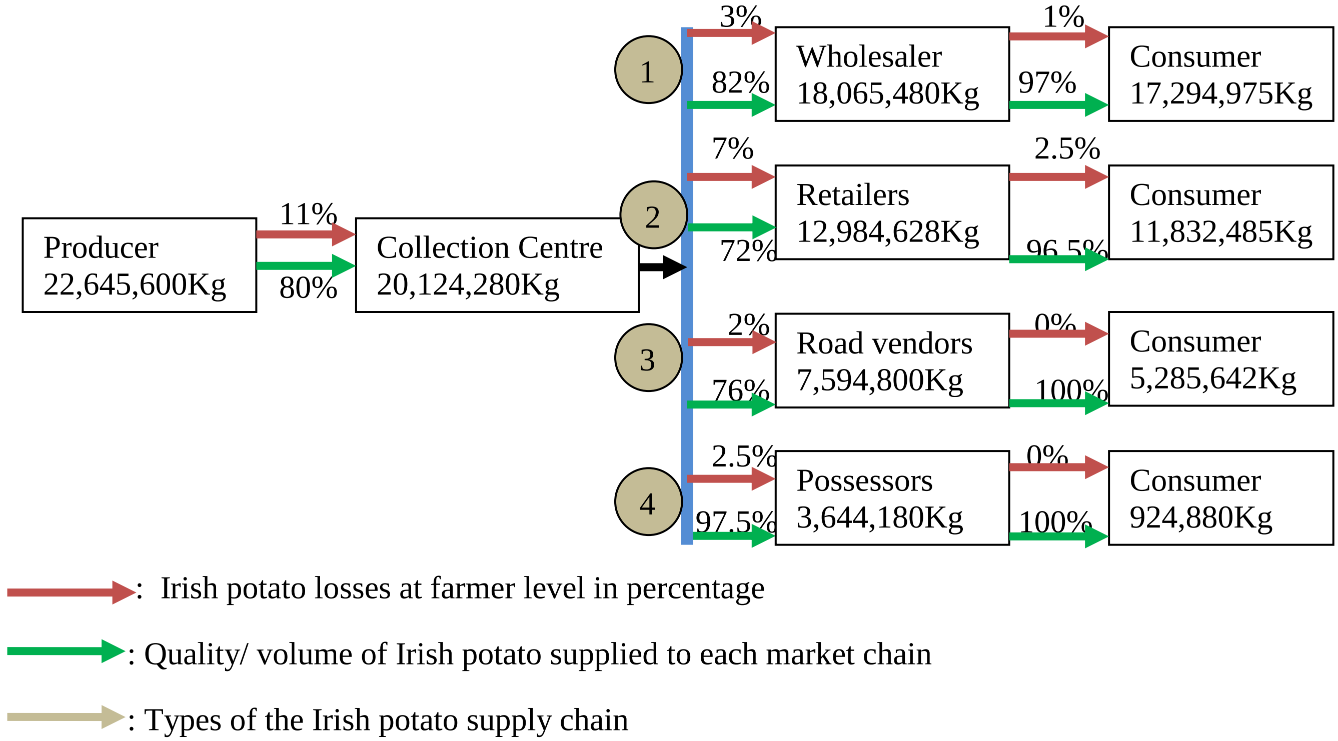
2.3.2 Application of Propensity score Matching (PSM)

