International Journal of Food and Agricultural Economics
ISSN 2147-8988, E-ISSN: 2149-3766
Vol. 8, No. 1, 2020, pp. 1-20

QUALITY MANAGEMENT AND THE ECONOMICS OF GREEN COFFEE HERMETIC STORAGE

Natalie K. Donovan
Strategic Sourcing Analyst, Abbott Nutrition, 2900 Easton Square Place
Columbus, OH 43219, USA

Kenneth A. Foster
Purdue University, Department of Agricultural Economics, 403 W. State Street,
West Lafayette, IN 47907, USA, Email: kfoster@purdue.edu

Carlos Alberto Parra Salinas
Universidad de Caldas, Faculty of Agricultural Sciences
Manizales, Caldas, Colombia

Abstract

Coffee (Coffea arabica L.) is an important agricultural product in Colombia accounting for 16 percent of agricultural GDP. Issues of high humidity in the Central Andean Mountain Range make managing post-harvest product quality a challenge. In fact, Colombian coffee farmers do not store coffee due to the climate and the lack of affordable storage technologies. This research analyzes the economic potential of hermetic storage of green coffee in the Central Andes region of Colombia. Seasonality in prices, the effectiveness of Purdue Improved Crop Storage (PICS) bags, and reuse of the bags lead to positive net economic benefits related to adopting this quality management approach. The estimated discounted net economic returns are between 1,480 COP ($0.50 USD) and 4,895 COP ($1.70 USD) per 50 kg bag over a three year expected life or approximately 329,327 COP ($113.50 USD) to 1,089,089 COP ($375.50 USD) for the average sized Colombian coffee farm's total expected production.

Keywords: *Coffee; Coffee Prices; Hermetic Storage; Quality Management; Seasonality*
JEL Codes: *Q11, Q13*

1. Introduction

Agricultural investments are on the rise in Colombia due to the newly formed peace accords between the Colombian government and the Revolutionary Armed Forces of Colombia (FARC) (Beeckmans & Emsden, 2016). Governmental programs, including agricultural subsidies, rural credit schemes, agritourism enhancement, and food and nutrition programs, focus on creating an attractive and vibrant rural economy that reduces the volatility of agricultural incomes. These programs provide producers of illegal crops, such as coca and opium poppy, opportunities to adopt alternative crops that the government hopes will decrease drug trade and the corresponding violence (Beeckmans & Emsden, 2016) as well as enhance the country's reputation. Coffee (*Coffea arabica L.*), a leading Colombian export, is one of the replacements crops proposed in this transition. With coffee production representing 16 percent of the country's GDP and with an estimated 600,000 Colombian coffee farmers, coffee is an important commodity when attempting to raise rural economic well-being and limit the drug trade (Gilbert & Gomez, 2016). The increase in agricultural investments and focus on new beginnings presents a favorable opportunity for technological innovation and economic revitalization in Colombia's coffee sector.

Agricultural investment is rising and producers have a strong support network in Colombia through cooperatives and the Federación Nacional de Cafeteros de Colombia (FNC) that provide extension education and technological research. FNC operates via 34 cooperatives with 530 purchasing points throughout the country. However, coffee farmers still face significant challenges during production and processing due to weather, small scale of production, and the lack of infrastructure.

Processing begins when coffee cherries are picked from coffee trees by hand. The coffee cherries are then deskinned and depulped, taking the meat of the cherry away from the bean or seed inside. A sticky film covers the beans, which is then washed away with water or fermented away over time. The coffee is then dried to 10-12 percent moisture content (mc), resulting in green coffee. Due to the small scale of production and limited resources of farmers, most Colombian coffee is dried using passive solar methods. High humidity in Colombia's Central Mountain Range, where the majority of coffee production takes place, plagues coffee farmers and cooperatives during drying and storage. The high humidity makes passive solar drying to the desired 10-12 percent moisture content difficult and, once dry, green coffee easily reabsorbs moisture from the humid environment.

High moisture content green coffee (>14 percent) may illustrate off-flavors, undesirable aroma, and mold during storage that adversely affect the final product's quality even after roasting. The success of Colombia's coffee industry rests heavily on the management of quality and the adoption of consistent processing and marketing processes. For this reason, cooperatives in Colombia will not purchase coffee beans containing 14 percent moisture content or greater. Farmers typically redry these beans but redried beans are generally lower quality and receive no or lower price premiums after scoring by sensory experts. Often such coffee goes to the low-value instant coffee market. For these reasons and due to a lack of affordable storage technologies, small-scale Colombian coffee farmers do not store coffee and cooperatives try to minimize the time coffee is stored in warehouses.[1] The situation leads to potentially unnecessary and costly management challenges related to logistics and product quality.

Green coffee in Colombia is traditionally stored and transported in woven jute sacks that do little to protect the beans from moisture or insect damage. This forces coffee farmers to sell their yield immediately after drying and to accept lower harvest-time prices. The volatility of the international coffee market, low prices, and the inability to store increases the risk of coffee farming and leaves farmers vulnerable until the next harvest period. While farmers are able to sell their green coffee immediately after harvest, cooperatives must collect enough volume to be eligible for export and are left exposed to potential moisture damage.

While coffee contains some nutritionally key minerals, B vitamins, and antioxidants, demand is primarily associated with the taste and aroma experiences of consumers. Thus, maintaining green coffee quality during production, processing, transportation, and storage is essential. Colombia's strong position as one of the world's leading exporters of premium arabica coffee means that international prices may vary seasonally with Colombia's production. This could lead to storage returns for Colombian farmers and cooperatives who adopt effective storage strategies and quality management. This combined with the producer support network provided by the Federación Nacional de Cafeteros de Colombia makes coffee a classic building on one's strengths strategy for the country.

To maintain the quality, and thus the price, of green coffee during storage, quality detriments, such as exposure to moisture and insects, must be controlled. Hermetic storage is a viable option for inhibiting moisture and gas transfer between the environment and the stored crop, and thus for maintaining quality. Hermetic storage bags, such as the Purdue Improved

Crop Storage (PICS) bags, have proven to be an effective tool in crop quality management, minimizing post-harvest loss, and increasing overall income in staple crops such as maize, cowpea, and wheat (Williams, Murdock, & Baributsa, 2017), (Baoua, Margam, Amadou, & Murdock, 2012), and (Ameri, Deering, & McNamara, 2018). More recently the bags have been shown to stabilize moisture content, water activity, and sensory scores in coffee (Donovan, Foster, & Parra, 2018). The three-layer polyethylene bag system drastically reduces the available oxygen inside the bags, suffocating any insects, and maintains the crop's moisture content by inhibiting moisture transfer from the outside atmosphere (Williams, Murdock, & Baributsa, 2017). By ensuring that the quality of green coffee is maintained over time farmers and cooperatives can become more flexible and autonomous in their market decisions.

The Colombian peace accords not only look to increase agricultural production, but agritourism as well to enhance rural incomes in the post-conflict period. Coffee farmers who wish to capitalize on the influx of tourists and sell green or roasted coffee beans directly to consumers must maintain quality during year-round operations and will be forced to store. To maintain quality, farmers must adopt new storage techniques to adhere to Colombia's high coffee quality standards and be competitive in the consumer tourism market.

