REGULAR ARTICLE

FACTORS DRIVING DISCONTINUANCE OF SMALLHOLDER DAIRY FARMING - EVIDENCE FROM TAMIL NADU, INDIA

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Abstract

Research background: There is limited understanding of reasons, promoting discontinuance especially from dairying activities farming in mixed farming systems where exit happens earlier than the complete exit from agriculture,
Purpose of the article: This study explores the households and farm associated economic factors that influence the farmer's intention to 'discontinue' from the smallholder dairy sector, in the changing context of increasing demand; poor participation of youth in agriculture; urbanisation and increasing role of non-farm sector in the Indian economy.
Methods: A total of 384 dairy households representing three different crop livestock systems were selected on a proportionate basis from the existing datasets of dairy households for the research. Descriptive and binominal logit regression was used for analysis of the data.
Findings, value added & novelty: The major findings are that more than half of households have an intention to discontinue or downsize their dairying operations and almost all are demotivating next generation to take up dairying. Moreover, in households with no crop activity, using high inputs and having low level of attitude towards dairying and in areas with poor markets are likely to discontinue. In the long run inadequate income from dairying, value system and developments in non-farm sector are driving discontinuance.

Keywords: Rural livelihood, Smallholder dairying, discontinue intention, future of farming
JEL codes: R58, Q120. Q180, Q130

INTRODUCTION

Smallholder dairy is an important livelihood option for the rural poor of third world countries. This sector engages about 150 million rural households which are mostly spread out in Asian and African countries **(FAO, 2010)**. It has been playing a substantial role in generation of employment, improving household food security, reduction of rural poverty and meeting the market demand of milk and milk products. Out of 1.4 billion estimated people living under absolute poverty, nearly 43 per cent are associated with livestock based livelihoods. Apart from being in low income countries, two-third of the smallholder livestock keepers is women. Thus, policy makers and developmental agencies have been promoting smallholder dairying as one of the pathways to move out from rural poverty and to achieve United Nation sustainable development goal; especially for reduction of poverty the dairy profession has been identified as one of the tools. This smallholder dairying contributes substantial share to global milk production. The South Asian countries contribute nearly one-fourth of global milk production and major share of recent growth in global milk production is from India, Pakistan and China **(FAO, 2010)**. These contributions are primarily from smallholder dairy farmers of the respective countries **(Siddiky, 2017).** Among the above countries, Indian share alone accounts 23 per cent of the global production, providing employment to 70 to 80 million rural households (around 50 to 60 per cent of rural households) and milk is the top most contributor to the national economy. Regrettably, the people associated with livestock / dairy in these countries are mostly marginalised sections of the rural society.
Indian dairy is mostly associated with the vulnerable rural section of the society and this section owns 59 per cent of total cattle of the country **(Rao and Birthal, 2008: 39-78).** The dairy sub-sector is witnessing the growth rate of about six per cent per annum and currently, India's estimated milk production is about 187.75 million metric tonnes of milk per year **(Government of India [GoI], 2019)**. This is mostly from smallholder dairying activities. Indian dairy sector accounts for more than 66per cent of the national livestock economy. At themarket end, the consumer expenditure and demand for animal origin foods has increased during 1983 to 2004 **(National sample survey organisation [NSSO] 2006: 66-69)**. The increasing urbanisation, changing consumer pattern and increased disposable income factors have created a vast market for animal protein such as meat, milk and eggs **(Birthal and Negi, 2012).** Within the animal origin-

food section, dairy products hold a dominant share. The demand for dairy products has been rapidly increasing **(NSSO, 2006: 66-67; Kumar *et al*., 2011).** The projected demand for dairy products for the year 2030, is more than 300 million tonnes per annum. Similar to national trends, the Tamil Nadu stands as one of the top leading milk producing state with 20.60millionlitresper day. The state possesses about10.4 million cattle and buffalo population **(GoTN, 2020)** distributed approximately in 2.3 million households. Further on the state government has been promoting dairying as livelihood through distribution of one milch animal for 87444 households during the period 2011-12 to 2018-19 and in the year 2019-20 it was extended to 12000 farmers.

At the same time, withdrawal of rural population from agriculture within the state and country is widely observed. In the period between 1983 and 2005, population engaged in agriculture declined from 69 to 57 per cent **(Sengupta, 2009: 110).** For the first time in Indian history, an absolute reduction of the population engaged in agriculture was reported **(Gandhi *et al*., 2014).** Further, the total rural population has also declined from 72 to 69 per cent between the period 2000 and 2011 **(MoH 2011: 5)**. Similar to national trends, there is steep decline in participation of rural households in agriculture in Tamil Nadu. Currently 35 per cent state rural households are engaged in agriculture and / or allied activities and 48 per cent of the population is living in urban areas. This demands understanding on reasons for exit from agriculture based livelihoods.

LITERATURE REVIEW

Globally also a significant proportion of rural households in many parts of the world are quitting and/or minimising their role in smallholder agriculture and allied sectors based livelihoods **(Sharma and Bhaduri 2007; Rae, 2008; Hazell, 2011; Bernhard *et al.*, 2013; Jodhka, 2014, Khanal, 2018andAhmad *et al*., 2020).** This event of quitting from agriculture has social and economic implications. The factors that are promoting discontinuance from agriculture / crop farming in third world countries **(Singh *et. al.,* 2009; Mollers and Fritzch 2010; Virra*et al.*. 2010)** and large scale dairying in industrialised countries **(Rahelizatovo and Gillespie 1999; Bragg and Dalton 2004; Stokes 2006; Ferguson and Hassan 2013)** have been widely studied and articulated well within the scientific community. But factors that influence the farmers to quit smallholder dairy farming within the crop-livestock mixed farming system have not been so well examined. Very few studies attempted to understand the above phenomena. In Bangladesh, **Bernhard*et al*., (2013)** made attempts to understand the exit pattern and **FAO (2010)** provided general observation on exit of next generation from smallholder dairying. Apart from above, few micro studies indicate that, the proportion of households owning livestock has also declined in India **(Athilakshmy *et al.,* 2013 and Jodhka, 2014)**. Thus, limited studies; changes in rural demography; urbanisation; increasing consumer demand and withdrawal trend of farmers from farming and ever-increasing milk production made us to study and understand the current status and the future course of smallholder dairy farming as livelihood choice in Tamil Nadu state of India. Furthermore, our study makes attempt to identify factors determining discontinuance.

DATA AND METHODS

Study area

Among various states of India, Tamil Nadu state was purposely selected on account of high urbanisation as compared to other states and its milk production. Nearing half (48.40 per cent) of the population lives in urban and it is most urbanising states of India. The agriculture accounts 13 per cent of the state Gross Domestic Product (GDP) and the remaining were contributed by manufacturing and service sector. Among the rural households, more than 3.24 million households are engaged in agriculture and allied sector activities including dairy farming. The diary animals of state are predominately part of mixed farming systems. Tamil Nadu state has three Crop Livestock systems (CLS 5.3, CLS 1.0, and CLS 15.0) as **per Rao and Birthal, (2008)** comprising 30 prime agriculture districts. It has cattle population of 9.52 million and buffalo population 5.2 million **(GoI, 2020)**. The average milk yield of bovines is around 5.60 litres per day **(NDDB, 2014)**.

Sampling Techniques and Sample size

For this research, datasets of the research titled “Transition of smallholder dairy farming in mixed crop livestock farming system of Tamil Nadu” were used, which was carried out in Veterinary College and Research Institute, Namakkal, Tamil Nadu. A total of 384 dairy households representing three CLS on a proportionate basis were selected from the 410 smallholder dairy households survey conducted in Tamil Nadu state by the first author. The purpose of the above survey was to understand the role of farming system in the future of smallholder dairy farming. In this research above said secondary data was used.

Method of Data Collection

The above said datasets were collected through interview of dairy farmers using semi structured pre-tested interview schedule. The schedule was developed in English and translated to local vernacular language for easier administration. The collected data was triangulated using participatory methods, involving farmers, representatives of animal husbandry department and local governing authorities.

Econometric Model Specification: Binominal logit regression

Binary logistic regression was used to understand the factors influencing the probability of "discontinue" and "continue" dairying. In the logistic regression, if the farmer's response was to discontinue or down size, the farms in next five years were coded as "one" and continue smallholder dairy farming with or without expansion as "zero". The logit model is as follows:

Discontinue intention = $\beta 0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ldots\ldots + \beta_n x_n$----------------Equation (1)

$x_1, x_2, x_3 \ldots\ldots x_n$ represent independent variables

$\beta 0$=constant

β_1, β_2 logistic regression coefficients (estimates)

Discontinue intention=0, (discontinue ≤ 0)

Discontinue intention=1, (discontinue > 0)

Bi-variate correlation between explanatory variables was estimated and variables having high correlation were identified**.** Highly correlated variables namely family income and non-farm income were excluded from the logistic regression analysis.

RESULTS AND DISCUSSION

Status quo of smallholder dairy farmers in Tamil Nadu

On average, a smallholder dairy farmer's household owns 2.81 acres (113.71 ares) of land (Table 1). These households spent about 21 per cent of the available man-days in households outside the origin place (migrated out). These dairy farming households, on an average, had an annual income of INR. 230,380 (INR-Indian National Rupees. 1USD = approximately 75INR). Furthermore, 48 per cent of households had regular incomes from own petty business and / or regular wage works by engaging in non-farm sector. More than half (51.11 per cent of family income) of household income (an average of INR 117,800 per annum) was from non-farm sector. About two-third of the households were lower to middle rural class of the rural society. These households were located 13.86 km away from the nearest town. Nearly 70 per cent of the households had crop farming in addition to dairying.

Table 1 Definition and descriptive statistics of Household and Farm characteristics

Variables	Definition	Mean	Expected effect
Household characteristics			
Land	Actual number of acres of land owned by the farmers	2.81 (113.71 ares)	+/-
Migration intensity	Percentage of man-days migrant(s) staying outside the origin place	21.00	+/-
Status of income from non-farm	Household has at least one member working as wage worker or owns a business in non-farm sector and earns regular income 1; otherwise 0	0.48	+/-
Non-farm income	Refers to total non-farm income of the family (in INR)	117800	+
Family income	Total income of the family (in INR)	230380	+
Rural class	Lower 1; Lower middle 2; middle 3; upper middle 4; upper 5. (1 to 5 refers to weightage to rural class value)	2.98	+/-
Town distance	Distance from household to nearest town	13.63	+/-
Crop cultivation	Status of crop farming (No- 0 and Yes-1)	0.30	+/-
Farm characteristics			
Gender role	Predominantly women 1; otherwise 0	0.84	+/-
Experience	Total years of farmer's experience in dairy farming	28.98	+/-
Involvement of old age group	Predominantly old aged people are engaged in dairying 1; otherwise 0	0.30	+/-
Attitude towards dairying	Farmer's tendency to perceive, feel, behave or act towards dairy farming. Measured using scale developed by Kokate (1984). Maximum score was 16 (high degree of positive feelings towards dairying) and minimum score was 0 (referred high degree of negative feelings).	9.37	-
Input system for dairying	Relatively Low input system = 1; Moderate input system= 2 high input system=3 (1 to 3 refers to weightage to input system)	0.92	+/-
Fodder area	Area under fodder in cents	40 (16.2 ares)	+/-
Access to animal health services	1- Low; 2-Moderate; 3-High (1 to 3 refers to weightage given to level of access to animal health services)	1.73	-

Sale price of milk	Average price received for sale of one litre of milk in INR	21.94	-
Milk marketing opportunities	No marketing opportunity 0; only informal 1; co-operative sector / organised private dairies 2; Co-operative sector and organised private dairies 3. (0 to 3 refers to weightage given to marketing opportunities)	1.63	-
BC ratio	Benefit cost ratio of farms	1.58	-
Share of dairy income	Share of dairy income to total family income	24.08	+/-

The labour requirement for dairying activities was mostly met out through family members and on rare occasions through hired labour force. Household women played a predominant role in two-third (66.50 per cent) of the households in dairying related activities. At the same time, 30 per cent of the dairy farms were predominantly operated by old aged (above 46 years of age) and in these households' meagre participation of other age groups noticed. Added to above, one-fourth of the households had youth (less than 35 years of age) engaged in dairying with or without other age groups. The average age of the persons engaged in dairying was 46 years. Moreover, the farmers had an attitude score of 9.37 towards dairying (maximum possible score 16 refers to a high degree of positive feelings towards dairying and minimum possible score is 0 which refers to a high degree of negative feelings towards dairy profession).

More than one-fourth (26.82 per cent) of the households reared dairy animals in relatively high input system (animals are mostly stall fed with available feed resources having opportunity cost and / or also used commercial compounded feed). About 37 per cent households raised the animals through extensively grazing (Low input system) and remaining were under moderate input system. Added to the above, more than two fifth (42.70 per cent) of the households cultivated fodder and the average area under fodder were 40 cents (16.2 ares) of land among the surveyed households. Nearly two-third (63 per cent) of the farmers had moderate access to animal health services (subsidised services from public sector) in their locality. Similarly, 64 per cent of farmers had access to dispose the surplus milk to organised dairy processing industries (dairy co-operatives and private organised dairies). About 29 per cent of the farmers were disposing their surplus milk through informal marketing system (refers to a small business man who procures 100 to 200 litres per day and transports through motor bikes / cycles and either sell it directly to consumers or processing industries). Remaining farmers (about seven per cent) have limited marketing opportunity. The farmers received an average price of INR 21.94 per litre of milk. These farmers on an average, had benefit cost ratio 1:1.58 (excluding family labour cost) from dairying activities through sale of milk or milk products, manure and calves. The dairying contributed nearly one fourth (24.08 per cent) to total family income.