Based on background and objective developed in section in section 1, the Psmatch 2 estimator was used to estimate propensity score matching for adopters and non- adopters of PHHS infrastructures to reduce post-harvest losses from Irish potato production. The dependent variable in this model is a binary variable/ dummy variable where a farmer was using any PHHS equipment in Irish potato Post harvest operations (Harvesting→End users) or not. The potential outcome framework is used to assess the effect of Irish potato post-harvest losses reduction on food security in Rwanda. Under the potential outcomes framework, each population unit with an observed outcome y has *ex-ante* two potential outcomes: an outcome when receiving a treatment and an outcome when not receiving a treatment. Here the treatment is a farmer who used any PHHS equipment in the last season of 2018 A and B. Let D_j be the binary variable indicating the being the farmer with production j with $D_j=1$ indicating the farmer adopted any PHHS infrastructure and D_j=0 indicating a counter factual by a population unit. Also, let $y_1 \equiv g(d_j^1, z)$ and $y_0 \equiv g(0, z)$ be the potential outcomes corresponding to the two mutually exclusive states of farmer adopted any PHHS infrastructure and their counter parties (non- adopters). For any population unit, the causal effect of PHHS use on the outcome y is defined $= y_1 - y_0$. However, the two potential outcomes cannot be observed at the same time. However, if we let Y be the random variable defined in some probability space (Ω, ∑, P) reflecting the distribution in the population of the outcome represented by the outcome variable y[1], then the average causal effect of adoption in the population, $E(Y1\ \text{-}Y0\ )$ (with E being the mathematical expectation operator), can be determined. Such a population parameter is called the average treatment effect (ATE) in the literature. One can also estimate the mean effect of the credits users on the sub-population group: $E(y_1 - y_0 \mid D_j = 1)$, which is called the average treatment effect on the treated and is usually denoted by ATT which are the adopters of PHHS technology. The average treatment effect on the *untreated*: $E(y_1 - y_0 \mid D_j = 0)$ denoted by ATU is another population parameter that can be defined and estimated. The population means impact parameters ATE, ATT, ATU can generally be identified under some statistical independence assumptions between the population distributions of the treatment status variable *D* and the two potential outcomes Y_1 and Y_0 (possibly conditional on some observed random vector X of covariates). Two alternative statistical independence assumptions are made to identify ATE, ATT and ATU [9]. The first one is the unconditional independence assumption: The population distribution of *D* is independent of that of Y_1 and Y_0. Under this assumption, ATE, ATT and ATU are identified by the mean difference of observed outcomes of credits user and counterfactual: $MD = E(Y \mid D = 1) - E(Y \mid D = 0)$ and this is easily estimated by its sample analogue. The second assumption is the *conditional independence* assumption also called "selection on observables", whereby the population distribution of *D* is independent of that of conditional on some observed component X of the vector $(a^*_{(N)}, Z)$ of exogenous and endogenous random variables whose values do not depend on a_N Under this assumption the conditional mean treatment effects are all identified by the conditional mean difference of observed outcomes. The Mean difference computation is$MD(X) = E(Y \mid X = x, D = 1) - E(Y \mid X = x, D = 0)$ and ATE, ATT and ATU are identified by the mean of MD(x) over x in the full population, the subpopulation with *D* =1 and the subpopulation with *D*=0, respectively. Several estimators are used to estimate MD(x) [9]. These include: 1) matching estimators (nearest neighborhood covariates matching, propensity score matching, genetic matching and coarsened exact matching, etc.); 2) regression-based estimators including parametric (OLS/NLS) and non-parametric (kernel, polynomial series, etc.); 3) inverse probability weighting (IPW) estimators; and 4) hybrid estimators which combine matching and regression or IPW and regression (the doubly robust estimator).

3. Results and Discussion

3.1 To map the key players of Irish potato value chain actors in Musanze district

To map the key players of Irish potato value chain actors in the study area, the researcher considered the channel assessment which was made primarily on volume parameters supplied to each market channel. Supply chain channels as mapped in figure 2 was developed from supply chain players' assessment. There were four main supply chain channels for Irish potato produce operating within national level markets in Rwanda. The total annual quantity of Irish potato obtained from the farm gate was 22,465,600 kg (100 percent) of the four sampled sectors of Musanze district (seasons of 2018A and 2018B). The researcher only was interested on the evaluation of Post-harvest losses at farmer level and the findings revealed that 11% of the total Irish production is lost at farm level while only 80% is supplied to markets and 9% is consumed at homestead.