The ability to manage green coffee quality during storage gives farmers and cooperatives more control over their production and harvest as well as the ability to capitalize on seasonality in prices. This study focuses on evaluating the economic returns from storing green coffee in Traditional (jute) bags, PICS bags with two layers (PICS2), and PICS bags with three layers (PICS3). PICS2 bags utilize one outside bag layer of woven polypropylene that protects the integrity of the inner bag from physical damage and one inner layer bag made of high-density polyethylene (HDPE) that provides the hermetic seal. PICS3 bags (the standard PICS technology) utilize one outside bag layer and two inner HDPE bag layers. The outcomes of this study will reveal the effects of hermetic storage technology on farm, cooperative and industry economic returns over time and inform whether storing green coffee creates positive expected net returns to Colombian coffee farmers and cooperatives.

2. Materials and Methods

2.1 Sample Preparation and Experimental Procedures

The experiment was conducted at the Universidad de Caldas in Manizales, Colombia from March to October 2017. Seven hundred kilograms of green coffee was purchased from the Cooperativa de Caficultores de Manizales in Manizales, Colombia. The green coffee was equally parceled into 9 Traditional bags, 9 PICS2 bags, and 9 PICS3 bags, totaling 27 bags[2]. Samples were taken from 3 bags of each technology every month, totaling 9 bags sampled each month. Three representative samples were taken from each of three bags of each treatment every month, totaling 27 total samples per month. Thus, each bag was sampled in two different months at three month intervals.[3] Ideally, there would be separate bags for each month, but this approach balanced the need for replication with limitations on cost and local capabilities for conducting the experiment. In order to ensure representative sampling the three samples were taken in separate terciles across the top of the bag as one scans from left to right using a probe. Samples were subsequently sealed in double ziplocked bags and taken to the Cooperativa de Caficultores de Manizales in Chinchiná, Colombia for quality testing and price assignment.

2.2 Coffee Price Determination

Various quality indicators were analyzed for each of the 27 monthly samples in order to assign a price to each sample. Moisture content is measured first and must be within 10-14 percent to be eligible for purchase by the cooperative. Green coffee that is over the 14 percent moisture content threshold can be redried either by passive solar means at the farm or by mechanical means. The local cost for mechanical drying is 200 COP per kilogram. Experimental samples over 14 percent moisture content were not redried or analyzed further in this experiment. All Traditional bag samples exceeded 14 percent during the research trials due to the lack of protection from ambient air. There were five PICS bags (2 PICS2 and 3 PICS3 bags) that were over 14 percent moisture content at initial testing at month 0.[4]

Green coffee physical attributes were analyzed to calculate the rendimiento that partially determines the price coffee farmers receive. The rendimiento is determined by taking a 100g sample of green coffee, dehulling the beans, and subtracting the weight of foreign matter and beans that are defective. Defective beans are determined by small size, insect damage, discoloration, or broken beans. The highest rendimiento score possible is 94 (hulls account for 6 percent of green coffee weight). The score is then entered into an equation that determines the rendimiento (see equation 1), that is susequently entered to another equation (see equation 2) to determine the base price the farmer receives before any enhanced quality premiums that may arise due to unique flavor or certifications (such as Rain Forest Friendly®). The price that farmers receive is per arroba[5]. Equation 2 utilizes a base price that is determined in the New York Stock Exchange (NYSE) for coffee and the pricing formula is regulated by the Federación Nacional de Cafeteros de Colombia.

$$\frac{7000}{(100g\ green\ coffee - weight\ of\ broken\ and\ damaged\ beans\ and\ hull)} = rendimiento \quad (1)$$

$$94 \times NYSE\ Price\ \div rendimineto = price\ to\ farmers\ (per\ 12.5kg) \quad (2)$$

Green coffee samples deemed high quality during the physical analysis are analyzed further through sensory analysis. Sensory or cupping score is determined by roasting green coffee, grinding, brewing, and analyzing the samples for ten key sensory characteristics, aroma, flavor, acidity, balance, cleanness of cup, sweetness, body, uniformity, residual flavor, and cupper's score. Cooperatives use this method to differentiate various lots of green coffee and to determine key flavor profiles that importers desire. Samples with remarkably high sensory score or unique flavor attributes are sold for higher prices to more influential buyers. Pricing and access to specific markets or buyers on an international level is determined through sensory score and volume.

For this study, the cooperative assigned prices on analyzed samples and provided the base price (NYSE). Samples that were not analyzed due to high moisture content (>14 percent) were assigned the base price from equation (2) minus the cost of redrying the beans (200 COP per kilogram or 10,000 COP per 50 kilogram bag). Redrying significantly decreases the quality of green coffee and thus the price, which indicates that redried samples would not receive prices higher than the base price. Thus, the estimated price minus drying cost represents the maximum price for high moisture content samples. Documentation concerning the success of both PICS bags treatments in maintaining moisture content and sensory scores can be found in Donovan, Foster, & Parra, 2018.

2.3 Price Analysis

Green coffee experimental prices were analyzed using Ordinary Least Squares (OLS) regression methods. Price data was assigned to each green coffee sample by certified cuppers at the Cooperativa de Caficultores de Manizales. The relationships between price and PICS2 bags, PICS3 bags, and time were analyzed using two forms of price: price premium (pp) and the natural logarithm of price (lnp). The price premium (pp) was calculated by subtracting the base price paid at the cooperative in month x from the observed sample prices taken in that month.[6] Prices were analyzed using two sets of data: the entire data set and a data set excluding bags that were over 14 percent moisture content at month 0.The price analysis regression equations are as follows.

$$pp_{it} = \beta_0 + \beta_1 PICS2_{it} + \beta_2 PICS3_{it} + \beta_3 x2_t + \beta_4 x3_t + \beta_5 x4_t + \beta_6 x6_t + \beta_7 x7_t + u_{it} \quad (3)$$

$$lnp_{it} = \gamma_0 + \gamma_1 PICS2_{it} + \gamma_2 PICS3_{it} + \gamma_3 x2_t + \gamma_4 x3_t + \gamma_5 x4_t + \gamma_6 x6_t + \gamma_7 x7_t + \epsilon_{it} \quad (4)$$

where i and t denote for bag technology and time, pp is the price premium, lnp is the natural logarithm of price, $PICS2$ and $PICS3$ are bag technology dummy variables, $x2$, $x3$, etc. are dummy variables for months in storage, u and ϵ are the error terms assumed to have zero means and constant variances, and the β's and γ's are parameters to be estimated using OLS.