Discontinue intention of farmers and perceived trends of dairying

The study found that more than half (54.95 per cent) of the farmers are likely to discontinue or downsize the farm in the next five years and 45.05 per cent remainder are likely to continue the farming with or without expansion. Further, 94.30 per cent of the respondents were not willing to motivate the next generation for taking dairying as a profession. The researchers also collected the reasons for not willing to motivate next generation in dairying. Results from table 2 show that, insufficient income from dairying, poor respect to dairying profession in the society (Value system associated with dairying profession among the rural community) and the drudgery involved are the main reasons within the dairy farming sector that are pushing out the farmers from dairying. Employment of the next generation in the non-farm sector, future opportunities in non-farm sector and marriage associated migration of younger age women are the main reasons, which are pulling out the farmers' form dairying profession.

Table 2 Reasons for not willing to motivate next generation in dairying

n=362

Reasons for not willing to motivate next generation	Number of farmers (per cent)
Push factors	
Inadequate income from dairying	348 (90.63)
Poor respect for dairy farmers among peer group / community	274 (71.35)
Drudgery associated with smallholder dairying	109(28.39)
Pull factors	
Next generation that is already employed in non-farm sector	150(39.06)
Opportunity for job in non-farm sector	218(56.77)
Migration of next generation due to marriage	13(3.39)

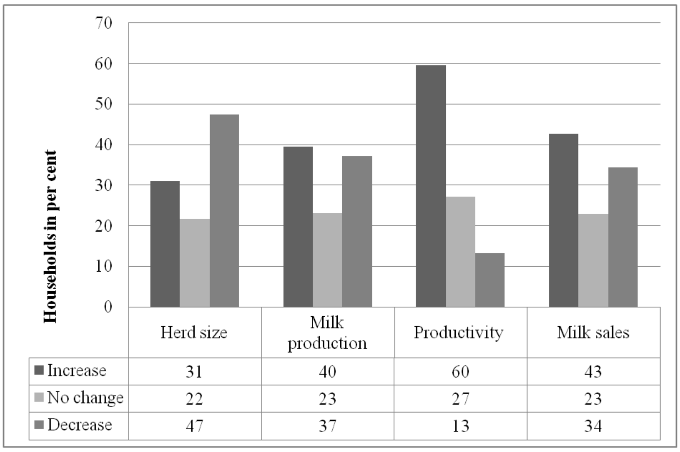

Figure 1 Perception of Trends on smallholder dairy household at household's level in last 10 years (per cent of households)

Added to above, about nearly half (47 per cent) of the farmers reported that there has been a reduction of herd size in their farm in the last 10 years (Figure 1.), while 60 per cent of the farmers reported an increase in milk productivity of animals in the last ten years. In last one decade, two-fifth of farmer's perceived increase in milk production in their farms, while 37 per cent of the farmers perceived the opposite.

Factors underlying the discontinue intention

The results of logistic regression are presented in table 3. The logistic estimates revel that there was highly significant negative relationship between explanatory variables, namely the attitude towards dairying and the milk marketing opportunity with the dependent variable discontinue intention. This implies that increase in attitude towards dairying decrease the probability of discontinue from dairying in next five years. Similarly, if the milk marketing opportunity for the milk increases, then the farmers are likely to discontinue the farming decreases. Access to animal health services has a significant negative relationship with discontinue intention. Furthermore, the farmers with crop income are more likely to have less discontinuance intention from dairying. At the same time, as dairying moves from low to high inputs (example -usage of commercial feed) the discontinue intention increases, and assured income through monthly salary /own business had positive relationship at 10 per cent level of significance with discontinue intention.

Table 3 Estimated coefficients of logistic regression

(n=384)

S.No	Explanatory variables	Estimated coefficient	Standard error
1	Land	1.05	0.06
2	Migration intensity	0.41	0.75
3	Non-farm regular income (as wages or business)	1.71#	0.33
4	Rural class	0.87	0.11
5	Town distance	1.02	0.01
6	Crop cultivation	0.60#	0.30
7	Gender role	0.62	0.32
8	Experience	1.01	0.01
9	Involvement of old age group	0.72	0.28
10	Attitude towards dairy farming	0.86**	0.04
11	Input system	1.65**	0.19
12	Fodder area	1.00	0.00
13	Access to animal health services	0.63*	0.23
14	Sale price of milk	0.98	0.02
15	Milk marketing opportunities	0.68**	0.15
16	BC ratio	0.81	0.19
17	Share of dairy income	1.01	0.01
	Constant	18.08	0.91
	Pseudo R^2 =0.22	**Loglikelihood=459.976**	

**** Significant at 1 per cent level *-Significant at 5 per cent level #-Significant at 10 per cent level**

The majority of the households had intention to discontinue or downsize the farm in next five years and nearly 47 per cent of them have reduced their herd size in last one decade. The findings are similar to the recent past micro studies where quitting from farming has been documented. **Athilakshmy *et al.,* (2013)** observed that about 20 per cent of the farmers had quit cattle rearing during the period 2005 and 2010. Likewise, **Jodhka (2014)** found that during the period 1988-89 to 2008-09 the number of rural households owning cattle declined from 90 to 58 per cent. Similar discontinue pattern from smallholder agriculture activities was noticed profoundly in third world countries **(Headey *et al.,* 2010; Akter, 2011; Bernhard *et al.,* 2013 and Ali, 2018).** Discontinuance of farmers and decline in absolute number of farms was also reported in industrialised dairy farming countries (**Rahelizatovo and Gillespie 1999; Bragg and Dalton 2004; Stokes, 2006 and Ferguson and Hanson 2013).**
At the same time, there is a 6.2 per cent annual growth rate of milk production in India and milk production has increased from 146.31 Million Metric Tonnes (MMT) to 209.96 MMT during the period 2014-15 to 2020-21**(GoI, 2022: 277).** This may be attributed to replacing of indigenous cattle with high producing exotic/crossbreed animals **(GoI 2015: 13 and 17)**. Specifically, during the period 1992 to 2012 the exotic/crossbreed cattle population has increased from 7 to 21 per cent and the absolute number has increased from 15 million to 40 million resulting in six per cent annual growth rate of milk. Moreover, an eight per cent decline of indigenous cattle population observed from the years 1992 to 2012. Hence, at the national level, an increase in the production of milk is also driven by an increase in productivity of animals rather than an increase in number of households engaged in dairying. During the period 1982 to 2012, the productivity of cattle increased from1.9 to 3.9 kg/day and in buffalo productivity increased from 3.7 to 6.2 kg/ day. Further on per animal productivity increased from 1428 Kgs to 1777 Kgs per year from the period 2017-18 to 2019-20 **(GoI, 2021).** This is in concurrence with the perception of farmers on productivity in last one decade of this study. Thus, urbanisation and increasing consumer demand is driving intensification within the smallholder production system through technologies (**Bitew *et al.,* 2013; Swain and Teufel 2013),** resulting in continuous growth rate in milk production. So, an increase in milk production has occurred through the enhancement of productivity rather than through increase in households undertaking the dairying profession. On similar lines, **Rahelizatovo and Gillespie (1999)** and **Bragg and Dalton (2004)** reported decline in farm numbers and increased production in the industrialised context of dairying activities.
Similar to the past research **(Borkaret al. 2001; Rao and Birthal 2002; Chauhan *et al.,* 2006; Birthal and Negi 2012)**, this study found that smallholder dairy farmers have poor land resources who own about 58 per cent of the cattle population of India. Furthermore, parallel to the past studies (**Reddy, 1999 and Lal *et.al.,* 2002),** the data indicated that majority of the households' women played major role in dairying. But, at the same time researcher observed that dairying is mostly an occupation of middle and old aged people and only in one-fourth of the households' youth participated in some dairying activities. This finding contradicts the past findings of **Nisha (1996)** and **Devaki (1999).** They found that majority of the farmers fell in the young age group (less than 35 years old). Furthermore, the findings of this study were also close to recent observations of researchers **Ramkumar *et. al.,* (2004), Rao *et. al.,* (2007) and Thombre *et. al.,* (2012).** This study observed that the average age of farmers is 46 years. Thus, the existing farmers may continue dairying for next 10 to 15 years. Similar trend was also noticed in industrialised farming situation of United States during the 1980s and 1990s (**Gale, 2002).** The experience in dairying was calculated from the year of entry in dairying till the survey year. Three farmers (0.8 per cent) had a year of experience. This means that, prior to the year of survey; only three farmers had taken up dairying and gained an experience of one year. In the periods, prior to year 1970, 1971-1980, 1981-1990, 1991-2000, 2001-2010 and from 2011 onwards the percentage of farmers who took up dairying as profession are 16.20, 16.10, 24.70, 16.70, 14.80 and 11.5 per cent respectively. This indicates that in last three decades, there was a limited entry of newer farmers to the dairying profession. Further this study found that the farms with crop activity tend to continue dairying. Those farmers who had the opportunity to cultivate crop particularly food-feed crops ensured availability of crop residue feed material for animal feeding, making dairying to less depend upon external inputs.
In dairying, the feed is a major recurring cost and it accounts for 60 to 70 per cent of milk production cost. The households which are meeting out feed requirements from grazing resources (Low input system- extensive system of rearing) and crop residues are likely to continue dairying rather than the households that primarily depend on commercial feeds. Data revealed that the farmers under extensive system of rearing primarily grazed the animals on road side, bunds of cultivated field, fallow lands, common lands and used crop residues (minimal input system). Further, access to animal health services, minimises the loss from dairying and promotes continuation of dairy farming. Added on, opting commercial feeds likely to increase the cost of production and promotes discontinue intention. Thus dairy farmers with primarily low cost inputs (grazing and access to subsidised health services) and meeting shortage of feed occasionally (during drought or natural calamities) from other sources are expected to continue farming. But these farms with low input have advantages till the agriculture becomes intensive in transactions beyond the farming gate and the regional economy transforms with use of capital intensive technologies and hired labour **(Hazell *et al.,* 2010**).
Added to above, marketing opportunities for milk play a crucial role in discontinuing of farmers. Limited marketing avenues promote discontinue intention. About one-third of the farms, in their operational areas do not have any formal milk processing industries (Dairy co-operative and private processing industries). The Indian government facilitated the private dairy processing industries through legal regulation in 1992 and subsequent amendments. Thus, in general

marketing opportunities for milk have increased, but still the private industries have not yet spread out to less privileged areas of the country. From the observation of author, the private industries invest and prefer to operate where the dairy co-operatives have invested and have well established milk production eco-system. The co-operatives and the private dairies put together, handle 20 to 30 per cent in India and in the study area around 40 per cent, leaving the remaining milk in informal sector. Thus, dairy industry is in a transition phase from informal to formal sector.

The contribution of dairying to the household income has also increased compared to the past. This study found that there is more than one-fifth contribution from dairying to household income now as opposed to the four per cent contribution by livestock sector in 2002-03 and 12per cent in 2012-13 **(NSSO, 2014: 23).** This might be due to enhanced productivity of animals and increasing market opportunities at the village level in the post liberalisation era. Added to above, **NSSO (2006: 66-67)** data suggests increased expenditure and also demand for milk and milk products. This may be due to increasing urbanisation and changing consumption pattern towards animal origin foods. All this has resulted in increased market demand and is reflected as an increased share of contribution to family income. But the share of dairying to family income has no influence on the discontinue intention. Similarly, the sale price of milk and benefit cost ratio also does not affect discontinue intention. This may be due to varying motives for rearing dairy animals. Only 44 per cent of farmers in the study area were rearing dairy animals primarily for additional income; while 33 per cent were for home consumption and remaining were rearing for other reasons.

At the same time, feelings (attitude towards dairying) associated with dairying have a highly significant negative relationship with discontinue intention. Low level of attitude promotes discontinue from dairying. Furthermore, the farmers reported value system associated with dairying as the reason for demotivating next generation. On similar lines **Agarwal and Agarwal (2017)** reported the social status associated with farming as one of the reasons for disliking farming. In industrialised dairy farming too, the value system towards dairying plays a determinant role in continuance of dairy farming **(Ferguson and Hanson, 2013).** The dairying is also not in a position to meet out the newer aspirations of the rural society. Researcher found that about three-fifth (59 per cent) of the households perceived dairying as a pathway to move out from poverty and only two-fifth (41per cent) perceived it as an ideal instrument for socio-economic improvement. The researchers observed that youngsters associated with dairying are discriminated among the peer group and find difficulty in getting a life partner with in caste and even in some cases it leads to breakage of feudal norms in marriage.