3.2 To analyse determinants of Irish potato post-harvest losses in Musanze district

The econometric findings from logistic regression model run of psmact2 estimator with the dependent variable of PHHS equipment use for farmers involved in Irish potato farming in the study area is shown in table 1. The factors that may affect Irish potato losses at farmer included the socio-economic factors, institutional factors and economic factors as well as other intervening or moderating factors. The econometric findings from Logit model results on the factors that affected Irish potato post-harvest losses in Musanze district were age of the farmer, farm size, proportion of land allocated for Irish potato farming, access to extension services, trainings on PHHS operations, materials used in Irish potato harvesting and storage duration of Irish potato production and were statistically significant at 1%; 5% and 10% level of significance respectively for smallholder farmers in the study area.

The results from logit model showed that age of the Irish potato producer affected positively the use of PHHS equipment and hence once there is an increase of one year to the age of the farmer up to 0.66% level of probability, the users of PHHS equipment and associated infrastructures increased by 1.09% of the total available users of such equipment.

The results also showed that there is a positive correlation between farm size and use of PHHS equipment/ infrastructures which implies that for an addition of one hectare of land a to the farm size owned by the farmer up to 0.39% level of probability, the user of PHHS infrastructures increased by 0.67 percent . Farmers with that bigger farm size are more likely to harvest lager crop production compared to farmers with small land. Furthermore, the findings also showed that there is negative relationship between proportion of land allocated for Irish potato farming and use post-harvest handling and storage equipment. This implies that farmers could not invest in PHHS equipment if they are harvesting a small quantity of Irish potato production and productivity. Unexpectedly, results from logit model indicated negative relationship between access to extension services and the use of PHHS equipment in the study area. The negative correlation implies that most extension agent do not cover the entire group of Irish potato producers in Musanze district. Unexpectedly, the inadequate number of extension agent will affect the increase in the number of extension visits, which therefore significantly and negatively affected use of PHHS tools and equipment and accessibility to nearby infrastructures ($p=0.078<0.1$). The marginal effect result indicated that lower extension visit by once time month would decrease the likelihood of farmers to use PHHS equipment by 0.49 percent from the total users. These findings are in line with [10] that confirmed that access to dairy extension services such as dairy techno- logy, information, training, field days, field visits and field tours received by households positively and significantly affected market outlet in Rwanda. As priori expectation, the findings from logit model indicated that there is positive correlation between trainings on post-harvest handling operations and the use of PHHS equipment which imply that one unit increase to trainings received by farmers on PHHS operations up to 0.38% level of probability, connects to an increase of 45.8 users of post-harvest handling equipment in the study area. Normally trainings increase the capacity of the farmers in terms of skills and knowledge. This indicates that farmers participating in training acquire sufficient knowledge and skill about the use of advanced of Irish potato post-harvest technology and these findings agree with the research findings of [11]. As expected, results from the logit model showed that materials used in harvesting negatively affect the use of PHHS equipment which may lead to farmer's experiencing any post-harvest losses of the Irish potato production chain in the study area. The negative correlation implies that most of the Irish potato producers were not aware to prepare for the harvesting period by organizing all needy materials to increase the quality of Irish potato produces such as bags, machete and tarpaulins to help the reduction of PHHS losses Improper utilization of PHHS equipment may deteriorate the physiological aspects of the Irish potato produce which lead to poor quality and spoilage. Therefore due to technological advancement, mechanical potato harvesters are being and perceived to reduce the post-harvest losses by improving also the quality of Irish potato to meet the market demand. These findings are consistent with the research findings of [12].. As *priori* expectation, the results indicate negative relationship between times used to store the Irish potato before selling and the use of post-harvest equipment to reduce losses in the study area. This means that one unit year increase in the time to store Irish potato in the store up to 0.32% level of probability, the production of commodity stored decreased by 4.86 percent from the total farmers users of PHHS equipment in Musanze district. This is an implication that long storage of Irish potato may lead to deterioration in the physical and chemical composition of the commodity including color size and chemical composition.