Analysis was also conducted including interaction variables between the PICS bag technology (combining both PICS2 and PICS3)[7] and monthly storage dummy variables. The equations are as follows.

$$pp_{it} = \beta_0 + \beta_1 PICS2_{it} + \beta_2 PICS3_{it} + \beta_3 x2_t + \beta_4 x3_t + \beta_5 x4_t + \beta_6 x6_t + \beta_7 x7_t + \beta_8 PICSx2_{it} + \beta_9 PICSx3_{it} + \beta_{10} PICSx4_{it} + \beta_{11} PICSx6_{it} + \beta_{12} PICSx7_{it} + \beta_{13} over_{it} + u_{it} \quad (5)$$

$$lnp_{it} = \gamma_0 + \gamma_1 PICS2_{it} + \gamma_2 PICS3_{it} + \gamma_3 x2_t + \gamma_4 x3_t + \gamma_5 x4_t + \gamma_6 x6_t + \gamma_7 x7_t + \gamma_8 PICSx2_{it} + \gamma_9 PICSx3_{it} + \gamma_{10} PICSx4_{it} + \gamma_{11} PICSx6_{it} + \gamma_{12} PICSx7_{it} + \gamma_{13} over_{it} + \epsilon_{it} \quad (6)$$

2.4 Counterfactual

Time in storage is potentially a determinant of price but because Colombian farm price depends heavily on the international price in New York (NYSE) it is likely that a part of any observed decreases in price throughout the experimental time frame are partially due to general decline in the NYSE price.[8] To determine the effect that fluctuations in the NYSE coffee prices had on the experimental green coffee sample prices, a counterfactual analysis was conducted. The counterfactual was calculated by using OLS regression methods analyzing price against PICS2, PICS3, dummy variable (Over14) for high moisture content bag observations (>14 percent mc at month 0) and the NYSE price. The framework for that equation is as follows:[9]

$$Price_{it} = \beta_0 + \beta_1 PICS2_{it} + \beta_2 PICS3_{it} + \beta_3 Over14_{it} + \beta_4 NYSE_t \quad (7)$$

The counterfactual analysis uses the estimated coefficients from OLS regression of equation (7), appropriate values of the PICS2, PICS3, and Over14 variables but inserts the month 0 value for the NYSE price. Thus, the counterfactual estimates what the sample prices would have been for different treatments if the NYSE price had remained constant over the experimental time frame and addresses the effect changes in the NYSE base price had on the patterns of the assigned sample prices that were observed. That is, to what extent was the pattern of observed sample prices during the study period a result of the storage treatment versus movement in the underlying NYSE price.

2.5 Seasonality

One of the primary benefits of crop storage is the ability to delay marketing from harvest time to a later date when prices may be higher. Supply of crops is at its highest during harvest time and thus prices are typically low. As supply is utilized, processors and exporters must offer higher prices to draw the crop out of storage. Coffee is a global crop that is produced throughout the tropics of the world. Coffee flowering is driven by rainfall and other weather phenomena. Therefore, the presence of seasonality is not a given because at least some coffee harvest takes place virtually year around in the world. However, Colombia's position in the world market is unique. It is the world's third largest producer of coffee, the world's second largest producer of Arabica coffee, and the world's largest producer of premium grade arabica coffee (Halstead, 2017). Thus, seasonality in Colombian coffee production has a distinct potential to impact world coffee prices and thus those received by Colombian farmers and cooperatives in a regular seasonal pattern.

Seasonality analysis was completed to better understand the intra-year fluctuations in Colombian coffee prices and to provide a benchmark storage premium for analysis of the expected return to storage. Seasonal patterns of prices were analyzed using historical monthly NYSE coffee prices in COP (per arroba or 12.5 kilograms) calculated by weighting the prices of the last 6 days of the month. Data ranged from 1989 to 2017 and was provided by the Federación Nacional de Cafeteros de Colombia ("Historical Statistics | Federación Nacional de cafeteros," 2018). Data was obtained in USD cents/pound and converted into COP pesos per arroba utilizing monthly exchange rate averages. Monthly effects were aggregated into quarterly dummy variables to reflect harvest and non-harvest periods that span multiple months. Statistical analysis was completed utilizing OLS regression methods to estimate the following equation.

$$NYSE_t = \beta_0 + \beta_1 NYSE_{t-1} + \beta_2 NYSE_{t-12} + \beta_3 Q1_t + \beta_4 Q2_t + \beta_5 Q3_t + \beta_6 T + u_t \quad (8)$$

where $\mathrm{NYSE_t}$ denotes the NYSE price for month t measured in COP/arroba, Q1, Q2, and Q3 quarterly dummy variables defined by calendar year quarters, T is a deterministic time trend (T), $\mathrm{u_t}$ is the regression error term assumed to have mean zero and constant variance, and the β's are coefficient to be estimated. Quarter 4 is the largest harvest period and was excluded from the seasonal regression because Q4 is most likely when storage would begin. Omitting Q4, also facilitates an easy way to interpret the effects of Q1 and Q2. Their estimated coefficients indicate the average change in prices in Q1 and Q2 compared to Q4, respectively. The coefficient, β_3, on Q1 represents the CARRY variable in Net Present Value calculations below. That is, it the model's estimate of how much higher prices are on average in the first quarter of the year than in the fourth quarter or the average gross return to carrying the crop harvested in Q4 into Q1 of the following year.

2.6 Net Present Value

Net present value (NPV) is a measurement of return on investment calculated by comparing the present value of cash outflows to the present value of cash inflows over a period of time (Gallo, 2014). In the present context, it addresses the question of whether or not investing in PICS bags is expected to be profitable over time, and if so, what the expected payback period is in terms of years or number of reuses of the bag. Net present value is an appropriate method to analyze the PICS bags' potential return to storage because it translates future cash flows to present monetary value and takes into account the higher buying power of present money than the same amount of money in the future (the time value of money). Ndegwa etal (2016) used a similar approach called partial budgeting to evaluate the multi-year economic returns to PICS bags for maize storage in Kenya. Their approach, however, overestimates the profitability by failing to account for the time value of money.

Net present value was computed to better understand the PICS bags effect on return to storage and the effects of storage over three years. In other crops, PICS bags have shown to be reusable with three years being an average lifespan of the PICS bags (Foy & Wafula, 2016 and Nouhoheflin et al., 2017).

Net present value for the first year of storage was determined by the equation (9) below.

$$E(NR1) = CARRY * (\%success) + 10{,}000 * (1 - \%success) - bag\ cost \quad (9)$$

With *E(NR1)* is the expected first-year net return to storage per bag, *CARRY* is the average price gain in COP per 50 kilogram bag expected from storing coffee from Quarter 4 to Quarter 1 estimated using the above mentioned seasonal regression, *%success* is the percentage of samples of PICS2 and PICS3 bags that were under 14 percent moisture content at month 0,[10] and *10,000* is the cost of redrying a 50 kilogram bag of green coffee in COP when for whatever reason a bag fails. The cost of the PICS bags is assumed to be ~$2.00 USD or about 5480 COP (Jones, Alexander, & Lowenberg-DeBoer, 2014). The equation for second-year expected net return to storage is as follows:

$$E(NR2) = \frac{CARRY*(\%success^2)+10{,}000*(1-\%success \times \%success)}{(1+Discount\ Rate)^2} \quad (10)$$

With the *discount rate* representing the time value of money in order to compute net returns in year one equivalent COP. The equation for year three expected net return to storage is as follows:

$$E(NR3) = \frac{CARRY*(\%success^3)+10{,}000*((1-\%success\ ) \times (\%success)^2)}{(1+Discount\ Rate)^3} \quad (11)$$

To err on the side of caution, equations (9) through (11) are constructed under the assumption that failed bags are discarded even though in reality the failure may have been due to operator error and the bags are actually reusable.

Theoretically, PICS2 bags would have lower manufacturing costs due to the decrease in plastic required. Analysis was also undertaken to evaluate the impact of this potential cost reduction. This was done by assuming the PICS2 bags cost 1.33 USD (2/3 the price of PICS3) and recalculating a NPV. This method of reducing bag cost assumes each bag layer costs the same amount and the entire discount would be reflected in the consumer price. Analyzing PICS2 with the full price, PICS3, and PICS2 with the reduced cost leads to a better understanding of overall potential for return to storage.