Among dairying households, this study found that nearly two-third (58.60 per cent) of the families migrated out, with more than 21per cent of the available man days of the families being spent in migrated areas. This finding is in concurrence with the observations of **Deshingkar (2010) and Sato (2011)** who reported similar trends of migration in the rural households of India. Even though the dairy farmers are with similar limited land holdings, as in the past, there are changes in the composition of household income. In this study, more than half (51 per cent) of the family income was contributed by non-farm sector. National Sample Survey Office NSSO:(2014) reported similar observation in the study area. In the year 2009, other than crop and livestock farming activities on an average contributed 32.1 per cent **(Kumar *et al.,* 2011) and NSSO (2014: 21)** reported a 40 per cent contribution to the family income in India. This indicates the growing importance of rural non-farm sector in India as well as in Tamil Nadu. Major sources of non-farm income in the study area were in construction, transport, retailing, textile and other sectors in the form of daily wages or income from petty business and in some cases in the form of monthly wages. Informal non-farm sector has been in the forefront in absorption of the labour force and promoting migration **(Jahanmohan *et al.,* 2013)** from the rural households. Thus, majority of rural section ends up with low paid wages of unorganised/informal sector or petty business where continuous employment and income is also a question mark **(World Bank, 2010; Binswanger 2013).** Even though there is inconsistency in non-farm sector employment and income, these income sources (from informal non-farm sector) had a (Table 3) positive influence on discontinue intention. Thus opportunities/employment in the non-farm sector and insufficient income from dairying were the reasons for demotivating the next generation to participate in dairying. **Agarwal and Agarwal (2017)** reported that non-farm income and non- profitability of agriculture are the reasons for disliking farming. Thus dairying households capitalise the current opportunities in non-farm sector and also foresee non-farm sector as a tool for income generation and as a ladder to move up social status.

Thus, farmers use non-farm income for stabilising the farming activity and continue dairying as safety net till the casual nature (informal) and low salary of non-farm sector ceases. This finding is in concurrence with the observations of **Kimhi & Bollman (1999) and Goetz and Dermertin (2000**). Thus, dairy farming families with income sources from informal non-farm is likely to continue till their next generation stabilises their livelihood in non-farm sector. In the long run when actively engaged person in dairying gets retired and non-farm sources stabilises then discontinue is likely to be more predominant. In addition to the above reasons, certain households may continue dairying with prime motive to meet out their household demand of milk rather than the market demands. In these cases, when options to access milk and milk products in the rural market improve, then chances of continuing smallholder milk production may decline.

In short term, the households which are having relatively high input dairying activity but with low level of attitude towards dairying, operating in poor marketing opportunity areas and having income from non-farm sector are likely to discontinue from dairying. While in the long run, inadequate income from dairying, value system associated with dairying and developments in the non-farm sector are limiting the entry of next generation. Thus, the factors that are responsible for discontinue from smallholder dairying in crop-livestock mixed farming are similar to the documented factors that are responsible for discontinue from agriculture and / or industrialised dairy farming except market opportunities. As per the observations of **Hazell *et al.,* (2010),** when selling shifts from farm gate and transactions

intensify beyond the farm gate then small farms have less advantage. But in this study the marketing opportunity is a determinant for continuing dairying in short term. This may be due to transition nature of the Indian economy.
Currently the emerging limitations in production side on account of discontinue and increasing market demand is addressed through increasing productivity of animals within the smallholder production system. On long run on account of economic transformation and increasing demand of food commodities, the smallholder farmer's role will reduce and drive consolidation of farms **(Hazell *et al.*, 2010)**. In future (after 10 to 15 years – when existing farmers reach 60 years of age from 45 to 50 years of age) smallholder dairying may not be a sole player in milk production. The emerging vacuum on the production side of the dairy value chain may be addressed by emerging specialised medium[1]and larger dairy farms **(Shah and Dave, 2010) or** through import from surplus countries[2].

CONCLUSION

With the limitations of geographical spread of the study, the authors conclude that external factors outside the dairy sector such as developments in non-farm sector, changing values in rural people and internal factors associated with dairying such as varying levels of market opportunities, feelings associated with dairying as occupation, insufficient income are driving the discontinue intention of farmers from dairying. Thus, smallholder dairy farmers under discontinue phase from production are increasing while alternative arrangements to meet the demand for milk are also emerging.

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REGULAR ARTICLE

CONSUMPTION FREQUENCY FOR SELECTED ROOTS AND TUBERS AMONG URBAN HOUSEHOLDS OF NAKURU COUNTY, KENYA

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ABSTRACT

Research background: With the ever-increasing population suffering from hunger and malnutrition, frequent consumption of roots and tubers (R&Ts) is likely to improve household health and nutritional status. R&Ts contribute to improved nutrition, provide medicinal benefits and are a cheaper source of carbohydrates, vitamins, and minerals hence much affordable for urban poor households. Despite their highlighted benefits, R&Ts consumption levels among urban consumers have reduced significantly and the reasons for the decline remain unknown. Assessing households' consumption frequency for R&Ts is essential in enhancing their utilisation.
Purpose of the article: This study evaluated factors influencing consumption frequency for selected R&Ts among urban households of Nakuru county, Kenya.
Methods: A stratified multistage sampling technique was employed to select a random sample of 385 urban respondents, and data were collected using a pretested semi-structured questionnaire. The collected primary data were analysed using a negative binomial regression (NBR) model.
Findings, Value added & Novelty: The mean consumption frequency for R&Ts was seventeen times a month. Household size, monthly income, household health, farming of R&Ts, nutritional knowledge, and availability of different types of R&Ts influenced their consumption frequency among urban households. In this regard, R&Ts value addition strategies such as peeling, washing, drying, packaging and labelling could increase their acceptance as convenient foods among urban dwellers. Food policies that improve R&Ts supply chain efficiency could increase their production and consumption, consequently broadening the food base at household and national levels.

Keywords: consumption frequency; negative binomial regression; nutrition security; root and tuber crops; urban households.
JEL Codes: D11; D12; I15; Q18

INTRODUCTION

As the human population increases, pressure mounts on the global food system resulting in hunger and malnutrition thereby affecting millions of people, especially in the developing world. Hunger and malnutrition indicate inadequate consumption of fruits and vegetables, roots and tubers included **(FAO *et al.*, 2020; Ogbonna *et al.*, 2017)**. For instance, the recommended World Health Organization's (WHO) minimum consumption of fruits and vegetables is 400g per person per day **(Mason-D'Croz *et al.*, 2019)**. However, Sub-Saharan Africa (SSA) is a specific area of concern, with projections suggesting that by 2050 around 1.9 billion people could be consuming low than the recommended levels of R&Ts per person per day **(Mason-D'Croz *et al.*, 2019)**. In Kenya, approximately 48 per cent of the urban households consume insufficient amounts of R&Ts **(Mohamed *et al.*, 2021; Wanyama, 2019)**, likely resulting in micronutrient deficiencies, stunted growth, impaired cognitive development, and susceptibility to diseases.

R&Ts found in SSA, Asia, and the Americas include Irish potato (*Solanum tuberosum* L.), sweet potato (*Ipomoea batatas* L. Lam.), cassava (*Manihot esculenta* Crantz), arrowroots (*Maranta arundinacea* L.), and yam (*Dioscorea alata* L.) **(MoALFI, 2019)**. They are the second most highly regarded food after cereals and play a significant role in sustainable production and consumption contributing to food and nutrition security at the household and national level **(Gweyi-Onyango *et al.*, 2020; Onodu *et al.*, 2020)**. Moreover, an estimated 300 million poor people in developing countries rely on R&Ts for consumption and income generation **(Thiele *et al.*, 2017)**.

R&Ts global production is projected to reach 1400 million tons by 2050, with SSA accounting for the largest proportion **(Petsakos *et al.*, 2019; Thiele and Friedmann, 2020)**. In Kenya, their production was estimated at 3,684,000 metric tonnes (MT) in 2018 compared to 2,419,000 MT in 2015. Unlike production, there is insufficient current aggregate R&Ts consumption data. However, using Irish potato consumption data as a proxy or representative measure, it is evident that their consumption in the country has declined. For instance, Irish potato consumption reduced from 2,507,000 MT in 2012 to 1,714,000 MT in 2019 **(Helgi Analytics, 2022; MoALFI, 2019)**. This drop in R&Ts consumption is an indication that their consumption frequency has also reduced and could be attributed to a shift in consumption patterns favouring low-cost imports, exotic foods, and conveniently prepared alternatives. Moreover, their high perishability and lack of efficient value addition strategies to prolong their shelf life further discourage consumption since consumers cannot purchase them in bulk like grains and cereals. Therefore, R&Ts remain some of the most underutilised foods among many urban dwellers **(Dawson *et al.*, 2009)**.

However, due to their unique characteristics such as; diverse maturity cycles, broader agroecological adaptation, and underground storage ability that allow for flexible harvesting duration, R&Ts have the potential of addressing hunger and essential element deficiency (malnutrition), especially in the developing world. As the primary source of cheap carbohydrates, they provide high energy and nutritional value per unit, contribute phenolic compounds, minerals (potassium, magnesium, calcium, and sodium), trace elements (iron, manganese, and zinc), and vitamins A, B, and C **(MoALFI, 2019; Suárez *et al.*, 2016; Dawson *et al.*, 2009)**. In addition, when frequently consumed at moderate intervals, they provide medicinal benefits that curb dietary-related diseases such as obesity and diabetes **(Saranraj *et al.*, 2019; Gayao *et al.*, 2018; Niehof *et al.*, 2018; Chandrasekara and Kumar, 2016)**.

R&Ts are consumed as staple foods during breakfast, lunch and dinner **(de Sousa *et al.*, 2019)**, therefore forming the majority of delicacies by households across the world's tropical regions. More often, R&Ts serve as complements, substitutes, seasonal vegetables during famine, and meals for special occasions. For instance, cassava, sweet potato, and arrowroot substitute or complement cereals and wheat products **(Chandrasekara and Kumar, 2016)**. The majority of R&Ts are consumed fresh or boiled, steamed, fried, roasted and mashed to form puree and often eaten with rice, leafy vegetables, and stew. Moreover, starch from R&Ts such as Irish potato and arrowroot are readily digestible, therefore, used to prepare food for infants **(Dereje *et al.*, 2020; MoALFI, 2019)**. Thus, the regular inclusion of different R&Ts recipes in household diets could significantly explain their consumption frequency. **Menza *et al.*, (2014)** revealed that R&Ts consumption ranges from daily to several times a week, with an average of about one kg of the crops being consumed per person per day. Similarly, **Low *et al.* (2009)** intimated an average R&Ts consumption frequency of two to four times a week. Therefore, this paper helps understand the influence of frequent R&Ts consumption on household health and nutrition security.

LITERATURE REVIEW

Despite their highlighted potential in contributing to food and nutrition security, curbing dietary-related ailments through their medicinal properties and acting as a source of income among households, R&Ts consumption is constrained by socio-demographics, institutional, economic, cultural, and food characteristics **(Baek and Chitekwe, 2019; Mbwana *et al.*, 2016)**. For instance, an increase in income allocated to R&Ts expenditures increases the likelihood of their consumption frequency **(Adeosun *et al.*, 2017)**. Furthermore, preparation skills and nutritional knowledge significantly influenced the diverse consumption counts of R&Ts **(Ochieng *et al.*, 2017)**. **Teweldemedhin and Mulonda (2016)** revealed that family size positively influenced consumption frequency for R&Ts. Older respondents consumed R&Ts more frequently than younger ones **(Lacaze *et al.*, 2012)**. Taste perception has a significant influence on R&Ts consumption; that is, the tastier the vegetable, the more it was consumed **(Gwladys *et al.*, 2020)**. Moreover, perceived nutritional value plays a significant role in how often R&Ts are consumed **(Bechoff *et al.*, 2018)**.

Strategies for enhancing nutrition security have emphasised the inclusion of R&Ts in the household dietary diversity to reduce overreliance on cereal-based foods facing supply disruptions during the Covid-19 pandemic and climate change **(Muthamilarasan and Prasad, 2021)**. Increasing R&Ts consumption frequency is a strategic way of addressing micronutrient deficiency and dietary-related diseases since they contain adequate essential elements, vitamins and minerals that are inadequate in grains and cereals **(Birol *et al.*, 2015)**. However, the low R&Ts consumption levels and frequency do not guarantee the highlighted benefits **(Mohamed *et al.*, 2021; Wanyama, 2019)**.

From the preceding, the study evaluates the role of socio-economic, institutional, and product attributes in influencing consumption frequency for selected R&Ts crops among urban households. This paper contributes to the limited literature on applying count model analysis in R&Ts consumption. To our knowledge, this is the first study to use the NBR model in analysing consumption count for R&Ts. Another unique aspect is the application of a one-month exposure period leading to non-zero R&Ts consumption. Findings from the study could inform food policy formulation through relevant authorities as they seek to increase R&Ts consumption frequency to enhance food and nutrition security and curb other dietary-related diseases.

DATA AND METHODS

Study area and sampling design

The study was undertaken in Nakuru Town East Sub County in Nakuru county, Kenya. The sub-county covers an area of 230.9 square km and is inhabited by 193,926 people distributed within a population density of 840 persons per square km **(KNBS, 2019)**. This sub-county has five wards; Biashara, Kivumbini, Menengai, and Nakuru East and enjoys a temperate climate all year round. It lies between longitude 36º 3′6″ East and 36º 9′45 ″ East and Latitude 0° 15′ 36″ South and 0° 30′ 0″ South, at 1,850 m above sea level. The sub-county hosts major agricultural retail and wholesale markets and serves consumers from within and outside the county **(NCIDP, 2018)**. Moreover, it hosts Kenya's largest retail and wholesale chains of supermarkets: Quick Mart, Naivas, and Gilani's supermarkets, convenient markets for R&Ts. Since agriculture is not the main socio-economic activity of this sub-county, the residents rely on food supplies from other regions. Therefore, the area is strategically located for conducting the study.