Table 1: Determinants of Post-harvest handling and Storage use equipment

Use of Post-harvest handling equipment	*Coef.*	*Std. Err.*	*z*	*P>/z/*
Gender	2.347225	1.80083	1.3	0.192
Age of the farmer	**0.109406**	**0.059593**	**1.84**	**0.066**
Marital status	-1.25223	0.858386	-1.46	0.145
Family size of Household	-0.24351	0.286253	-0.85	0.395
Education level	-0.00835	0.247108	-0.03	0.973
Farming experience	0.060917	0.074561	0.82	0.414
Distance to main road	-0.00326	0.075029	-0.04	0.965
Distance to markets	0.002697	0.042501	0.06	0.949
Distance to financial institutions	-0.00849	0.040315	-0.21	0.833
Distance to nearest water source	0.000564	0.016399	0.03	0.973
Farm size in Ha	**0.067434**	**0.032741**	**2.06**	**0.039**
Land allocated for Irish potato farming	**-0.08244**	**0.0415**	**-1.99**	**0.047**
Access to credits	-0.01795	0.018254	-0.98	0.326
Access to extension services	**-0.04863**	**0.027645**	**-1.76**	**0.079**
Trainings on diseases management	2.21115	1.396884	1.58	0.113
Trainings on PHHS operations	**4.576269**	**2.208121**	**2.07**	**0.038**
Materials used in Irish potato harvesting	**-0.5487**	**0.02364**	**-1.06**	**0.04****
Mode of transport of Irish potato	-0.8096	0.12754	-3.46	0.641
Storage duration of Irish potato	**-0.4863**	**0.41683**	**-2.05**	**0.032****
_cons	-3.55927	3.519702	-1.01	0.312
Logistic regression				
Number of Obs	=			63
Prob > chi2	=			0.0008
LR chi2(17)	=			41.29
Pseudo R2	=			0.4749
Log likelihood	=			-22.8269

Note: *, ** and *** are statistical significance levels corresponding to 10%, 5% and 1%

3.3 Assessing the effect of Irish potato post-harvest losses on farmers' revenues in Musanze District

The food security situation as defined as a measure of food availability, food accessibility and food utilization which makes the analysis once dietary consumption and rate of nutrients contents. To better understand the current food security situation, the following sub headings were taken into consideration.

3.3.1 Irish potato production by ATT covariates matching estimates

The Irish potato production of small holder farmers in the study area is shown in table 2. Except the productivity parameter and area allocated for Irish potato production, other factors were considered constant and only the researcher talked about production of Irish potato between the users and non-user of PHHS equipment/ infrastructures by comparing the yield outcomes and were compared from season of 2018A and 2018B. The effect on increased production were computed using the three matching algorithms namely, nearest neighbour matching (NNM), kernel matching (KM) and radius matching (RM) as shown in table 2 and ATT values were presented by types of matching logarithms to estimate average yield and mean difference as program impact on increased production from Irish potato growers adopted PHHS technological package. During 2018A, the average Irish potato production was 6979.31kg/ha or 6.979ton/ha and the mean difference in terms of production was 933.62 kg/ha; 854.72 kg/ha and 1,039.97 kg/ha using NNN, KM and RM and all estimates were not statistically significant at 5% level of significance. During the next farming season of 2018B, the average Irish potato production was 4,327.59kg/ha or 4.3tons/ha and the mean difference in terms of production was 1,179.37 kg/ha; 1,779.44 kg/ha and 1,195.89 kg/ha using NN, KM and RM respectively. The mean difference between treated and control increased from -806.37Kg/ha; 16.80 Kg/ ha and 374.41 Kg/ha using NN, KM and the production parameter was not statistically significant at 5% level of significance. This is an implication that low level of Irish potato productivity lead to food insecurity in the sampled sectors of Musanze district and these agree with the research conducted by [13].