Break-even calculations were performed to understand how much change in bag cost, %success, interest rate, and net return value would result in a zero net return to storage after three years for PICS2, PICS3 and reduced cost PICS2 bags. The calculations between PICS2 and PICS3 bags vary because of the difference in success rate. PICS2 bags have a 76.2 percent success rate at maintaining the moisture content of green coffee under 14 percent after month 0, while PICS3 bags have an 83.3 percent success rate[11]. Break even analysis demonstrates how much the variable must change to just meet the profitability threshold for storage over a three year horizon.

Calculations were also performed to determine the elasticity of the Net Present Value with respect to bag cost, success rate, interest rate, and net return value to understand the effect on prices at the 1 percent change level for PICS2, PICS3, and reduced cost PICS2 bags. Elasticity calculations give a better understanding of the relative impacts of changes in underlying determinants than the break-even calculations. This is because the determinants are all measured in differing units. Such information is a useful guide to practitioners and researchers in their efforts to improve economic outcomes and sustainability. Elasticity was calculated by shocking the underlying variable by 5 percent of its base value. The net present value was recomputed for the shocked variable, put into an elasticity equation, and divided by 5 to obtain the results for 1 percent change. The equation for elasticity calculations is as follows:

$$\varepsilon = \left(\frac{\Delta NPV}{\Delta V}\right) * \left(\frac{V}{NPV}\right) \div 5 \tag{12}$$

3. Results

3.1 Price Analysis

In all cases, the samples from the traditional bags exceeded 14 percent moisture and their prices were assigned the drying discount resulting in negative price premiums (pp). Figures 1 and 2 present the distributions of the price premiums (pp) for all three bag types over the seven months of the experiment. Figure 1 contains the premiums for all of the data and Figure 2 excludes the observations from bags that began experiment with moisture content in excess of 14 percent. While the moisture content of those bags did not generally rise it also did not fall below 14 percent at any time and thus those bags received the drying discount. Figure 2 demonstrates that the PICS bags are not foolproof. In both PICS treatments there was a bag which received high moisture discounts in all likelihood due to errors in sealing the bags.

Average prices (p), price premiums (pp), and changes in prices (p0) are presented in table 1. They are presented by bag type and month for both the total set of observations and for the reduced set that excludes those bags that had greater than 14 percent initial moisture content. For the most part, negative price premiums arise, on average, from high moisture samples and most of those are accounted for by the initial moisture content in case of five PICS bags and the general unsuitability of the traditional bags for storage. As the seasonality regression and counterfactual analysis below will show, the negative price changes for PICS samples are primarily due to the time of the year when the experiment was conducted and the generally falling international price during that time of the year relative to March 2017 when the experiment commenced.

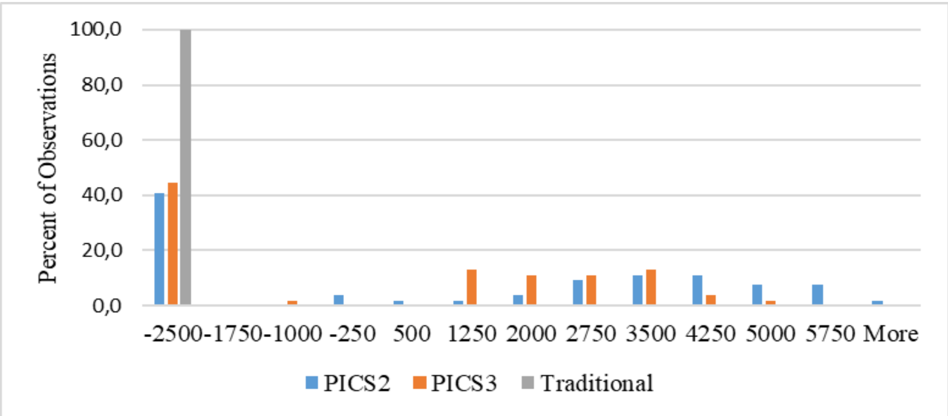

Figure 1. Distributions of Price Premiums (Pp) in COP/Arroba – All Data.

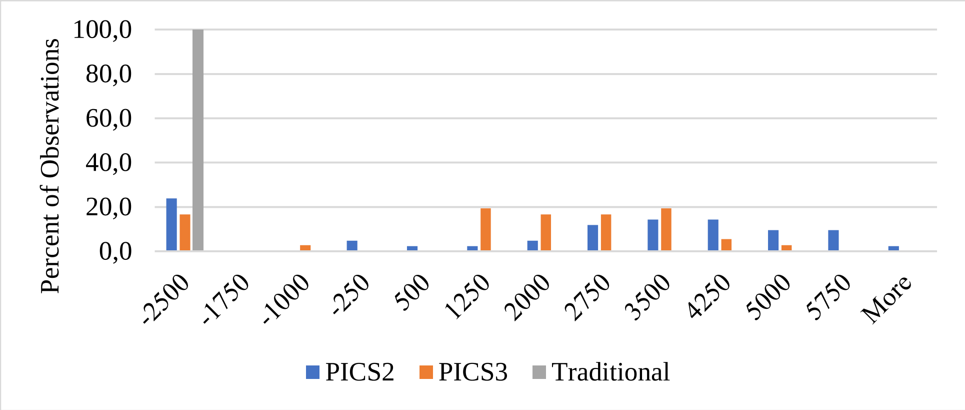

Figure 2. Distributions of Rice Premiums (Pp) in COP/Arroba – High Initial Moisture Content Bags Excluded

Table 1. Means of Price Variables (COP/Arroba) for All Months and Bag Types.

Bag		All Data			Excluding Over 14% Bags		
	Months in Storage	Price (p)	Price Premium (pp)	Price Change (p0)	Price (p)	Price Premium (pp)	Price Change (p0)
PICS2	Month 2	81276	-224	-657	82414	914	-5437
	Month 3	79985	1485	-7866	81977	3477	-5874
	Month 4	86581	3081	-1270	86581	3081	-1270
	Month 5	77500	-2500	-10351	77500	-2500	-10351
	Month 6	83549	-450	-4301	84574	574	-3277
	Month 7	81031	4031	-6820	81031	4031	-6820
	All	81654	904	-6197	82555	1876	-5296
PICS3	Month 2	81612	112	-6239	82918	1418	-4933
	Month 3	78238	-262	-9613	79358	858	-8494
	Month 4	84129	629	-3722	85693	2193	-2158
	Month 5	80479	479	-7372	81968	1968	-5883
	Month 6	82680	-1320	-5171	83269	-731	-4582
	Month 7	77855	855	-9996	79532	2532	-8319
	All	80832	82	-7019	82123	1373	-5728
Traditional	Month 2	79000	-2500	-8851	79000	-2500	-8851
	Month 3	76000	-2500	-11851	76000	-2500	-11851
	Month 4	81000	-2500	-6851	81000	-2500	-6851
	Month 5	77500	-2500	-10351	77500	-2500	-10351
	Month 6	81500	-2500	-6351	81500	-2500	-6351
	Month 7	74500	-2500	-13351	74500	-2500	-13351
	All	78250	-2500	-9601	78250	-2500	-9601