Respondents were selected using a stratified multistage sampling technique. The first stage used a purposive selection of Nakuru County due to the heterogeneous nature of consumers. The second stage purposively selected Nakuru Town East Sub-County because it hosts the largest number of R&Ts markets. In the third stage, R&Ts markets were stratified into supermarkets, organised open-air markets, and roadside stalls across all Nakuru Town East Sub County wards. The fourth stage employed a mixed sampling technique divided into two categories. The first category applied judgmental sampling because the population of R&Ts consumers in the study area was infinite with unknown ward distribution **(Kothari, 2004)**. Respondents were distributed evenly across the selected markets and in all wards. The second category used random sampling to select an equal number of respondents from each market outlet across the wards **(Kothari, 2004)**.

The sample size was obtained using **Kothari (2004)** approach, and data were collected from mid-April to the end-April 2021, where 385 respondents were selected and spread equally across all the R&Ts markets in all wards. For research clearance in Kenya, the National Commission for Science, Technology, and Innovation and Ethics research permits were sourced from responsible authorities. Pretesting the questionnaires was done to assess the suitability and feasibility of the data. After correcting anomalies in the data tool, well-trained enumerators used the semi-structured questionnaire to collect primary data. Respondents were interviewed immediately after buying R&Ts at the market outlets.

The information collected from the respondents includes decision-makers' gender, age, years of schooling, household size, income level, distance to the market, frequency of R&Ts consumption (recall of one month), availability of R&Ts, respondents' perceptions regarding R&Ts retail prices, and R&Ts characteristics. According to **MoALFI (2019)**, the main roots and tubers identified as commonly produced and consumed in Kenya include Irish potatoes (*Solanum tuberosum* L.), sweet potatoes (*Ipomoea batatas* L. Lam.), cassava (*Manihot esculenta* Crantz), arrowroots (*Maranta arundinacea* L.), and yams (*Dioscorea alata* L.). Therefore, information on all five R&Ts was collected. Respondents' quality perception and nutritional knowledge of R&Ts were assessed using the questions ''Does the quality of R&Ts influence their consumption frequency?'', and "Does nutritional knowledge influence R&Ts consumption frequency?". The responses were categorised as "Yes = 1" and "NO = 0". Further questions then accompanied this on the positive response (Yes), where respondents selected essential nutrients found in various R&Ts. The collected data were then entered, coded, and data entry errors removed, followed by diagnostic and econometric analysis of the model using Stata 12 **(StataCorp, 2014)** computer program.

Econometric modelling of factors influencing consumption frequency of R&Ts

Consumption frequency in this study was measured as the number of times a household consumed R&Ts in the past one month regardless of the type of R&T crop because of variation in consumer taste and preferences. Nutritional benefits obtained from the consumption of R&Ts can be achieved by maintaining regular consumption intervals. This is important, especially in developing countries suffering from hunger and malnutrition. The duration of 1 month was presumed adequate for analysing consumption frequency for R&Ts. The estimated results could be helpful in policy formulation for enhancing R&Ts consumption. Therefore, count data models were preferred in this study to evaluate consumption frequency for R&Ts **(Gujarati and Porter, 2004)**. The survey analysed all the four-count models to identify the one that best fit the study.

The standard Poisson regression model was the first to be analysed **(Gujarati and Porter, 2004)**. However, the model suffered from an over-dispersion problem where its conditional mean was lower than its variance function, violating its basic assumption. The test for over-dispersion was conducted using Deviance and Pearson goodness of fit tests as explained in the results and discussion section. The limitation was addressed using the advanced negative binomial regression (NBR) model **(Greene, 2002)**. The NBR model ran and passed all the goodness of fit tests such as; the lower Akaike information criterion (AIC) and Bayesian information criterion (BIC), implying the NBR was more appropriate than the standard Poisson. Higher models were analysed to ascertain the validity and feasibility of the NBR. The third model was the zero-inflated Poisson (ZIP) model. Unfortunately, it suffered from an over-dispersion problem of the data set as revealed by Deviance and Pearson goodness of fit tests, where the observed response variance was greater than the conditional mean **(Gurmu and Trivedi, 1996; Mullahy, 1986)**. The fourth to be analysed was the zero-inflated negative binomial (ZINB) model **(Minami *et al.,* 2007)**. However, the model failed because the data lacked zero consumption counts for R&Ts for the one-month exposure time. Moreover, the goodness of fit tests (AIC and BIC estimates) had higher values than the previous models. Comparing the AIC and BIC values for all the four models suggested using the NBR model, which passed all the necessary goodness of fit tests and had lower AIC and BIC values. Therefore, the NBR was used (Equation 1);

$$q\ (y_i|\mu_i\ ,\theta) = \frac{\Gamma(\theta+y_i\ )}{\Gamma(\theta)\ \Gamma(y_i+1)}\left(\frac{\theta}{\theta+\mu_i}\right)^{\theta}\left(\frac{\mu_i}{\theta+\mu_i}\right)^{y_i}\ \text{ for } y_i = 0,1,2,3,\dots \qquad (1)$$

where $q\ (y_i|\mu_i\ ,\theta)$ is the probability function on non-negative integers, y_i is the consumption outcome for household i, μ_i is the mean incidence rate y per unit of exposure. Exposure may be space, time, distance, volume, area, or population size. θ is the precision or size parameter $\Gamma(.)$ is a gamma distribution function. μ_i are log-likelihood functions represented by In $\mu_i = B_i'\beta$, such that, B_i is the row vector of covariates and β is the parameter estimate.

The socio-economic, institutional, and product-related characteristics used as covariates in analysing factors influencing consumption frequency for selected roots and tubers among urban households of Nakuru County were derived from previous studies **(Fang *et al.,* 2019; Wahyudi *et al.,* 2019; Kimambo *et al.,* 2018; Saghaian and Mohammadi, 2018; Gido *et al.,* 2017, 2015; Gitonga, 2013; Teklewold *et al.,* 2013; Lacaze *et al.,* 2012; Minami *et al.,* 2007)**.

RESULTS AND DISCUSION

Descriptive results

Descriptive and summary statistics (Table 1) indicate that majority of the respondents were of middle age and literate, having attained secondary school level. Many of the decision-makers were females, probably because food consumption decisions are made mainly by women which agrees with **Wahyudi *et al.* (2019)**. A majority of the decision-makers earned low incomes and had fewer household members. The distance from the residence to the R&Ts market was reasonably long (approximately 7km). However, the respondents argued that these distant markets were convenient for accessing diverse and high-quality R&Ts, which agrees with **Gido *et al.* (2017)**. Households culture and an outbreak of the Covid-19 pandemic influenced the frequent consumption of R&Ts probably due to their medicinal benefits **(CIP, 2020)**.

Table 1 Description of variables and descriptive statistics

Variable	Description of variables and their measurements	Mean
Continuous variables		
Age	Age of the decision-maker[1] in years	39.85
Education	Years of education of the decision-maker	12.61
Household Income	Monthly income of the decision-maker in KES[2]	31,822.73
Household size	Number of household members	4.31
Market distance	Distance from home to the market outlet for R&Ts[3] (in km[4])	6.58
Categorical variablesPercentage		
Gender	% of male decision-makers	47.79
Nutrition knowledge	% of respondents whose nutritional knowledge influences the frequency of consumption for R&Ts	86.49
Prices for R&Ts	% of respondents who perceive prices of R&Ts are affordable	90.13
Farming R&Ts	% of respondents with their own farm production of R&Ts	25.71
Culture	% of respondents whose culture influence preference for R&Ts	79.22
Household health	% of respondents who prefer R&Ts for health reasons	25.71
Covid19	% of respondents who consume R&Ts due to the Covid-19 pandemic	74.29
Preparation time	% of respondents who perceive R&Ts take a shorter time to prepare	69.61
Production place	% of respondents who were concerned about the production place for R&Ts	63.90
Availability R&Ts	% of respondents who perceive the availability of different types of R&Ts influence consumption of the crops	67.01
Size of R&Ts	% of respondents concerned about the size of R&Ts	96.10
Quality of R&Ts	% of respondents who were concerned about the quality of R&Ts	97.14
Taste for R&Ts	% of respondents who perceive taste for R&Ts influence frequency of consumption	92.47

[1] Decision-maker is the household member responsible for making food consumption decisions
[2] KES refers to the Kenyan shilling (official Kenyan currency); the exchange rate to US$ is 1 $US = KES. 113.05
[3] R&Ts = Roots and Tubers
[4] km refers to the distance in kilometers

The average consumption frequency of R&Ts among urban households was seventeen times a month (Table 2). The monthly maximum R&Ts consumption count was 85 because; Consumption frequency was a summation of R&Ts meal counts for each of the selected five crops. The study focussed on the number of R&Ts meals consumed in a month rather than the number of days. Finally, some households reported having consumed up to four R&Ts meals in a day; Therefore, likely to result in higher monthly counts. This could be attributed to varying dietary habits among households **(Ferraro *et al.,* 2016)**. For instance, households recording higher consumption frequency for R&Ts utilised them as a substitute for wheat products during breakfast and food for infants throughout the day. R&Ts complemented other meals during lunch and supper, acting as staple food among households. On the lower counts, no zero consumption level was revealed during the survey implying that all households consumed R&Ts at least once per month.

Table 2 Monthly consumption frequency of R&Ts meals among households

Variable Statistics	Obs.	Mean	St. Dev.	Min	Max
Cons_frequency	385	17.22	11.12	1	85

Determinants of consumption frequency for R&Ts

Four count models were estimated consecutively to identify the model that best fits the data in explaining consumption frequency for R&Ts. The standard Poisson model was estimated first (Appendix 1). To determine its appropriateness, a test for goodness of fit was done (Appendix 2) and a test for overdispersion (Appendix 3). For comparison, NBR model was estimated (Table 3). Its results revealed an overdispersion problem because the likelihood ratio test was significant, as shown by alpha greater than zero, implying NBR was more appropriate than the standard Poisson model. Estimation of Akaike information criterion (AIC) and Bayesian information criterion (BIC) was done to ascertain the goodness of fit for the NBR model (Appendix 4). Lower values of either AIC or BIC indicate a better fit. The lower AIC and BIC values for NBR suggested that it was preferred to the standard Poisson model.

Table 3 NBR model results on factors influencing consumption frequency for R&Ts

	Variables for Cons_frequency	Coef.	Std.Err.
Socio-economic factors	Age	-0.003	0.003
	Gender	-0.057	0.052
	Education	-0.007	0.009
	Household size	0.047***	0.015
	Household income	0.140***	0.053
	Culture	-0.002	0.028
	Household health	0.069*	0.037
	Covid-19	0.012	0.029
Institutional factors	Market distance	-0.003	0.004
	Farming R&Ts	0.139***	0.040
	Nutrition knowledge	0.095***	0.036
	Prices for R&Ts	0.006	0.035
	Production place	-0.023	0.026
	Availability R&Ts	-0.124**	0.063
Product related factors	Size of R&Ts	0.054	0.047
	Quality of R&Ts	0.039	0.045
	Taste for R&Ts	0.060	0.040
	Preparation time	0.009	0.028
	Constant	0.951**	0.461
	/lnalpha	-1.713	0.095
	Alpha	0.180	0.017
LR test of alpha=0: $chibar^2(01)$	= 692.240	Prob >= chibar2	= 0.000***
LR test for the model $chi^2(18)$	= 150.750	Prob > chi2	= 0.000***
Akaike crit. (AIC)	= 2680.703	Bayesian crit. (BIC)	= 2759.768

***, **, * = Significant at 1%, 5%, and 10%, respectively

The third level estimated the ZIP model (Appendix 5). ZIP model results did not display the z-test for Vuong because the model crushed; therefore, the appropriateness of the model over the Poisson could not be ascertained. The model returned the message "Cons_frequency never equal to zero; use Poisson instead," implying that it was not a significant improvement over the standard Poisson model. The possible reasons for the ZIP model crushing were the lack of zero consumption counts and the overdispersed data that the ZIP model could not handle. Additionally, estimating the fit statistics for AIC and BIC indicated that the ZIP model was not preferred over NBR (Appendix 6). Finally, the ZINB model was estimated (Appendix 7), where the model fit was tested and compared to the NBR. The zip option tests for an alpha of zero had a significant likelihood ratio test, implying that the ZINB was more appropriate than the ZIP model. The z-test for Vuong was insignificant, indicating that the ZINB was not a significant improvement over the NBR model. A further comparison of model fit for all the four regression models (Appendix 8) indicated that the NBR model was more suitable for this study; therefore, it was adopted. The NBR results are shown in Table 3. Several variables