Table 2: ATT estimates of Irish potato production for food security

Variable	Sample	Treated	Controls	Difference	S.E.	T-stat
Nearest Neighbor Matching (NNM)						
Yield (2018A)	Unmatched	6,979.31	6,361.76	617.55	1,062.92	0.58
	ATT	6,979.31	6,045.69	933.62	1,796.26	0.52
Yield (2018B)	Unmatched	4,327.59	4,577.94	(250.35)	1,391.82	-0.18
	ATT	4,327.59	3,148.22	1,179.37	2,476.05	0.48
Kernel matching (KM)						
Yield (2018A)	Unmatched	6,979.31	6,361.76	617.55	1,062.92	0.58
	ATT	6,979.31	6,124.59	854.72	2,108.81	0.41
Yield (2018B)	Unmatched	4,327.59	4,577.94	(250.35)	1,391.82	-0.18
	ATT	4,327.59	2,548.15	1,779.44	2,811.49	0.63
Radius Matching (RM)						
Yield (2018A)	Unmatched	6,979.31	6,361.76	617.55	1,062.92	0.58
	ATT	6,979.31	5,939.34	1,039.97	1,807.19	0.58
Yield (2018B)	Unmatched	4,327.59	4,577.94	(250.35)	1,391.82	-0.18
	ATT	4,327.59	3,131.70	1,195.89	2,402.80	0.5

3.3.2 Storage of Irish potato for food security

Table 3 pertained to quantity of Irish potato stored by farmers of the sampled sectors from Musanze district. The results were obtained by comparing framers who could not sell directly (counter factual) their produces to their treated group (famers who store) their harvested crop for curtain period of time. In season A of 2018, the average quantity of Irish potato stored was 57.69Kg per household while the mean difference was 57.69Kg; 56.07Kg and 55.93Kg using NNM, KM and RM and all estimates were statistically significant at 5% level of significance. While in season B of 2018, no farmers stored Irish potato. In Rwanda Irish potato producers are not familiar with potato storage. Typically, they do so to save the seeds for the next farming season as opposed to storage of commercial purpose and our results agree with research by Okonkwo et.al (1995) reported that Irish potato losses can be as high as 70% during a four months storage period. Thus to handle the matter, there is a need to increase the dissemination of technological package from government extension agents and other partners engaged in Irish potato chain to improve storage structures like cold chain rooms at collection points and other storage management skills.

Table 3: Quantity (Kg) of Irish potato storage by households, by ATT covariates

Nearest Neighbor Matching (NNM)						
Variable	Sample	Treated	Controls	Difference	S.E.	T-stat
Quantity stored 2018A	Unmatched	234.1463	3.092784	231.0536	53.93477	4.28**
	ATT	57.69231	0	57.69231	31.94855	1.81**
Quantity stored 2018B	Unmatched	197.561	0	197.561	53.62281	3.68**
	ATT	0	0	0	0	.
Kernel matching (KM)						
Quantity stored 2018A	Unmatched	234.146341	3.09278351	231.053558	53.93477	4.28**
	ATT	57.6923077	1.6257775	56.0665302	32.01933	1.75**
Quantity stored 2018B	Unmatched	197.560976	0	197.560976	53.62281	3.68**
	ATT	0	0	0	0	.
Radius Matching (RM)						
Quantity stored 2018A	Unmatched	234.1463	3.092784	231.0536	53.93477	4.28**
	ATT	57.69231	1.758936	55.93337	32.0123	1.75**
Quantity stored 2018B	Unmatched	197.561	0	197.561	53.62281	3.68**
	ATT	0	0	0	0	.