Table 2 presents the regression analysis for the variables used in the price analysis. Price models 1 and 2 utilized the entire data set and Price Models 3 and 4 analyzed the same data set but excluded the observations from bags that were over 14 percent moisture content at month 0. Models 1 and 3 are the regressions using the price premium (pp) as the dependent variable and Models 2 and 4 are the regressions using the logarithm of price (lnp) as the dependent variable. Table 2 shows that PICS2 and PICS3 have a significantly positive effect on both the logarithm of price[12] and the price premium regardless of whether or not bags with more than 14 percent moisture at month 0 were included. Price Model 3 implies larger absolute price premiums for PICS storage than Price Model 1 due to excluding the high moisture content bags because placing high moisture coffee in the PICS bags at the beginning of the experiment guaranteed high moisture when samples were taken from those bags later and the drying discount incurred. For all models presented in table 2, the price increase is higher for PICS2 than for PICS3 when compared to Traditional bags. However that difference in price between PICS2 and PICS3 is not statistically significant[13]. This is important for further return to storage analysis and has important implications for PICS2 effectiveness and profitability. All significant month coefficients were positive. This indicates positive relationship between PICS bags and storage and that time in storage did not have a negative effect on prices.[14]

Table 2. Results for Price Regression Analysis

	Price Model 1 (pp)	Price Model 2 (lnp)	Price Model 3 (pp)	Price Model 4 (lnp)
Variable	β *(Std. Err.)*	β *(Std. Err.)*	β *(Std. Err.)*	β *(Std. Err.)*
PICS2	3404*** (419.1)	0.0422*** (0.00521)	4242*** (374.8)	0.0525*** (0.00464)
PICS3	2560*** (419.2)	0.0322*** (0.00521)	3835*** (390.9)	0.0482*** (0.00484)
x2	647.3 (577.7)	0.0281*** (0.00719)	747.6 (542.62)	0.0296*** (0.00671)
x3	1192* (572.8)	-0.00316 (0.00713)	1381* (536.9)	-0.0004214 (0.00664)
x4	1965*** (587.8)	0.0676*** (0.00731)	1743** (537.2)	0.0648*** (0.00665)
x6	138.6 (587.77)	0.0521*** (0.00731)	102.5 (554.5)	0.0517*** (0.00686)
x7	2358*** (587.77)	-0.00811 (0.00731)	2184*** (537.2)	-0.00991 (0.00665)
Intercept	-3550*** (475.8)	11.24*** (0.005920)	-3526*** (426.7)	11.24*** (0.005279)
R^2	0.3901	0.6251	0.6110	0.7541
Adjusted R^2	0.3623	0.6080	0.5890	0.7402
Root MSE	2177.6	0.02709	1815.5	0.02246

Notes: * Significant at the 0.10 probability level. ** Significant at the 0.05 probability level. *** Significant at the 0.01 probability level

Table 3 presents the results for the price regressions including interaction variables for PICS technology and months in storage dummy variables. Price Model 5 analyzes the price premium (pp) and Price Model 6 analyzes the natural logarithm of price (lnp). Table 3 shows that the samples from PICS bags received significantly higher prices in months 4 when compared to month 5 Traditional bag samples (the omitted effects). The increases in price for months 3 and 7 are most likely due to increases in the NYSE price. The high moisture content bags at month 0 were controlled for by including the "Over14" dummy variable.

Table 3. Results for Price Regression Analysis with Interaction Variables

	Price Model 5 (pp)	Price Model 6 (lnp)
Variable	*β* (*Std. Err.*)	*β* (*Std. Err.*)
PICS2	2954*** (675.7)	0.03581*** (0.008335)
PICS3	2516*** (686.5)	0.03093*** (0.008468)
x2	3.27e-11 (757.8)	0.01917* (0.009349)
x3	3.55e-11 (757.8)	-0.01954* (0.009349)
x4	1.98e-11 (757.8)	0.04417*** (0.009349)
x6	2.96e-11 (757.8)	0.05033*** (0.009349)
x7	2.86e-11 (757.8)	-0.03949*** (0.009349)
PICSx2	857.3 (917.1)	0.01190 (0.1131)
PICSx3	1607 (913.6)	0.02222 (0.01127)
PICSx4	2239* (926.9)	0.02619* (0.01143)
PICSx6	117.2 (924.5)	0.001509 (0.01141)
PICSx7	2827** (926.9)	0.03814** (0.01143)
Over14	-3714*** (353.8)	-0.04644*** (0.004364)
Intercept	-2500*** (535.9)	11.26*** (.006610)
R^2	0.6805	0.8070
Adjusted R^2	0.6525	0.7900
Root MSE	1608	0.01983

Notes: * Significant at the 0.10 probability level. ** Significant at the 0.05 probability level. *** Significant at the 0.01 probability level

3.2 Counterfactual Analysis

As noted above, the sample prices are generally lower than the initial price during the study period. The negative change in price (p0) could have been the result of general price declines in the key international market, given Colombia's role as a significant coffee exporter, rather than quality deterioration. To examine this, a counterfactual analysis was performed. Table 4 presents the results for the regression analysis used to calculate the counterfactual for prices to determine how much affect the change in NYSE price had on the prices for the samples. All variables are statistically significant at the one percent level, with PICS2, PICS3, and the NYSE price having positive coefficients, while the "Over14" dummy variable (representing observations from bags that were over 14 percent moisture content at month 0) was negative.

The latter is to be expected because the samples from those bags remained above 14 percent moisture content and therefore always received the drying discount below the base price. The positive effects of PICS2, PICS3, and NYSE indicate that, on average, prices for PICS treatments were significantly higher than for the traditional bags and that a higher NYSE price translated into a higher sample price all other factors equal. Using the means of sample prices and the NYSE price both measured in COP/arroba the regression implies that for every one percent increase in the NYSE price, on average, there is a 0.25 percent increase in local price in Colombia with all other factors equal.

Table 4. Results for Counterfactual Regression

	Counterfactual Regression 1
Variable	*β (Std. Err.)*
PICS2	4279*** (551.4)
PICS3	3895*** (571.3)
NYSE	0.1669** (0.05432)
Over14	-3939*** (601.8)
Intercept	57911*** (6631)
R^2	0.3811
Adjusted R^2	0.3653
Root MSE	2780

Notes: * Significant at the 0.10 probability level. ** Significant at the 0.05 probability level. *** Significant at the 0.01 probability level

The results of the counterfactual, along with monthly average prices by bag type can be seen in table 5. The counterfactual prices were computed using the coefficients in table 4 while setting the Over14 variable to zero, entering the appropriate values for PICS2 and PICS3, but using the month 0 NYSE price. That is, answering the question: "What do the data suggest the average prices by bag type would have been had the NYSE price remained constant throughout the experiment?"

Table 5. Counterfactual Prices and Observed Average Prices

Variable	Counterfactual	Average	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7
Traditional	79398	78250	79000	76000	81000	77500	81500	74500
PICS2	83677	81653	81275	79984	86580	77500	83549	81031
PICS3	83293	80831	81611	78238	84128	80478	82679	77854

The counterfactual calculations for Traditional, PICS2, and PICS3 bags are greater than each technology's average price received over the seven months. In addition, with the exception of the fourth month average price, the counterfactual prices for both PICS treatments were higher than their associated month average sample price. This indicates that if the NYSE price had stayed constant over the experimental time frame, the average prices for all bag types would have generally been higher than those observed. The conclusion being that observed sample price declines were heavily influenced by declining NYSE prices rather than quality deterioration of coffee in PICS storage.[15] It is important to reiterate that the counterfactual prices for PICS2 and PICS3 treatments are substantially higher than for traditional bags.