significantly influenced the consumption frequency of R&Ts among urban households.
Household size significantly and positively influenced consumption count for R&Ts by decision-makers. Larger households require high quantities of food resulting in increased expenditure on meals. R&Ts are generally more affordable than other food items, therefore more likely to be frequently consumed in large households. Similarly, **Zani *et al.* (2019)** found that households with many members were more likely to increase the consumption of starchy staples (cassava in this case) than smaller households. This was attributed to less cost incurred in purchasing enough cassava for a larger family. Contrary, **Villano *et al.* (2016)** found a negative association between household size and consumption of sweet potatoes because they retailed at higher prices, therefore expensive to feed large families.
Increased monthly income significantly and positively influenced consumption frequency for R&Ts among households. High-income earners have higher purchasing power and are more likely to incorporate R&Ts in their dietary diversity and quality **(Mmasa *et al.*, 2012)**. The results agree with **Sanusi and Babatunde (2017)** confirming a positive relationship between household income and consumption of sweet potatoes possibly for the same highlighted reason. Moreover, **Zani *et al.* (2019)** found household income to positively influence cassava consumption because it is a staple food, attracting more spending. However, according to Engel's Law, the increase in food spending is at a lower proportion than an increase in income **(Mansfield, 1982)**. Higher levels of income enable incorporation of R&Ts into households' dietary systems improving their nutritional quality.
Households' health status significantly and positively influenced the frequency of R&Ts consumption. Households with pre-existence health conditions are cautious of their diets **(de Ridder *et al.*, 2017)**; Therefore, they are more likely to consume R&Ts known to boost body immunity in the fight against various diseases. Discussions with the respondents revealed that the medicinal benefits of R&Ts increased their frequency of consumption among households. For instance, sweet potato consumption has been promoted due to its distinct nutritional and health properties **(Gething *et al.*, 2012)**. **Wallace *et al.* (2020)** found similar results where sweet potato and white potato were more accepted for consumption among households suffering from dietary-related diseases (diabetes, obesity, and cancer) because of their medicinal properties.
Own farm production of R&Ts by households was more likely to influence consumption count for the crops at a 1% significant level. Farming of R&Ts by urban dwellers is a survival tactic, especially by the poor, who are net food buyers and suffer when prices of food items go up. Through this strategy, urban households producing R&Ts from their own farms; either urban farming or rural farming, are likely to increase the consumption frequency of the crops compared to those who buy them in the market due to reduced food expenditure. Moreover, the excess R&Ts can be sold to generate household income and purchase alternative food items not produced on the farm; therefore, improving their dietary system **(Petsakos *et al.*, 2019; Tasciotti and Wagner, 2015)**, contributing to household's food and nutrition security **(Cohen and Garrett, 2010)**.
Nutritional knowledge among decision-makers significantly and positively influenced consumption frequency for R&Ts a 1% significant level. Nutritional knowledge provides dietary information that enables households to diversify their consumption plans by making food choices that improve metabolism and life quality **(Olatona *et al.*, 2019)**. Through enhanced nutritional knowledge, decision-makers know the recommended daily consumption of different food items enabling them to consume a balanced diet by incorporating R&Ts in meals. Moreover, nutritional knowledge assists households in selecting R&Ts with high nutritive value and developing different recipes which are acceptable to all the family members. This finding corroborates with that of **Villano *et al.* (2016)**, who found a positive association between nutritional knowledge and consumption of sweet potato, attributed to its role in curbing malnutrition.
The availability of different types of R&Ts is less likely to influence their consumption frequency. Perhaps because of exposure to a wide variety of foods many urban households have shifted their consumption trends from traditional diets (R&Ts in this case) in favour of other food items that are more convenient to prepare **(Cockx *et al.*, 2019)**. Consequently, as time goes by, the households are less aware of selecting the best quality R&Ts and how to prepare them for meals. As to health impact, R&Ts such as cassava possess antinutrients (cyanide) which are likely to cause various ailments, further discouraging its consumption. The fear of contracting thyroid syndrome due to cassava consumption and gastrointestinal disorders caused by sweet potato consumption creates a negative perception of R&Ts among households, therefore reducing their consumption **(Koostanto *et al.*, 2016)**. Moreover, some arrowroot varieties are suspected of harbouring toxic substances, while others have a bitter taste. The highlighted adverse effects associated with some R&Ts varieties coupled with lack of information concerning the benefits of the crops create an overall negative perception, therefore, discouraging their consumption. There is a need to enhance awareness of the nutritional benefits of different R&Ts to boost their consumption frequency **(Hunter *et al.*, 2019; Laurie *et al.*, 2018)**.

CONCLUSION AND RECOMMENDATIONS

The study evaluated determinants of consumption frequency for selected roots and tubers among urban households using a negative binomial regression (NBR) model. Findings indicated a mean consumption frequency of 17 R&Ts meals in a month; therefore, significant in the diets of many urban households. Larger households had a higher consumption frequency of R&Ts attributed to their affordability. Increased monthly income positively influenced consumption counts for R&Ts, probably because of the household's higher purchasing power. Households with underlying health conditions had a higher frequency of R&Ts consumption because of their medicinal benefits. Own farm production of R&Ts by households reduced food expenditure, increasing the crops' consumption frequency. Decision-makers with nutritional knowledge had a high consumption count for R&Ts, while the availability of different types of R&Ts had a contrary effect.

The findings from this study have food policy implications that seek to enhance consumer awareness of nutritional benefits of R&Ts consumption, various methods of preparing them, and increasing diversity of the crops in food systems. Through sensitisation programs, knowledge regarding R&Ts is passed to households, increasing their consumption frequency. This can be achieved by circulating information through training, advertisements on social, mass, and print media, producer and consumer organisation workshops, and roadside campaigns conducted in local dialects to reach as many households as possible.

R&Ts value addition strategies that involve peeling, washing, drying, and packaging them in properly labelled containers could enhance their marketability. Additionally, these strategies could save time required at the initial R&Ts preparation stages before cooking among urban consumers. Finally, food policies that improve R&Ts supply chain efficiency could increase their production and consumption, consequently broadening the food base, and contributing to households and national nutritional security. This study recommends a need for similar future research that could consider consumer choice of market outlet for R&Ts, which might affect their behavioural preference regarding availability and accessibility of the crops.

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Appendix 1

Table 4: Standard Poisson results on factors influencing consumption frequency for R&Ts

	Variables for Cons_frequency	Coef.	Std.Err.
Socio-economic factors	Age	-0.001	0.001
	Gender	-0.054**	0.025
	Education	-0.006	0.004
	Household size	0.042***	0.007
	Household income	0.156***	0.026
	Culture	-0.018	0.013
	Household health	0.049***	0.016
	Covid-19	0.026*	0.014
Institutional factors	Market distance	-0.004*	0.002
	Farming R&Ts	0.125***	0.018
	Nutrition knowledge	0.094***	0.017
	Prices for R&Ts	0.001	0.016
	Production place	-0.019	0.012
	Availability R&Ts	-0.107***	0.031
Product related factors	Size of R&Ts	0.061***	0.023
	Quality of R&Ts	0.03	0.022
	Taste for R&Ts	0.053***	0.019
	Preparation time	0.012	0.013
	Constant	0.757***	0.23
LR test for the model $chi^2(18)$ = 785.65		Prob > chi^2	= 0.0000***
Akaike crit. (AIC) = 3370.943		Bayesian crit. (BIC)	= 3446.054

***, **, * = Significant at 1%, 5%, and 10%, respectively

Appendix 2

Table 5: Standard Poisson regression model test for goodness of fit

Test for the goodness of fit (model is not fit)	Test for overdispersion
Deviance goodness-of-fit = 1595.388	Deviance gof [1] /df = 1595.388/366 = 4.358984
Prob > chi2(366) = 0.0000***	> 1 implies over distribution
Pearson goodness-of-fit = 1796.69	Pearson gof /df = 1796.69/366 = 4.908989
Prob > chi2(366) = 0.0000***	> 1 implies over distribution

[1] gof refers to the goodness of fit of the model.

Appendix 3

Table 6: Overdispersion test using conditional mean and variance for the standard Poisson model

Availability R&Ts	Mean	variance	N
No	16.079	106.168	127
Yes	17.787	131.803	258
Total	17.223	123.695	385

The variance is greater than the mean across, implying the presence of data overdispersion

Appendix 4

Table 7: AIC and BIC test for goodness of fit between Poisson and nbreg

Model	Obs	ll(null)	ll(model)	df	AIC	BIC
poisson	385	-2059.296	-1666.471	19	3370.943	3446.054
nbreg	385	-1395.724	-1320.351	20	2680.703	2759.768

Lower values of either AIC or BIC indicate a better fit

Appendix 5

Table 8: ZIP model results on factors influencing consumption frequency for R&Ts

	Variables for Cons_frequency	Coef.	Std.Err.
	Standard Poisson regression		
Socio-economic factors	Age	-0.001	0.001
	Gender	-0.054**	0.025
	Education	-0.006	0.004
	Household size	0.042***	0.007
	Household income	0.156***	0.026
	Culture	-0.018	0.013
	Household health	0.049***	0.016
	Covid-19	0.026*	0.014
Institutional factors	Market distance	-0.004*	0.002
	Farming R&Ts	0.125***	0.018
	Nutrition knowledge	0.094***	0.017
	Prices for R&Ts	0.001	0.016
	Production place	-0.019	0.012
	Availability R&Ts	-0.107***	0.031
Product related factors	Size of R&Ts	0.061***	0.023
	Quality of R&Ts	0.03	0.022
	Taste for R&Ts	0.053***	0.019
	Preparation time	0.012	0.013
	Constant	0.757***	0.23
	Logistic regression for zero inflation		
	Age	-2228.591	.
	Gender	-96164.124	.
	Education	-7051.493	.
	Household size	-18326.45	.
	Market distance	-7812.849	.
	Prices for R&Ts	-38902.759	.
	Production place	-45234.745	.
	Constant	-96229.874	.
LR test of alpha=0: chibar2(01)	=.		Prob>=chibar2 = .
Vuong test of zip vs. standard Poisson: z =.			Prob > z =.
LR test for the model chi2(18)	= 785.65		Prob > chi2 = 0.0000***
Akaike crit. (AIC)	= 3370.943		Bayesian crit. (BIC) = 3446.054

***, **, * = Significant at 1%, 5%, and 10%, respectively.

Appendix 6

Table 9: AIC and BIC test for goodness of fit between Poisson, nbreg, and zip

Model	Obs	ll(null)	ll(model)	df	AIC	BIC
poisson	385	-2059.296	-1666.471	19	3370.943	3446.054
nbreg	385	-1395.724	-1320.351	20	2680.703	2759.768
zip	385	-2059.296	-1666.471	19	3370.943	3446.054

Lower values of either AIC or BIC indicate a better fit.

Appendix 7

Table 10: ZINB model results on factors influencing consumption frequency for R&Ts.

	Variables for Cons_frequency	Coef.	Std.Err.
Socio-economic factors	Negative Binomial regression		
	Age	-0.003	0.003
	Gender	-0.057	0.052
	Education	-0.007	0.009
	Household size	0.047***	0.015
	Household income	0.14***	0.053
	Culture	-0.002	0.028
	Household health	0.069*	0.037
	Covid-19	0.012	0.029
Institutional factors	Market distance	-0.003	0.004
	Farming R&Ts	0.139***	0.04
	Nutrition knowledge	0.095***	0.036
	Prices for R&Ts	0.006	0.035
	Production place	-0.023	0.026
	Availability R&Ts	-0.124**	0.063
Product related factors	Size of R&Ts	0.054	0.047
	Quality of R&Ts	0.039	0.045
	Taste for R&Ts	0.06	0.04
	Preparation time	0.009	0.028
	Constant	0.951**	0.461
		Logistic regression for zero inflation	
	Age	0.00	376.068
	Gender	0.00	7551.433
	Education	0.00	1072.673
	Household size	0.00	2145.366
	Market distance	0.00	620.33
	Prices for R&Ts	0.00	3755.689
	Production place	0.00	3739.744
	Constant	-22.408	22199.142
	/lnalpha	-1.713***	0.095
	Alpha	0.18	0.017
Likelihood-ratio test of alpha=0: chibar^2(01)	= 692.24	Prob>=chibar2 = 0.0000***	
Vuong test of zinb vs. standard negative binomial: z = -0.01		Prob > z = 0.5052	
LR test for the model chi2(18)	= 150.75	Prob > chi2 = 0.0000***	
Akaike crit. (AIC)	= 2696.703	Bayesian crit. (BIC) = 3446.054	

***, **, * = Significant at 1%, 5%, and 10%, respectively

Appendix 8

Table 11: AIC and BIC test for goodness of fit between Poisson, nbreg, zip, and zinb models.

Model	Obs	ll(null)	ll(model)	df	AIC	BIC
poisson	385	-2059.296	-1666.471	19	3370.943	3446.054
nbreg	385	-1395.724	-1320.351	20	2680.703	2759.768
zip	385	-2059.296	-1666.471	19	3370.943	3446.054
zinb	385	-1395.724	-1320.351	28	2696.703	2807.394

Lower values of either AIC or BIC indicate a better fit.

Authors' contributions

Three authors contributed to the success of this study. FON conceptualised the paper, managed the literature review, designed the methodology and the questionnaire with the close help and guidance of EOG and OIA. EOG and OIA coordinated the field survey, data analysis, write-up of the first draft, and interpretation of the results. All authors read and approved the final manuscript.

Authors' contributions

The authors declare that they have no competing interests.

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REGULAR ARTICLE

PROFIT EFFICIENCY OF SMALLHOLDER MAIZE FARMERS IN SAGNARIGU MUNICIPAL OF NORTHERN GHANA

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ABSTRACT
Research background: Maize is the most important cereal crop produced by most households in Ghana for income and household food security. Despite its economic importance, not much study has been carried out on maize profit efficiency in Ghana, hence this study.
Purpose of the article: This study estimated profit efficiency of maize farmers in the Sagnarigu municipal of Ghana to understand producers' profit efficiency level and its determinants as well as the challenges faced by maize producers.
Methods: Data was sourced from small-scale maize producers while stochastic frontier analysis was applied to estimate a Cobb-Douglas profit function that simultaneously identified the sources of inefficiency. Kendall's coefficient of concordance was used to analyse the constraints facing maize producers.
Findings & Value added: The findings indicated that maize farmers produced at 71% profit efficiency. This is one of very few studies on profit efficiency of Ghanaian maize farmers. The result means that 29% of the achievable maximum profit was forfeited as a result of production inefficiency. Educational attainment and access to agricultural extension service decreased the level of profit inefficiency while age, herd ownership and membership of farmer organization increased profit inefficiency level of farmers. The most critical challenges reported by farmers were financial constraints, high cost of ploughing and difficulty in acquiring chemical fertilizer. The study recommends that access to agricultural extension service should be improved to cover more farmers while efforts should be made to expand educational access in rural areas to enhance the profit efficiency of farmers.