3.3.3 Annual consumption of Irish potato food consumption

The study also sought to assess the monthly consumption of Irish potato per family household in the study area. The results were compared for users and non-users of Irish potato PHHS equipment during storage. We can divide the year into two seasons (2018A and 2018B). From the season of 2018A, average quantity of Irish potato consumed was 825Kg per while the mean difference was ranging from 511.54Kg, 303.09Kg and 254.18Kg of cooked Irish potato using NNM, KM and RM logarithms for users of PHHS equipment. During the next farming season of 2018B, the average mean quantity consumed was 748.08Kg while the mean difference of treated and control was 542.63Kg; 337.9Kg and 294.29Kg using the NNM, KM and RM and all parameters were statistically significant at 5% level of significance.

Table 4: Seasonal Irish potato consumption by ATT estimates

Variable	Sample	Treated	Controls	Difference	S.E.	T-stat
Nearest Neighbor Matching (NNM)						
Quantity consumed 2018A	Unmatched	632.9268	535.567	97.35982	157.0443	0.62
	ATT	825	313.4615	511.5385	144.0862	3.55**
Quantity consumed 2018B	Unmatched	580.4878	441.5464	138.9414	120.6821	1.15
	ATT	748.0769	205.4487	542.6282	146.1239	3.71**
Kernel matching (KM)						
Quantity consumed 2018A	Unmatched	632.926829	535.56701	97.359819	157.0443	0.62
	ATT	825	521.911731	303.088269	180.1684	1.68**
Quantity consumed 2018B	Unmatched	580.487805	441.546392	138.941413	120.6821	1.15
	ATT	748.076923	410.176017	337.900906	164.5435	2.05**
Radius Matching (RM)						
Quantity consumed 2018A	Unmatched	632.9268	535.567	97.35982	157.0443	0.62
	ATT	825	570.8154	254.1846	176.6594	1.74**
Quantity consumed 2018B	Unmatched	580.4878	441.5464	138.9414	120.6821	1.15
	ATT	748.0769	453.7878	294.2891	162.5843	1.81**

3.3.4 Intra seasonal price fluctuation of Irish potato by ATT covariates estimation

Although high prices can technically be good news for farmers, price fluctuation is extremely dangerous, as farmers and other agents in the food chain risk losing their investments if prices fall. Table 3 indicated the price fluctuation for Irish potato during 2018A, 2018B and their effect among the treated groups is shown in table 5. In season of 2018A, the average price of Irish potato was 177 Frws/ Kg and the mean difference for users was ranging from 29.09 Frws/Kg, 49.84 Frws/Kg, and 29.78 Frws/Kg, using NNN, KM and RM. In the next season of 2018B, the average mean farm gate price for Irish produce was 112Frws/ Kg and the mean difference for users ranged from -3.19 Frws/Kg, 13.55 Frws/Kg and -2.92 Frws/Kg using NN, KM and RM and all prices in two seasons were not statistically significant at 5% level of significance compared to t-stat computed values. The current findings are in line with the last Irish potato price of 2018 where in the previous season, the farm gate price was between Rwf150 and Rwf160/kg for Kinigi variety which is the highest for while consumers would pay Rwf210 and Rwf215/kg for the retail markets in Kigali. The price for other potato varieties was Rwf130 Rwf135/kg to farmers with retailing at Rwf180 to Rwf185/kg in Kigali. Low farm gate price also led to farmers' inability to buy other daily needs for their homes which after food security. The explanation of negative sign for price is that most of Irish potato producers do not adopt PHHS equipment and poor infrastructures during the storage process for at least a period of three months after crop harvesting to reach the expected market price.