3.3 Seasonality

A primary motivator of storage is the potential for prices to rise seasonally as post-harvest stocks are depleted relative to demand. Table 6 presents the results for the seasonality analysis and shows that the Q1 (first quarter effect) coefficient is statistically significant and positive. This indicates, on average, that storing green coffee from Q4 to Q1 would lead to higher gross income. The average difference between Q1 and Q4 prices is ~1900COP/arroba (rounded from 1920), which is ~7600 COP per 50 kilogram bag.[16] This value was represented by the variable *CARRY* in earlier general representations of expected net return to storage (see equation 4). Average annual production for Colombian coffee farmers is 222.5 fifty kilogram bags, which could result in an additional ~1,691,000 COP of income per year for farmers (Gilbert & Gomez, 2016).

As seen in the table 6, there is a strong stochastic trend (one month lag in price with a coefficient close to one) imparting a lot of inertia in coffee prices over time. That is, high prices breed high prices and low prices breed low prices, all else constant. The coefficient on P_{t-1} indicates that 97 percent of this month's price carries over to the next month. The inclusion of the 12 month lag incorporates year over year stochastic seasonal effects and also enables potential cyclical price effects that may spill over from global economic business cycles and the importance of global trade in Colombian coffee. In fact, all 12 of the roots of the characteristic polynomial of the estimated difference equation are complex and lie outside the unit circle.[17] The deterministic time trend variable (T) is also highly statistically significant and positive. This term likely captures general global price inflation over the sample period. The regression analysis for seasonality determined that there are significant seasonal price increases on average between Q4 and Q1, which indicates that there is a potential of a positive net return to storage by investing in PICS bags.

Table 6. Results for Seasonality Analysis

Variable	β *(Std. Err.)*
P_{t-1}	0.97*** (0.01850)
P_{t-12}	-0.05321** (0.01849)
T	28.96*** (7.479)
Q1	1920* (786.6)
Q2	-575.2 (787.0)
Q3	129.1 (783.3)
Intercept	-2694* (1174)
R^2	0.98
Adjusted R^2	0.98

Notes: * Significant at the 0.10 probability level. ** Significant at the 0.05 probability level. *** Significant at the 0.01 probability level

Recall that Colombia has a minor harvest in Q2 so that storage from Q2 to Q3 would be an option for farmers. However, both the Q2 and Q3 are not statistically significant in the analysis of price seasonality nor is the difference (Carry) between them so it is unlikely that storage between those two quarters would generate positive returns to storage on average[18].

3.4 Net Present Value

Table 7 presents the results for the net present value analysis and the return to storage over the 3 years of reuse of the PICS bags. The table compares the profitability between bags, farms, and export minimums, which represent profitability for cooperatives. PICS2 bags that were priced the same as PICS3 bags (~$2.00/ bag or 5480 COP/bag) were not as profitable over the 3 year horizon but still had a positive net return to storage at 1480 COP per bag. PICS3 bags generated a negative net return in the first year (-1147 COP per bag), but had a positive net return to storage beginning in the second year and became profitable after the second (2250 COP per bag) and third years (4895 COP per bag). PICS2 with the reduced cost (~$1.33/ bag or 3644 COP/bag) also had a negative return to storage in the first year (-457.4 COP per bag), but was much lower than the initial loss for the other two bag types. Because the initial cost of the bag was lower, PICS2 reduced cost bags reached a positive return to storage in the second (4062 COP per bag) and third years (3427 COP per bag). This indicates that PICS2 bags, with their lower success rate, are not as profitable as PICS3 bags unless the cost is reduced. PICS3 bags were the most profitable over the three years and farmers could begin to see positive net returns in the second year. Reduced cost PICS2 were the most profitable over two years of storage. However, farmers would not recoup their initial investment in the first year of storage for all bag technologies at the current prices and estimated success rates.

Table 7. Net Present Value Analysis Results

	PICS2	PICS3	Reduced cost PICS2
Year 1			
Per bag	-2404	-1147	-457.4
Per farm	-534996	-255282	-101768
Per export minimum	-818003	-390323	-155603
Year 2			
Per bag	2269	3397	2269
Per farm	504844	755767	504844
Per export minimum	771900	1155559	771900
Year 3			
Per bag	1616	2645	1616
Per farm	359479	588604	359479
Per export minimum	549640	899968	549640
Total			
Per bag	1480	4895	3427
Per farm	329327	1089089	762554
Per export minimum	503537	1665205	1165937

Table 8 presents the break-even values of bag cost, success rate, discount rate, and net return to storage to communicate how much those variables must change in order to generate a zero net present value over three years. All PICS bag cost break-even points are higher than the current projected bag price of 5814 COP, indicating that both PICS bag options have profit enhancing potential. It is also important to note how the success rates can drop for those estimated and still result in a break-even outcome, especially reduced cost PICS2 (67.97 percent). PICS bags effectiveness at mitigating moisture transfer over subsequent uses for green coffee is an area for further research and understanding how low the PICS bags success rate can be to still make a profit is important. The initial success rates for PICS2 and PICS3 bags were 76.2 and 83.3 percent, respectively. These were determined from the experimental outcomes. Those rates could decline by several percentage point and still result in a break-even outcome and in the case of the reduce cost PIC2 scenario the success rate could decline substantially. The discount rate in the NPV equation was initially set at 7 percent. Sensitivity analysis suggest that the discount rate could rise substantially (up to 30 percent or even over 100 percent) before profitability is threatened. The expected seasonal price increase during the storage period was initially set at the value derived from the seasonal price analysis: 7600 COP/50kg. The investment in PICS would still breakeven if that value fell to 6692, 5040, and 5497 for PICS2, PICS3, and reduced cost PICS2 bags, respectively.

Table 8. Net Present Value Break-Even Analysis Results

	PICS2	PICS3	Reduced Cost PICS2
Variable			
Bag Cost	7294	10709	7294
Success rate	72.79%	72.79%	67.97%
Discount Rate	30.76%	116.6%	170.0%
CARRY	6692	5040	5497

Table 9 presents the elasticities for bag cost, success rate, discount rate, and net return to storage for PICS2 bags, PICS3 bags, and PICS2 reduced cost bags. These elasticities are interpreted as the percentage change in three-year NPV from a one percent change in the underlying determinant and are measured around the base values of the determinant. The strongest elasticities belonged to success rate and bag cost. The elasticities were more pronounced in reduced cost and full cost PICS2 bags than in PICS3 bags. This is due to a decrease in marginal net return for success rate. Because the success rate varies from 0-1, the closer the success rate is to 1, the smaller the change effects the net present value outcome in percentage terms, and therefore the change has a smaller effect on the already successful PICS3 scenario. This analysis highlights that the greatest return would arise from education and training in proper use of hermetic bags and perhaps improved drying to avoid placing coffee with moisture higher than 14 percent in storage.

Table 9. Net Present Value Elasticity Analysis Results

	PICS2	PICS3	Reduced Cost PICS2
Variable			
Bag Cost	-0.7856	-0.2376	-3.915
Success Rate	4.779	1.792	8.717
Discount Rate	-0.08249	-0.03915	-4.314
CARRY	1.674	0.5938	0.02730

4. Discussion

This study uses experimental data and data recorded by the National Federation of Coffee Growers in Colombia to estimate the economic effects of storing green coffee in PICS2 and PICS3 bags for a period of six months. This study also examines seasonality for the Colombian coffee prices in the NYSE and whether or not that seasonality is strong enough to make an impact on storage patterns and could lead to higher received prices. Net return to storage calculations were completed to estimate the effects of storing green coffee in PICS2 and PICS3 bags and whether it could lead to higher prices received per bag, per farm, and per export minimum. This is the first study of its kind to estimate changes in price during green coffee storage and will add to the literature on hermetic storage and the economics of Colombian coffee.