Keywords: profit efficiency; maize; stochastic frontier analysis; smallholder farmers; Ghana
JEL Codes: C21; D24; Q12

INTRODUCTION

The multi-dimensional role of agriculture in reducing hunger and poverty under the Sustainable Development Goals (SDGs) is well acknowledged. The agricultural sector in Africa is estimated to play a key role in poverty reduction **(Christiaensen *et al.*, 2011)**. Small-scale farming accounts for over 90 per cent of the economically active rural population of Ghana **(Ghana Statistical Service, 2014)**. Farmers involved in small-scale agriculture have limited access to assets that facilitate the transition from less productive farming to modern commercial farming. Compared to other countries worldwide in terms of agricultural productivity, Ghana still lags behind **(Fuglie & Rada, 2013)**.
Invariably, certain obstacles exist that prevent Ghana's agricultural sector from realising its full potential. Studies have shown that inefficiencies and significant yield gaps exist in small-scale farming in several developing countries **(Anang *et al.*, 2016; Abdulai et *al.,* 2013; Al-hassan, 2012).** These inefficiencies are related to factors such as low adoption of improved technologies, lack of access to farm inputs and services, poor technical knowhow, environmental factors, among others.
Improving the profitability of farming particularly among smallholder farmers is a very important goal for most developing countries because majority of the population in these countries are engaged in farming as a source of livelihood. Farm households are involved in agricultural production with the aim of achieving household livelihood goals such as food and income security. Farmers operate in a competitive environment and must therefore combine resources in a judicious manner to ensure that they achieve optimum levels of production and profit from farming.
The goal of profit maximization may not be explicitly stated by smallholders, nevertheless, any production system that is not profitable may not be sustainable over time. Enhancing the level of profitability requires technical skills in producing optimally and eliminating waste. It also relates to right combination of inputs taking into consideration the input price levels. Thus, profitability can be influenced by managerial as well as institutional and marketing factors. Factor prices and capability in allocating these resources are essential to raise profitability of smallholder farmers.
Maize is an important staple food and cash crop produced by most smallholder farmers in Ghana. The crop is produced by most farm households as it forms an important part of the diet of Ghanaians and brings considerable income to producers. Maize production is however not without challenges, especially with regards to acquisition of external inputs such as chemical fertilizers, cost of land preparation, unavailability of improved seeds and pest and disease challenges. These challenges affect the profitability of maize production and the total area farmers are likely to put under cultivation.

This study therefore explores the profit efficiency of small-scale maize farmers in the Sagnarigu municipal of Ghana to highlight the sources of inefficiency as well as the critical challenges confronting farmers.
There are not many studies focusing on profit efficiency of maize production in Ghana which warrants this study. A search through the literature reveals that there is paucity of research on profitability and profit efficiency of maize cultivation in Ghana and particularly the study area. This is against the backdrop that maize is the most widely cultivated and consumed cereal crop in Ghana, and plays a very crucial role in household food and income security. The few studies that have examined maize profit efficiency in Ghana have shown varied results and include **Wongnaa *et al.* *(2019)***, **Ansah *et al.* *(2014),*** and **Bidzakin *et al.* (2014).** The study by **Wongnaa *et al*. (2019)** focused on four ecological zones of Ghana and estimated the mean profit efficiency at 48.4%, while **Ansah *et al.* (2014)** focused their study on the forest belt of Ghana and reported a mean profit efficiency of 89**%. Bidzakin *et al.* (2014)** undertook their study in northern Ghana and reported a mean profit efficiency of 61%. Clearly, the results are quite inconclusive regarding the level of profit efficiency among Ghanaian maize farmers. The scarcity of research in this area of study means that there exist inadequate research findings necessary to enhance maize profit efficiency and profitability across the country. This study therefore contributes to the body of knowledge on maize profit efficiency of peasant farmers and fills an important research gap.

LITERATURE REVIEW

According to **Konja *et al.* (2019)**, agriculture is key to economic development in Ghana, hence the need to pay attention to output and productivity growth. Resource constraints, high cost of farm inputs, use of rudimentary equipment in farming among others contribute to low farm profits in many developing countries. Most farms in Ghana and other developing countries remain small with little investment of capital to increase farm profits. Increasing the profitability of smallholder farmers therefore remains a critical challenge confronting policymakers and researchers.
Agriculture in sub-Saharan Africa is dominated by food crop production **(Mujuru *et al.,* 2022)**, with crop farming contributing immensely to rural development, income and food security and rural livelihoods **(Khoza *et al.,* 2019)**. Maize is an important food crop produced in most parts of Africa, notably among farm households and is the main dietary staple in Ghana and several African countries. The profitability of maize production hinges very much on conditions in the input and output markets **(Mujuru *et al.,* 2022)**, as well as farm and farmer characteristics that influence the level of productivity. Farmers' ability to reduce inefficiency in production and optimise resource-use efficiency are necessary to improve productivity and profitability of maize production.
Profit efficiency connotes the ability of farmers to produce at the highest possible profit taking into account input prices and the level of fixed production inputs **(Ali and Flinn, 1989; Rahman, 2003).** It entails producers' ability to produce on the profit frontier while any deviations from the frontier are construed as inefficiency of production. In profit efficiency analysis, producers are regarded as profit-maximisers, as opposed to cost-minimisers (where output level is regarded as exogenously given). Output and inputs are decided by the producer, with the objective of maximizing profits.
Measurement of efficiency typically follows a parametric or non-parametric approach. The parametric approach is centred on econometric estimation of a production frontier. The approach is made up of the stochastic frontier and deterministic frontier models. The parametric frontier methods impose a functional form on the production function based on assumptions made about the data. The commonly used functional forms consist of the Cobb–Douglas, constant elasticity of substitution, and translog production functions. The parametric approaches are divided into deterministic frontiers and stochastic frontiers. A deterministic frontier is based on the assumption that all deviations from the production or cost frontier are as a result of inefficiency of firms/farmers. Conversely, stochastic frontiers assume that a portion of the discrepancies from the frontier is as a result of random noise such as measurement error and statistical noise and also partially as a result of firm-specific inefficiency **(Forsund *et al.,* 1980; Coelli *et al.,* 2002).** The stochastic frontier approach tries to differentiate effects of random noises from the effects of inefficiency. As a result, it has the strength of testing statistical hypothesis over the deterministic frontier.
The application of the non-parametric approach in efficiency analysis includes the free disposal hull (FDH) and the data envelopment analysis (DEA), with DEA being the most popular non-parametric method. DEA was first initiated by Farrell (1957) and introduced into modern economic literature by **Charnes *et al.* (1978)** while FDH was developed by **Deprins *et al.* (1984).** DEA is used to analyse production, cost and revenue and profit data without technology parameterization (Greene, 2008). It does not impose a functional form on the production and cost frontier nor make any assumptions about the distribution of the error term. DEA uses either an input or output orientation to measure efficiency, based on whether the producer has more control over inputs or output level. The efficiency frontier in DEA stems from the concept of Pareto optimality; a firm may increase (decrease) output without necessarily increasing (decreasing) production of another product. DMUs on the frontier are considered as Pareto optimal units and are assigned an efficiency score of one (fully efficient). DMUs that are not on the efficient frontier are considered to be relatively inefficient and are given a positive efficiency index of less than one **(Chimai, 2011).**
While there are also semi-parametric techniques in assessing efficiency, these techniques have not gained much prominence in the literature. Semi-parametric techniques are statistical models that have parametric and nonparametric components; a finite-dimensional component and an infinite-dimensional component. Semi-parametric techniques include productivity indices, growth accounting, index theory, and many others.

RESEARCH METHODOLOGY

The study area and sampling procedure

The research was carried in the Sagnarigu municipality of the Northern Region of Ghana. The municipality is located in the Guinea savanna and covers 200.4 km² of land with a population of 148,099 **(Ghana Statistical Service, 2010).** It has a single rainfall regime and a long dry spell during the dry season. The area experiences high annual temperatures during the dry season (up to about 40 degrees Celsius) and dry harmattan winds. The economy of the municipality is mainly agriculture and commerce-based. The cultivation of maize, rice, and soybean is a major activity in the municipality.

The research involved primary data collection from smallholder farm households in the area. Multistage random sampling was used in the data collection. Sagnarigu municipal was first chosen within the northern savanna as a major maize producing area. This was followed by random sampling of six maize producing communities in the municipality. Thereafter, simple random sampling was applied to select thirty respondents per community to provide a total of 180 respondents. The respondents were interviewed using a semi-structured questionnaire with the interviews conducted in the local dialect since most of the respondents could not read and write. One respondent was dropped from the analysis due to incomplete information. The data covered activities for the 2018/2019 cropping season.

Efficiency concepts and measurement

Efficiency measurement was introduced by **Farrell (1957**) and described by **Kumar and Gulati (2010)** as a measure of operational excellence in the resource utilization process. Closely related to efficiency is productivity. Productivity in its simplest form is determined by dividing the output realised by the total physical inputs or resources (land, labour, seed, etc.) utilised in production. In other words, productivity is simply efficiency in production **(Syverson, 2011)**. Single-factor productivity also measures or reflects units of output produced per unit of a particular input. A firm is said to be inefficient when it does not attain to the potential maximum output.

A firm in the production process is likely to experience some components of productive efficiency, namely: technical, allocative and economic efficiencies. Discrepancies in output between farmers can be explained by the differences in efficiency. Thus, the production frontier describes the highest attainable output given the minimum inputs needed to obtain a particular output. In other words, for each input mix the production frontier depicts the maximum attainable output. Technical inefficiency denotes failure of the farmer or firm to attain the frontier level of output, given the level of inputs **(Kumbhakar, 1994**). Consequently, inefficiency arises when the observed output lies below the frontier. Allocative efficiency is a firm or farmer's ability to use inputs in their optimal way, given their respective prices **(Uri, 2001)**. If a farmer fails in allocating inputs at minimized cost, given the relative input prices, then there is allocative inefficiency or resource misallocation. The implication is that, misallocating resources will result in increased cost of production and hence decreased profit. Again, if the marginal rate of technical substitution between any two inputs is not equal to the resulting proportion of factor prices, a firm or farmer is said to be allocatively inefficient. This could be due to sluggish adjustment to price changes and regulatory challenges **(Atkinson and Cornwell, 1994)**. In the production process, a firm may be technically efficient but allocatively inefficient, allocatively efficient but technically inefficient, both technically and allocatively efficient, and at worse, technically and allocatively inefficient. Economic efficiency seeks to pool technical and allocative efficiencies to depict the ability of a firm or farmer to produce at possible minimum cost, given input price and a set of inputs. Consequently, achieving technical or allocative efficiency is only a necessary but not a sufficient condition for economic efficiency. A firm or farmer must at the same time achieve both technical and allocative efficiencies if it is to achieve economic efficiency.

Stochastic profit frontier model

The stochastic profit frontier function is modelled based on **Battese and Coelli (1995)** as Equation (1).

$$\pi_i = f(P_i, Z_i)\, exp(e_i)\,; \quad e_i = v_i - u_i \qquad (1)$$

where π_i is normalized profit, P_i is normalized input price, Z_i denotes the level of a fixed inputs, and e_i represents the composed error term. v_i is random errors beyond the producer's control while u_i denotes factors within the farmer's control.

The inefficiency effects (u_i) is modelled as Equation (2).

$$u_i = \delta_0 + \sum_{k=1}^{n} \delta_k\, W_{di} + \varepsilon_i \qquad (2)$$

where W_{di} represents the factors associated with inefficiency, ε_i is random error and δ_0 and δ_k are unknown parameters. Profit efficiency is obtained as the ratio of the observed profit to the frontier profit **(Aigner *et al.*, 1977**; **Meeusen and Van den Broeck, 1977)** (Equation 3 – Equation 6).

$$\pi_e = \frac{\pi_i}{\pi_{max}} \qquad (3)$$

$$\pi_e = \frac{f(P_{ij}, X_{ij}, \beta_i).exp(v_i - u_i)}{f(P_{ij}, X_{ij}, \beta_i).exp(v_i)} \quad (4)$$

$$\pi_e = exp(-u_i) \quad (5)$$

$$\text{Profit inefficiency} = 1 - \pi_e \quad (6)$$

where π_e is profit efficiency, π_i is observed profit, and π_{max} is the frontier profit.

The study adopted the Cobb-Douglas functional form for the analysis. The empirical Cobb-Douglas stochastic profit frontier model can be expressed as Equation (7).

$$ln\pi_i = \beta_0 + \beta_1 lnx_{1i} + \beta_2 lnx_{2i} + \beta_3 lnx_{3i} + \beta_4 lnx_{4i} + \beta_5 lnx_{5i} + \beta_5 lnx_{6i} + \beta_5 lnx_{7i} + v_i - u_i \quad (7)$$

The x_i variables include both conventional inputs and fixed production inputs used in the cultivation of rice. The variables included unit price of seed, labour, fertilizer, herbicide, ploughing cost per acre as well as the size of land and amount of capital used in production.