Table 5: ATT estimates of Irish potato farm gate price (Frws/kg) for food security

Variable	Sample	Treated	Controls	Difference	S.E.	T-stat
Nearest Neighbor Matching (NNM)						
Price (2018A)	Unmatched	176.90	144.41	32.48	12.81	2.54
	ATT	176.90	147.80	29.09	15.34	1.9
Price (2018B)	Unmatched	112.41	90.74	21.68	22.72	0.95
	ATT	112.41	115.61	(3.19)	35.80	-0.09
Kernel matching (KM)						
Price (2018A)	Unmatched	176.90	144.41	32.48	12.81	2.54
	ATT	176.90	127.05	49.84	28.07	1.78
Price (2018B)	Unmatched	112.41	90.74	21.68	22.72	0.95
	ATT	112.41	98.86	13.55	42.73	0.32
Radius Matching (RM)						
Price (2018A)	Unmatched	176.90	144.41	32.48	12.81	2.54
	ATT	176.90	147.12	29.78	23.72	1.26
Price (2018B)	Unmatched	112.41	90.74	21.68	22.72	0.95
	ATT	112.41	115.34	(2.92)	36.93	-0.08

3.3.5 Farmers' revenues from Irish potato production by ATT estimates for food security

The farm gross margin from investment in Irish potato production is shown in table 6. In all two farming season of 2018A and 2018B. The seasonal findings from PSM after ATT showed that the average farmers' revenues per hectare of the farmers was 1,394,517 Frws/ha and 1,161,103 Frws/ha using NNN, KM and RM matching logarithms. Based on propensity scores matching logarithms, the mean difference differ seasonality and according to matching logarithms. In 2018A, the mean difference ranged from 383,592Frws/ha; 411,854 Frws/ha and 396,722 Frws/ha using NNM, KM and RM in season of 2018B, the mean difference ranged from 171,816 Frws/ha; 211,577 Frws/ha and 200,606 Frws/ha and all estimates were not statistically significant at 5% percentage level of significant. The high farm gross margin is a result of joint action of Irish potato cooperatives and their collection centres which reduce local traders and middlemen to buy their produce at unpredicted price and other subsidies to farmer groups.

Table 6: Farm gross margin (Frws/kg) analysis based on ATT propensity score matching

Variable	Sample	Treated	Controls	Difference	S.E.	T-stat
Nearest Neighbor Matching (NNM)						
Revenues (2018A)	Unmatched	1,394,517.24	1,059,147.06	335,370.18	160,031.05	2.1
	ATT	1,394,517.24	1,010,925.29	383,591.95	257,217.87	1.49
Revenues (2018B)	Unmatched	1,161,103.45	1,022,235.29	138,868.15	177,998.35	0.78
	ATT	1,161,103.45	989,287.36	171,816.09	284,621.27	0.6
Kernel matching (KM)						
Revenues (2018A)	Unmatched	1,394,517.24	1,059,147.06	335,370.18	160,031.05	2.1
	ATT	1,394,517.24	982,662.93	411,854.32	329,951.92	1.25
Revenues (2018B)	Unmatched	1,161,103.45	1,022,235.29	138,868.15	177,998.35	0.78
	ATT	1,161,103.45	949,526.21	211,577.24	346,052.11	0.61
Radius Matching (RM)						
Revenues (2018A)	Unmatched	1,394,517.24	1,059,147.06	335,370.18	160,031.05	2.1
	ATT	1,394,517.24	997,794.97	396,722.27	281,142.24	1.41
Revenues (2018B)	Unmatched	1,161,103.45	1,022,235.29	138,868.15	177,998.35	0.78
	ATT	1,161,103.45	960,497.29	200,606.16	297,501.60	0.67

3.3.6 Densities of the estimated propensity score over treatment and control

Figure 2, presents the results of the covariate balancing test to verify the hypothesis that both groups have the same distribution in covariates after matching. It presents the covariates' means, their t-test of differences in means as well as the percentage bias before and after matching, for all covariates, the matched sample means are almost similar for both the treatment and the control. The graph shows that no treated Irish potato producers are out of support region indicating that all the treated in Irish potato growers using PHHS equipment/ infrastructures were appropriate matched among the counter factual hence all the treated and the untreated individuals were found within the same region of common support, showing that the whole assumption of common support was satisfied [14].