The results of this study suggest that storing green coffee in PICS bags is effective in managing quality and can lead to higher received prices and farmer incomes. The ability to successfully manage quality is key to obtaining higher price, on average, through storage due to seasonal price patterns. In addition, the use of hermetic storage is scale-appropriate for the size of coffee farms in Colombia and other parts of the world where coffee is grown. Coffee farm tourism is a growing sector in Latin America that requires farms to store green coffee in order to service tourism activities related to coffee tasting experiences and roasting demonstrations using coffee grown on the farm. PICS and other hermetic storage bags represent an appropriate technology to support these income opportunity for farmers.

The magnitude of return to hermetic bags depends on bag type and the initial cost of the bags. An analysis of Net Present Value revealed that all bag technologies resulted in a negative net return in the first year of storage, which indicates that reusing the bags is an essential element and care should be taken in handling to bags to maximize their reuse. PICS3 bags had the best overall outcome in the long-term net return to storage over three years. This is due to PICS3's higher success rate at 83.3 percent. Reduced cost PICS2 (~ 1.33USD/ 50 kilogram bag) bags were the next most profitable. Reduced cost PICS2 bags had the smallest first-year net income loss due to the decreased bag cost, which led to a positive discounted net return over the three years in storage. Both PICS3 and reduced cost PICS2 became profitable in year two of storage. Full-price PICS2 bags only become profitable in the third year. This indicates that without a reduced cost or improvements in performance, PICS2 bags are unlikely to be adopted to store green coffee and PICS3 bags would be chosen due to the higher net return rates over time. While this study estimated the cost of PICS2 bags to be 1.33 USD, the highest the PICS2 bags can cost before a negative net return to storage is ~2.66 USD. Thus, unless the price of PICS bags rise from the standard ~2.00 USD per bag, PICS2 bags will remain profitable in the long-term.

Price regressions on price premiums and the logarithm of price from the storage experiment showed a positive price effect from storing in PICS2 and PICS3 bags when compared to base prices at the local cooperative. Because the Traditional bags did not protect the green coffee from moisture damage, there were significant drops in price for Traditional samples. Price regressions were analyzed on all data observations and with initial high moisture content bags excluded from the regressions. The price premiums between the two datasets had limited discrepancies, indicating that the analyses were not highly affected by including the high moisture content bag observations. As seen in figures 1 and 2, the price premiums for PICS2 and PICS3 were larger on average when high moisture content bag observations were excluded. Volatility in sample price premiums was also a result of changes in the international price. As seen in table 5, counterfactual calculations for the absolute prices were higher than the observed average prices per bag technology.

Many of the observed changes in prices (p0) were negative. However, because the experimental time frame was from March to October, this study only represents half of the harvest year. In the seasonality analysis shown in table 5, Q1 (January through March) was the only quarter indicator that was statistically significant. The experimental time frame did not encompass the prime storage period where prices significantly rise. If the study had extended or begun in Q4, positive changes in price (p0) might have been observed. One must also take into account that while farmers have the option to sell immediately upon harvest and bypass any quality or price loss due to moisture exposure, the cooperatives must store green coffee in order to collect enough volume for export. Green coffee at cooperatives currently is stored in Traditional bags for up to two months.[19] This means that cooperatives are losing on average -9601 COP (~3.50 USD[20]) per arroba or -768 COP per kilogram every month in Traditional storage. With an international export minimum of 17,010 kilograms, this means that cooperatives can lose up to 13,065,040 COP (~4,768 USD) per month in storage for every export (Gilbert & Gomez, 2016). For a country that exports nearly 738,000,000 million kilograms of coffee each year, the loss for the Colombian coffee industry can be nearly 566,784,000,000 COP (206,855,474 USD) per month in storage (Gilbert & Gomez, 2016). Losses like these can hold back industries and economies. Mitigating price loss during storage at the cooperatives by utilizing PICS bags or other forms of hermetic storage can help to close the gap between production realities and possibilities.

By incorporating improved quality management into the Colombian coffee industry, farmers and cooperatives can become more independent in their production decisions. Farmers who were forced to sell their harvests immediately upon drying can afford to store part or all of the harvest until prices rise. Cooperatives that have to store green coffee until enough volume is collected for export can mitigate quality/price loss due to moisture or insect exposure. Cooperatives are either calculating this price loss into what farmer's receive for their lots or cooperatives are purchasing green coffee at a higher price than what they can sell it for later. Either way, by minimizing quality/price loss farmers and cooperatives can reap the benefits of increased profits through hermetic storage. It is also important to note that the price premium for storing green coffee in hermetic technology will not be constant over time. Should farmers and cooperatives begin storing large volumes of coffee between Q4 and Q1, they will likely arbitrage some of the storage premium away. It is important for further study to better understand the Colombian coffee market and at what point the shift in short run supply would trigger a substantial evening out of prices across seasons. However, this does not mean that storage would become unprofitable, but that as people's expectations about the value of storage evolve from year to year, the price premium benefits may be less and storage becomes more risky.

Further research is needed to better understand ways to lower the cost of the PICS bags and make the PICS bags' success rate higher. In the elasticity analysis in table 8, success rate had the highest elasticity for PICS2, PICS3, and reduced cost PICS2, 4.779, 1.792, and 8.717, respectively. This indicates that focusing on increased success rates would create the biggest improvement in the net present value return to storage. PICS bag success rate can be affected by many factors, including the following: ensuring only properly dried green coffee is placed into the bags, properly creating the hermetic seal, protecting the bags from being damaged, keeping the bags away from direct sunlight (Baributsa, Baoua, Abdoulaye, & Murdock, 2015), and education of users. Cooperatives that may be forced to store green coffee despite the high humidity should invest in long-term reusable hermetic storage options that allow for the largest net return to storage. While the initial cost of the PICS3 (standard PICS bags) bags creates a negative net return to storage in the first year, PICS3 bags do become profitable after the second year, indicating that farmers and cooperatives can reap the benefits a year after the initial investment. It is also important to better understand the PICS bags effectiveness at mitigating green coffee quality over subsequent uses and whether or not the success rate changes from year to year, which would greatly affect economic success. Another important area for future research is evaluating more closely the quarter 4 to quarter 1 storage seasonality and collecting observational data over those time periods in storage. This would give a better idea of the available premiums in the market.

Because Colombia's coffee sector is heavily export oriented, adoption of hermetic storage bags will depend on acceptance of the technology in the global supply chain. This suggests a need for efforts to further validate the effectiveness of the technology and to evaluate the use of mechanisms like IoT devices in random bags to assess quality indicators such as moisture content without the need to break the hermetic seal.

Further research is also needed to address how access to storage might affect other coffee farmer decisions. Previous research indicates that access to improved storage technology may lead to greater risk taking and adoption of productivity enhancements (Ricker-Gilbert & Jones, 2015).

Effective storage methods in the context of quality management can decrease the effects of market volatility in the Colombian coffee industry and make it easier for farmers to transition from illicit to legal crops. Through the peace accords and influx of agricultural invests, opportunities and technological innovations like the PICS bags can revolutionize the industry and contribute to socioeconomic stability.