The inefficiency model is given as Equation (8).

$$u_i = \delta_o + \delta_1 z_{1i} + \delta_2 z_{2i} + \delta_3 z_{3i} + \delta_4 z_{4i} + \delta_5 z_{5i} + \dots\dots\dots + \delta_n z_{ni} \quad (8)$$

The z_i variables include individual, household, farm and institutional factors identified in the literature to affect profit efficiency.

Descriptive statistics of the respondents

The variables used in the study are described in Table 1 which reveals that the farmers are within the economically active age for farming. A youthful farming population is likely to be more willing to explore new technologies to enhance productivity and profitability. It was also revealed that only 25% of the respondents are educated which could be a drawback to information seeking and technology adoption. On the average, the respondents owned farms with an average size of 3.4 acres suggesting that they are small-scale producers. The study further indicated that most (70%) of the respondents belonged to a farmer-based organization. Thus, new technology or innovation aimed at increasing output and profit could be channel through these organizations to farmers. Also, it was found that most (84%) of the farmers owned cattle, which play a useful role in farming in most rural settings, where they are used to cart goods and plough fields to reduce drudgery associated with farming.

Table 1 Descriptive statistics of the variables

Variable	Measurement	Mean	Std. Dev.	Min.	Max.
Profit	Ghana cedi (GH¢)	1196	879.7	90	5000
Maize price	Ghana cedi/kg	0.997	0.018	0.9	1
Labour price	Ghana cedi/man-day	10.61	1.852	7	15
Seed price	Ghana cedi/kg	1.530	0.706	1	3
Fertilizer price	Ghana cedi/kg	1.267	0.710	0	2.4
Herbicide price	Ghana cedi/litre	14.94	9.815	0	25
Ploughing cost	Ghana cedi/acre	72.01	7.505	45	100
Farm capital	Ghana cedi	297.3	180.4	62	1402
Farm size	Acreage	3.402	2.241	0.5	14
Age	Number of years	42.50	11.64	24	77
Education	Number of years	2.229	4.435	0	16
Owned cattle	1 if yes; 0 otherwise	0.838	0.369	0	1
Extension visits	1 if visited; 0 otherwise	0.447	0.499	0	1
Farmer group	1 if member; 0 otherwise	0.704	0.458	0	1
Fertility of soil	1 if fertile; 0 otherwise	0.330	0.471	0	1

Note: 1 Ghana cedi = USD 0.19. Source: Authors' computation, 2020.

RESULTS AND DISCUSSION

Maximum likelihood estimates of the stochastic frontier profit function

The results in Table 2 show the stochastic profit frontier estimates. The dependent variable, profit, and the input variables were all mean-corrected to zero and log-transformed, implying that the first-order coefficients denote the corresponding elasticities. The results show a good fit of the data as indicated by the significance of the variance parameters. The results show that 61% of the variation in profit is associated with factors within the control of farmers.

Table 2 Stochastic frontier estimates of the profit function for maize farmers

Variable	Parameter	Estimate	Std. Error
Constant	β_0	0.949	1.691
Labour price	β_1	0.491**	0.192
Seed price	β_2	– 0.149*	0.080
Fertilizer price	β_3	0.062***	0.011
Herbicide price	β_4	0.012*	0.007
Unit cost of ploughing	β_5	0.350	0.335
Capital	β_6	0.593***	0.161
Farm size	β_7	0.421***	0.126
Variance parameters			
Gamma: $\gamma = \sigma_u^2/(\sigma_u^2 + \sigma_v^2)$	γ	0.606***	0.015
Sigma squared: $\sigma^2 = \sigma_u^2 + \sigma_v^2$	σ^2	0.403***	0.018
Log-likelihood	L	– 92.58	

Note: ***, **, and * denote significance at 1%, 5% and 10% level, respectively. Source: Authors' computation, 2020.

The price of labour is positive and significant at 5%, implying that an increase in the average price of labour services increases farm profit. However, the positive effect of labour in this study is at variance with **Amesimeku and Anang (2021)** in their study in northern Ghana. Seed price was also found to be significant at 10% and negatively correlated with profit, revealing that an increase in seed price results in reduction in farm profit. The negative effect of seed price disagrees with **Amesimeku and Anang (2021)** who reported a positively significant effect of seed price on profit of soybean farmers in Ghana. Fertilizer application was found to be significant at 1%, implying an increase in fertilizer price positively correlates with profit of maize farmers. Price of herbicide was found to be significantly related to profit at 10% while the value of farm capital and cultivated land area were both significantly related to profit 1%. This indicates that an increase in herbicide price, capital and cultivated land area increases farm profit. The positive influence of capital is consistent with the result of **Chikobola (2016)** which indicated a positive effect of farm capital on the profit level of groundnut production in Zambia.

Distribution of profit efficiency scores of maize farmers

The results in Table 3 show the distribution of the profit efficiency scores of the respondents. The producers recorded an average profit efficiency of 71.3%, with a range of 18.2% and 94.2%. This implies that the farmers lose about 28.7% of the profit due to inefficiency. Hence, the farmers could potentially increase profit efficiency by 28.7%.

Table 3 Distribution of profit efficiency scores

Efficiency range	Frequency	Percent
0.00 – 0.10	0	0
0.11 – 0.20	1	0.6
0.21 – 0.30	3	1.7
0.31 – 0.40	8	4.5
0.41 – 0.50	14	7.8
0.51 – 0.60	12	6.7
0.61 – 0.70	30	16.8
0.71 – 0.80	44	24.6
0.81 – 0.90	61	34.1
0.91 – 1.00	6	3.4
Mean	0.713	
Minimum	0.182	
Maximum	0.942	

Source: Authors' computation, 2020.

Most (62.1%) of the farmers had profit efficiency above 70% while very few (14.6%) had profit efficiency up to 50%. Generally, most of the farmers are profit oriented and achieve more than 50% of profit efficiency. This technically allows farmers to be in production, since they are able to meet their average cost of production. On the contrary, farmers' inability to attain 100% profit efficiency could be attributed to limited usage of the available technology for maize production and external shocks such as poor environmental conditions that affect farmers' productivity.

Identifying the sources of profit inefficiency

Table 3 shows the determinants of profit efficiency. Six variables were found to influence profit efficiency either positively or negatively at various significant levels.

Table 4 Determinants of profit inefficiency

Variable	Parameter	Estimate	Std. Error
Constant	α_0	– 3.982**	1.640
Age	α_1	0.036**	0.018
Years of education	α_2	– 0.311*	0.183
Years of education squared	α_3	0.020	0.015
Herd ownership	α_4	1.241**	0.615
Extension visits	α_5	– 0.720*	0.431
Farmer-based association	α_6	0.934*	0.541
Soil fertility status	α_7	– 1.117**	0.481

Note: ***, **, and * indicate significance at 1%, 5% and 10% level, respectively. Source: Authors' computation, 2020.

Age is positive and significant at 5% implying that an increase in age increases profit inefficiency of maize farmers in the Sagnarigu municipality. This finding is in line **Setsoafia *et al.* (2017)** who found that older artisanal fishers in Pru district of Ghana were less profit efficient as opposed to the younger counterparts. Younger farmers may be more adventurous in terms of adopting new technologies thereby improving their efficiency of production.
Education was measured as a continues variable and was found to positively influence profit efficiency (or negatively influence profit inefficiency) at 10%. This shows that a yearly increase in one's educational level increases the chances of enhancing profit efficiency. This could be due to the influence of education in exposing farmers to modern technologies through knowledge seeking. Farmers who can read and write are more likely to be aware of productivity-enhancing technologies and their correct application. They are also more likely to take advantage of opportunities that improve the lot of farmers such as participation in formal credit market and training programmes, among others. The finding concurs with **Wongnaa *et al.* (2019**) who observed that education correlated positively with profit efficiency of maize farmers in Ghana.
Farmers' access to agricultural extension was significant and negative in relation to profit inefficiency. This shows that access to extension services reduces profit inefficiency (in other words, it enhances profit efficiency). The result agrees with Amesimeku and **Anang (2021)** as well as **Konja *et al.* (2019)** in separate studies with smallholders in northern Ghana. Extension agents are important in smallholder production because they offer technical advice to farmers which contribute to higher productivity and profitability. Extension agents provide a link between farmers and researchers and their role in educating and training farmers on modern production practices to enhance yield and profitability cannot be overemphasized.
Herd ownership and farmer-based organization membership were also significant and positive in relation to profit inefficiency, implying that profit efficiency decreases with herd ownership and farmer-based organization (FBO) membership, which is contrary to expectation. This is because FBOs are expected to serve as a platform for technology adoption and farmer education, thus belonging to a farmer group is anticipated to enhance producers' knowledge about new technologies and their adoption strategies which could directly or indirectly influence profit efficiency. Thus, the FBOs in this study may not be actively engaged in carrying out their core duties or there may be issues of free-riding by some members, thus reducing their effectiveness.
Soil fertility status was found to negatively influence maize farmers profit inefficiency in the Sagnarigu Municipality. The result implies that producers with fertile land achieve higher profit efficiency relative to producers with infertile land. The reason could be that farmers with fertile soils need fewer external inputs to improve the level of soil fertility thereby reducing production costs and increasing the profitability of farming. Farmers with infertile soils need to apply more external inputs to improve soil fertility which is expected to increase the cost of production and thereby negatively impact on profitability and profit efficiency.

Ranking of constraints faced by maize farmers

Eleven major constraints were identified and ranked as shown in Table 5. The problem with the least mean rank was identified as the most serious constraint and vice versa. Farmers identified financial constraints as the topmost problem affecting their production activities. Smallholder farmers usually find it difficult to access credit from both formal and informal sources. Thus, access to finance remains a critical challenge that confronts Ghanaian smallholder farmers. Smallholders are also generally resource-poor, which affects their access to production inputs. This result is buttressed by findings of **Dimitri and Richman (2000)** and **Garcıa-Gil *et al.* (2000)** which revealed that financing is the main challenge faced by farmers. **Amesimeku and Anang (2021)** reported similar finding in a study in northern Ghana involving smallholder soybean farmers.

Table 5 Ranking of constraints facing maize farmers

Variable	Mean score	Std. Dev.	Rank
Financial constraints	2.40	1.84	1st
High cost of ploughing	3.22	2.42	2nd
Difficulty in acquiring fertilizer	4.22	3.56	3rd
Pest and diseases	4.69	2.34	4th

Poor soils	5.73	1.99	5th
Low yields	6.32	1.93	6th
Cost of chemicals for weed control	6.53	3.67	7th
Lack of ready market	7.18	2.05	8th
Low maize price	7.94	1.58	9th
High cost of seeds	8.63	1.87	10th
Unavailability of improved varieties	9.01	2.16	11th

Source: Authors' computation from field survey, 2020.

The next constraint in terms of importance to the respondents is high cost of ploughing. Usually, farmers depend on commercial tractor operators who live within their communities or nearby villages. However, due to the limited number of such operators, the demand for tractor services always outstrips the supply, driving up prices. The provision of mechanization centres at the community level is necessary to promote access to tractor services. The study's finding resonates with **Amesimeku and Anang (2021**) who reported high cost of ploughing as the second most important constraint among soybean farmers in northern Ghana.

Farmers identified difficulty in acquiring fertilizer as a major constraint in maize production. Maize is a heavy feeder when it comes to fertilizers and the soils in northern Ghana are generally low in fertility. Lack of access to chemical fertilizer is therefore a major challenge to farmers whose livelihoods depend on crop production. Hence, measures are required to improve farmers' access to chemical fertilizer. This could be done by ensuring efficiency and transparency in the distribution of subsidized fertilizer under the Planting for Food and Jobs (PFJs) initiative of the Government of Ghana. There is also the need to provide incentives and an effective regulative framework to ensure that private input dealers supply farmers with chemical fertilizer and other production inputs at their door steps and at approved prices.

Issues of pests and diseases have become critical in recent times as a result of the emergence of the fall army worm and other pests that devastate the farms of farmers in Ghana. This drives up the cost of chemical pest control which affects profitability of farming. Poor soils were reported as the fifth constraint; poorer soils lead to higher input use with less return. This is closely related to low yields, which was reported as the sixth constraint. Other constraints included the cost of chemical control of weeds, lack of ready market for farm produce, low produce price, high cost of seeds and the unavailability of improved varieties. Adoption of improved seeds is below expectation as many smallholders still cultivate traditional varieties. It is often argued that farmers choose traditional varieties as a risk management tool, since these traditional varieties are better adapted to the local environment and require fewer external inputs, although they give fewer yields. Thus, resource-poor farmers who lack access to credit are more likely to choose local varieties that give minimum yield with minimum external inputs. The challenge is to facilitate smallholders' access to input subsidies to promote adoption of improved varieties to enhance farm yields and profitability.

CONCLUSION AND RECOMMENDATIONS

The study assessed profit efficiency of small-scale maize producers in Sagnarigu municipal of Ghana using stochastic profit function approach. The results indicated that 29% of the potential profit was lost as a result of production inefficiency of farmers. Educational attainment and access to agricultural extension decreased the level of profit inefficiency while age, herd ownership and farmer group membership increased profit inefficiency level. The study also identified several challenges confronting the maize farmers. The most critical challenges reported by farmers included financial constraints, high cost of ploughing and difficulty in acquiring chemical fertilizer.

As a means to improve profit efficiency of producers, the authors recommend that access to agricultural extension services to farmers should be improved. This is because farmers learn from extension agents and acquire knowledge and relevant information that help them to optimize yield and achieve higher efficiency.