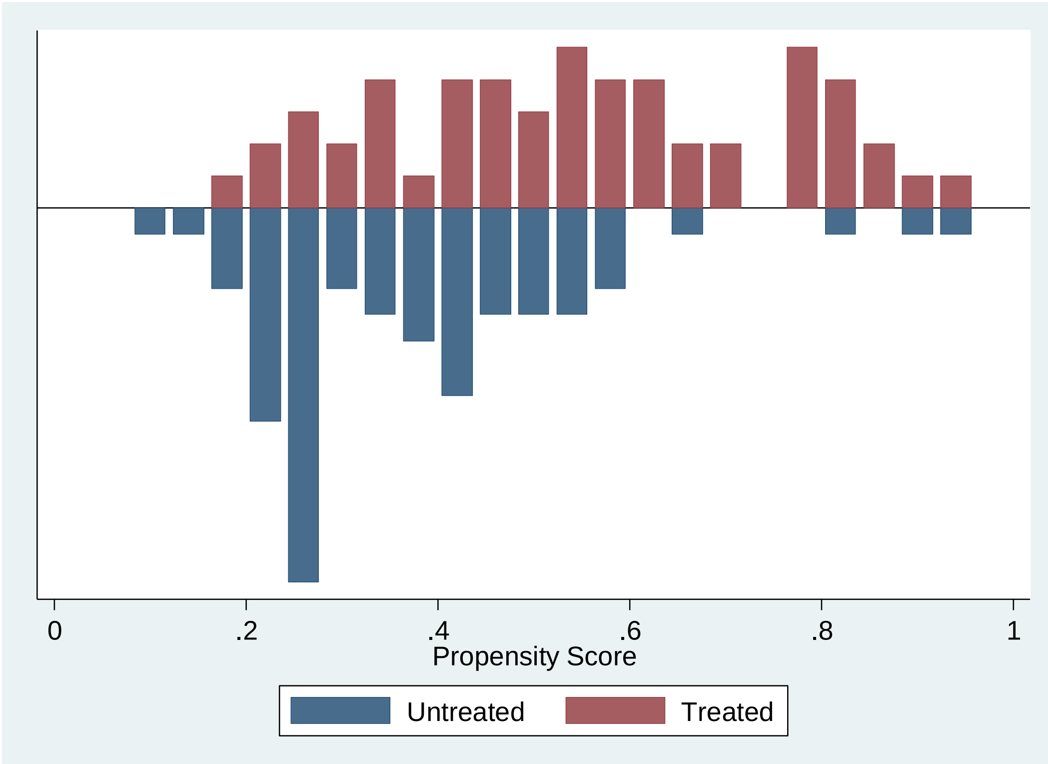


Figure 2: Densities of the estimated propensity score over treated and control groups

Conclusion and recommendations

The study used the Propensity score matching to assess the Irish potato post-harvest losses reduction among small scale famers for food security. The study concluded that 11% of the total Irish production is lost at farm level while only 80% is supplied to markets and only 9% is consumed by farmers. The factors that affected Irish potato post-harvest losses in Musanze district were age of the farmer, farm size, proportion of land allocated for Irish potato farming, access to extension services, trainings on PHHS operations, materials used in Irish potato harvesting and storage duration of Irish potato production and were statistically significant at 5% and 10% level of significance respectively for smallholder farmers in the study area. The study finding also concludes that the food security is affected by price fluctuation and farmers' low revenues that may hamper producers participating in retail markets outlets and creating dietary needs for their households' members.

The study findings suggestions

The following recommendations may results for better management of potato storage:

- Improvements to storage system layout should be achieved by considering the various aspects of marketing strategies and the existing facilities.
- The ideal atmosphere for optimum Irish potato storage conditions should be maintained for the different varieties of Irish potatoes grown in different soils profile.
- The extension services from public and private institutions should be improved to encourage Irish potato producers to sell at better farm gate price which in turns, increase the farmer's profit.
- Irradiation technique that can significantly improve the storage life of Irish potato commodities should be adopted.

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