Acknowledgement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. Support for this research was provided by the Purdue University College of Agriculture, Universidad de Caldas, and the Cooperativa de Caficultores de Manizales.

References

Ameri, S., Deering, A. & McNamara, K. (2018). The economic benefits of small-holder use of hermetic storage for wheat in Afghanistan. *International Journal of Food and Agricultural Economics*, 6(3): 33-46.

Baributsa, D., Baoua, I., Abdoulaye, T. & Murdock, L. (2015). *A guide on the use of PICS bags for grain storage*. West Lafayette. Retrieved from https://extension.entm.purdue.edu/publications/E-265.pdf

Baoua, I.B., Margam, V. ,Amadou, L. &Murdock, L. (2012). Performance of triple bagging hermetic technology for postharvest storage of cowpea grain in Niger. *Journal of Stored Products Research*, 51, 81-85. https://doi.org/10.1016/j.jspr.2012.07.003

Beeckmans, B. & Emsden, C. (2016). Rural development is Colombia's peace dividend, President Santos says. Retrieved September 12, 2017, from http://www.fao.org/news/story/en/item/461047/icode/

Donovan, N. (2018). *Quality and Economic Analysis of Green Coffee Beans Stored in Purdue Improved Crop Storage Bags*, Master of Science Thesis, Department of Agricultural Economics, Purdue University, West Lafayette, IN.

Donovan, N., Foster, K. & Parra-Salinas, C. (2018). Analysis of green coffee quality using hermetic bag storage. *Journal of Stored Products Research*, 80(January): 1-9. https://doi.org/10.1016/j.jspr.2018.11.003

Foy, C. & Wafula M. (016). *Scaling up of hermetic bag tecnhology (PICS) in Kenya*. Retrieved from https://agrilinks.org/sites/default/files/resource/files/BFS Scaling Review - Kenya Report REVISED 508 11-16-16.pdf

Gallo, A. (2014). A refresher on net present value. Retrieved March 19, 2018, from https://hbr.org/2014/11/a-refresher-on-net-present-value

Gilbert, A. & Gomez, L. /2016). *2016 Colombian coffee annual report*. Retrieved from https://gain.fas.usda.gov/Recent GAIN Publications/Coffee Annual_Bogota_Colombia_5-13-2016.pdf

Halstead, T. (FAS/USDA) (2017). *Coffee: world markets and trade*. Retrieved from https://apps.fas.usda.gov/psdonline/circulars/coffee.pdf

Historical Statistics | Federación Nacional de Cafeteros. (2018). Retrieved January 8, 2018, from https://www.federaciondecafeteros.org/clientes/en/quienes_somos/119_estadisticas_historicas/

Jones, M., Alexander, C. & Lowenberg-DeBoer, J. (2014). A simple methodology for measuring profitability of on-farm storage pest management in developing countries.

Journal of Stored Products Research, 58(July): 67-76. https://doi.org/10.1016/j.jspr.2013.12.006

Ndegwa, M., De Groote, H., Gitonga, Z. & Bruce, A. (2016). Effectiveness and economics of hermetic bags for maize storage: Results of a randomized controlled trial in Kenya. *Crop Protection*, 90: 17-26. https://doi.org/10.1016/j.cropro.2016.08.007

Nouhoheflin, T., Coulibaly, J., D'Alessandro, S., Aitchedji, C., Damisa, m., Baributsa, D. & Lowenberg-Deboer, J. (2017). Management lessons learned in supply chain development: The experience of PICS bags in west and central Africa. *International Food and Agribusiness Management Review*, 20(3): 427-38. https://doi.org/10.22434/IFAMR2016.0167

Ricker-Gilbert, J. & Jones, M. (2015). Does storage technology affect adoption of improved maize varieties in Africa? Insights from Malawi's input subsidy program. *Food Policy*, 50: 92-105. https://doi.org/10.1016/j.foodpol.2014.10.015

Williams, S., Murdock, L. & Baributsa, D. (2017). Storage of maize in Purdue Improved Crop Storage (PICS) bags. *PloS One*, *12*(1), https://doi.org/10.1371/journal.pone.0168624

---

[1] Some larger cooperatives occasionally store coffee to very high altitudes where the humidity is lower, but the costs of transportation over poor roads is extremely costly.

[2] The PICS bags were rated for 50 kg capacity based on cowpea density. Green coffee is considerably less dense by volume such that these bags could accommodate approximately 40 kg of green coffee but were loaded with 26 kg for this study.

[3] The bags within each treatment were randomly assigned to their group of three that determined in which months they would be sampled.

[4] At purchase all coffee was at 12 percent moisture, however, that day was typical of the local climate and very humid and raining. Before all samples could be bagged some became elevated in moisture content.

[5] Arroba is a Colombian coffee mass measurement corresponding to 12.5 kilograms.

[6] Results of analysis of the change in price from the initial price to the sample price can be viewed in Donovan (2018) but because the initial price paid for all coffee was the same these results are just an intercept shift and logarithmic transformation of those for the logarithm of price presented in this paper.

[7] There were not enough degrees of freedom to analyze bag type and months in storage interactions for the PICS treatments separately.

[8] Due to the experimental design and time frame of the experiment, the NYSE price and month in storage variables are perfectly collinear and could not be simultaneously included in the regressions. Ideally, the experiment would be repeated for another time period with different NYSE prices but this was beyond the resources of this project but represents important future research.

[9] For consistency with the experimental data, the NYSE price is observed monthly. Because the same NYSE price applies to all sample within a given month, it does not vary across bag types. Therefore, Equation 7 does not include month effects that were included in the earlier price regressions due to perfect correlations between monthly binary variables and the NYSE price variable.

[10] The percentage of bags that fail each year is considered constant. That is, the %success is constant over time.

[11] Bags that were over 14 percent moisture content at month 0 were excluded from the success rate calculation.

[12] The exchange rate between COP and USD is ~2740 COP to 1 USD.

[13] Price Model 1 t-statistic for H_0: PICS2 effect = PICS3 effect: 1.423
Price Model 2 t statistic for H_0: PICS2 effect = PICS3 effect: 1.348
Price Model 3 t-statistic for H_0: PICS2 effect = PICS3 effect: 0.7528
Price Model 4 t-statistic for H_0: PICS2 effect = PICS3 effect: 0.6408

[14] It is important to note that prices received by farmers depend on the international market and significant monthly effects could be related to fluctuations in the international price.

[15] Keep in mind that the experiment began in March 2017 at the beginning of the secondary harvest period and month 7 was October 2017 at the beginning of the primary harvest period.

[16] Earlier it was noted that the bags used in the experiment held only 40 kg of coffee. Should storage of coffee be adopted then manufacturers would likely produce a slightly larger bag to accommodate 50 kg of coffee.

[17] Complex roots give rise to limit cycles and roots outside the unit circle ensure that the dynamics of the estimated difference equation are stable (mean reverting).

[18] Due to Colombia having two harvests per year, calculations were also completed for three consecutive harvests, rather than just the main harvest for three years. It was found that storing over three years only from Q4 into Q1 led to higher net present value than over three harvests.

[19] Larger cooperatives occasionally transport green coffee to extremely high altitude for storage where the humidity is lower. This incurs substantial transportation costs and can be a long process depending on road conditions during which the coffee may become damaged or absorb moisture.

[20] The exchange rate between COP and USD is 2740 COP to 1 USD.