Furthermore, expanding access to education in rural areas is another important measure required to increase the profit efficiency of smallholder farmers. Education improves the human capital which improves knowledge of yield-enhancing technologies. Education also improves smallholders' access to information leading to improved farm performance.

Farmers' most pressing constraint was financial, hence increasing access to credit is essential to enhance farm performance. Credit is necessary to purchase farm inputs and ensures timely farm operations. This is critical because smallholder farming is usually time-bound due to the dependence on rainfall for production. Failure to carry out major farm operations timeously could lead to severe crop failure. Also, farmers identified high cost of ploughing as the second most critical constraint. Hence, improving access to agricultural mechanization services is required to improve smallholder farming. Tractorization improves soil preparation and enhances soil aeration, while it also facilitates timely farm operations.

The respondents identified poor soils as one of the constraints to maize production. This was buttressed by the efficiency analysis which indicated that farmers with poorer soils experienced lower profit efficiency. Thus, training of farmers in soil fertility management is needed to enhance profit efficiency of farmers. This could be achieved by incorporating soil fertility management as a critical part of extension service delivery to farmers.

Competing interest

None to declare

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REGULAR ARTICLE

WHAT DRIVES THE CHOICE OF SEED STORAGE STRUCTURES? EVIDENCE FROM CERTIFIED MAIZE TRADERS IN GHANA

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ABSTRACT

Research background: Quality maize seed is a necessity to meet the ever-increasing demand for maize production for domestic and commercial uses in Ghana. The need for appropriate storage structures to maintain quality seeds is essential to attain food security and poverty reduction. Proper storage ensures that the gains of seed breeding programmes are maintained. It also maximizes profits through an increase in the quantity, quality, and a reduction in the commercial loss of seeds
Purpose of the article: Research in the seed value chain in Ghana has concentrated on farmers with lesser emphasis on the activities of seed traders although they are a critical link between seed producers and farmers. The infrastructure available for their trade has a telling effect on the seeds they offer for sale. This study investigates the type of seed storage structures used by maize seed traders in the Brong Ahafo Region. Factors that affected their choice were also examined.
Methods: We made a total population sampling of 82 certified maize seed traders across 8 districts in the region. A discrete choice model is used to examine the traders' choice of storage structures, as well as the determinants influencing their choice.
Findings & Value added: We find that traders predominantly store seeds in concrete and metal structures. While we find traders with more years of trading maize seeds tending to store their seeds in concrete structures, older farmers tend to use metal structures. Storage duration, age and perception of affordability of rent charges tend to decrease the likelihood of using metal as the storage structure. From a policy perspective, given the marked heterogeneity in characteristics influencing traders' choice of storage technology, it is relevant to critically consider these differences in policy design.

Keywords: *certified seeds; binary logistic regression; concrete; metal*.
JEL Codes: C25; Q13; Q16;013

INTRODUCTION

Seed storage is extremely relevant in the agricultural production system given the time widening period between harvesting and the next planting seasons. According to **Wambugu et al. (2009),** Sustainably storing seeds for uninterrupted and continuous production is crucial for the dual goals of poverty and food insecurity reduction. In addition to the good agronomic practices to preserve the vigour and vitality of seeds, storage structures certainly play an important role. Seed storage structures are facilities used to hold seeds during the storage period (**FAO, 2018a**). Appropriate storage structures and mechanisms are essential requirements for every seed business. Through an efficient intermediating role of traders, farmers can harness the potential benefits of seed breeding programs. Thus, proper storage also ensures profit maximization through a reduction in qualitative, quantitative and commercial losses **(Yousaf *et al.*, 2016)**. Seed storage further guarantees the stabilization in price by minimizing seed demand and supply shocks **(Pichop and Mndiga, 2007a)**. **Wambugu *et al.* (2009)** described poor seed storage infrastructure or facility as a major threat to seed security in Africa.
Different materials have been used for the construction of storage structures, including concrete, brick, wood and metal **(Semple *et al.*, 1992a)**. The different materials used in construction have varying attributes. Concrete storage structures, for instance, can provide insulation from heat, and are considered impervious. However, they tend to be considerably more expensive **(FAO, 2011a)**. When cracked, concrete structures tend to provide conducive conditions for insects, which could potentially attack the stored seeds **(FAO, 2011b, 2018b)**. Metal structures, on the other hand, are good conductors of heat and therefore allow for a rapid rise in temperatures **(Blight, 2006)**. At low temperatures, the problem of condensation also arises, leading to an increased moisture content of seeds and hastened deterioration **(Befikadu, 2014; Mijinyawa *et al.*, 2006)**. However, metal structures such as metal silos have the advantage of protecting seeds

from rodent attacks. It can also be made air-tight in which case it prevents insect proliferation by inhibiting respiration **(Tefera *et al.*, 2011)**. However, the high cost of construction may deter actors in the seed value chain from using them **(Nduku *et al.*, 2013)**.

Brong Ahafo region has a comparative advantage in maize production and maize seed multiplication due to its' conducive climate. However, the region lacks adequate modern storage facilities to support maize seed traders **(Amanor, 2013a)**. Farmers and traders often improvise on rather less effective traditional methods for storage. Even though these methods may offer partial effectiveness, they can lead to varying issues including low farmer confidence in certified seeds due to poor seed quality **(Pichop and Mndiga, 2007b)**. This may lead to low sales and profitability of the seed business. Furthermore, the low trust in certified seeds may incentivize farmers to use seeds stored from their previous harvest and may lead to lower yields due to a lack of guaranteed seed quality and a mix-up of varieties leading to loss of desirable traits after repeated use **(Aidoo *et al.*, 2012)**.

There is a growing body of evidence on the seed sector in Ghana. However, most of these studies have largely concentrated on seed delivery systems **(AGRA-SSTP, 2016; Aidoo *et al.*, 2012, 2013, 2014a; Almekinders and Louwaars, 2008; Amanor, 2013b; Etwire *et al.*, 2016, 2013; Krausova and Banful, 2010; Lyon and Afikorah-Danquah, 1998; Tripp and Mensah-Bonsu, 2013; Tripp and Ragasa, 2015)**, as well as seed policies in Ghana **(Amanor, 2012; Poku *et al.*, 2018; Zhou and Kuhlmann, 2016)**. Other studies conducted regarding maize storage also focused mainly on grains and farmer-saved seeds **(Aggrey, 2015; Peprah, 2004; Ragasa *et al.*, 2014)**. It appears most of these studies have generally concentrated on farmers, with less research on maize seed traders. Given the crucial role of traders in facilitating the seed business, it is relevant to undertake the study, to gain more insights into traders' activities in the value chain. The study contributes to the growing body of evidence by assessing the factors that influence the choice of maize seed storage structure among maize traders in the Brong Ahafo region of Ghana. Specifically, the study seeks to identify the storage structures used by seed traders and the determinants of their choice.

LITERATURE REVIEW

The Food and Agriculture Organisation of the United Nations establishes that "seed security exists when men and women within the household have sufficient access to quantities of available good quality seed and planting materials of preferred crop varieties at all times in both good and bad cropping seasons" **(FAO, 2015)**. Interactions between climate change and other factors such as household wealth, access to credit and ethnic conflicts among marginalised groups and their superior counterparts have also led to situations of seed insecurity in Sub-Saharan Africa **(Madin *et al.*, 2022; Mcguire and Sperling, 2016)**.

Different strategies have been employed in times of drought, late onset of rains and conflicts in acquiring seeds when planted seeds are lost or destroyed and seed stocks are depleted. These include switching to other more resilient or shorter-duration crops or varieties. Another strategy is to seek seeds from kinsmen in other communities. However, there are likelihoods of refusal or not getting the desired quantities in some instances. Some cultural norms also frown upon seeking seeds from the same social network year after year **(Violon *et al.*, 2016)**. Wealthier households construct seed stores close to their homes to prevent losses from livestock, bushfires or destructions during conflicts **(Madin *et al.*, 2022)**.

The impact of seed security on food security cannot be overemphasised. This has led to interventions and investments in crop improvement to mitigate the impact of climate change **(Poku *et al.*, 2018)**. Governmental support to address the shortcomings of the traditional seed acquisitions has been the creation of a more formalised seed system through the supply of subsidised seeds **(Tripp and Mensah-Bonsu, 2013)** has been one of the adaptation strategies to curb the impact of climate change.

Ghana's formal seed sector has had a long and checkered history. The first formal seed unit was the Hybrid Maize Unit set up in 1958 **(Etwire *et al.*, 2013)**. A new seed company called the Ghana Seed Company was established in 1979. This company had the mandate to produce certified seeds until it was privatised in 1989 as part of reforms implemented during the Structural Adjustment Program of the Government of Ghana **(Lyon and Afikorah-Danquah, 1998)**. Currently, governmental agencies play regulatory roles whiles commercial seed production is done by the private sector. The Ghana Seed Inspection Division (GSID) has the mandate of regulating the seed sector through the certification of seed producers and retailers and conducting field inspections for adherence to seed production protocols **(Zhou and Kuhlmann, 2016)**. They also carry out inspections at storage and sales facilities. Laboratory tests for purity and germinability are done before seeds are certified for packaging and sale to farmers by GSID **(Poku *et al.*, 2018)**. Varietal development is done mainly by public research institutions and universities **(Etwire *et al.*, 2013)**.

Production of certified seeds is done by private seed producers and a majority are members of the Seed Producers Association of Ghana (SEEDPAG) **(Etwire *et al.*, 2013)** or National Seed Trade Association of Ghana (NASTAG) **(AGRA-SSTP, 2016; Zhou and Kuhlmann, 2016)**.

The sale of certified seeds in Ghana is done by dealers who also sell other inputs like fertilizer and pesticides. Some seed traders are in an association by the name Ghana Agri-Input Dealers Association (GAIDA). According to **Tahirou *et al.* (2009)** and **Etwire *et al.* (2013)**, seed distribution is done through direct sales to farmers, NGOs and governmental organizations.

Seed traders have used different facilities to hold seeds until distribution or their final use. There is a wide range of materials or options to select from when constructing storage structures. They include; concrete or brick, wood or metals **(Semple *et al.*, 1992b)**.

Seeds are living; therefore, they respire during storage and release heat and moisture during the process. So, poorly ventilated seed storage rooms enhance temperature and moisture accumulation in the seed lot resulting in rapid loss of seed viability and health **(Bewley *et al.*, 2013; McDonald and Copeland, 1997)**.

According to **FAO (2011a)**, factors such as the type and purpose of the structure and the economics of constructing and maintaining the structure should be a guide when making a choice. Other factors to consider are the availability of raw materials and labour to construct the structure, comparison of quality and durability of alternatives, cost of transporting the construction materials, compatibility of construction materials and individual preference.

Various studies have been conducted to ascertain the factors that affect the adoption of technologies by farmers **(Maboudou *et al.*, 2004a; Maonga *et al.*, 2013a; Owach *et al.*, 2017a)**. The review of factors that affect adoption will be categorised as; socioeconomic, technical or institutional factors and perceptions.

Socioeconomic Characteristics Influencing Adoption

Age has often been associated with the accumulation of wealth thereby increasing the potential of acquiring more durable and comparatively expensive storage facilities **(Owach *et al.*, 2017a; Thamaga-Chitja *et al.*, 2004)**. In other studies, an increase in age has been linked to an aversion to new technologies **(Bokusheva *et al.*, 2012a; Maonga *et al.*, 2013a)**. Thus, the effect of age on the choice of storage structures has been mixed.

The positive impact of experience stems from the fact that more informed choices are likely to be made when a person remains in that field for an appreciable number of years **(Okoruwa *et al.*, 2009a)**. This was corroborated by **Adetunji (2007a)** in a study on grain storage technologies used by farmers in Nigeria. In their study, additional years of experience in maize storage increased farmers' adoption of modern structures compared to local and semi-modern options. Contrary to the above, **Ainembabazi and Mugisha (2014)** reported that experience influenced choice at the introductory phase of a product or technology, but after testing they will either adopt or discontinue use based on the performance of the technology or system.

Education: Education has been known to increase exposure and the ability to access and adopt modern technologies **(Maonga *et al.*, 2013b; Uaiene *et al.*, 2009a)**. Some empirical studies have shown the positive effect education has on farmer choice. Adetunji and **Okoruwa *et al.* (2007b; 2009b)** found that increased years in formal education enhanced the use of modern storage methods in different states in Nigeria. An increase in years spent in formal education and experience was likely to enable farmers to make more informed choices. Education also afforded a person the ability to keep records **(Djokoto *et al.*, 2016)** and thus be able to compare the performance of different systems. Increased years of formal education of household heads were also found to increase the adoption of modern storage and agricultural technology in Agrarian communities in Northern Uganda and Mozambique **(Owach *et al.*, 2017b; Uaiene *et al.*, 2009a)**. Additional years of education also enhanced the adoption of small metal silos by farmers in Mwingi Central Sub-County in Kenya and Malawi **(Kimani, 2016a; Maonga *et al.*, 2013b)**.

Income levels, land ownership and Farm size

Bokusheva *et al.* (2012b) reported a positive influence on land ownership and adoption of metal silos. Farmers who own lands were seen as wealthier and thus their ability to purchase metal silos which were relatively more expensive compared to their substitutes in Nicaragua, El-Salvador, Guatemala and Honduras. Such farmers were also willing to invest more in their lands and business since they would not have tenancy renewal issues compared to farmers who rented lands. They would be willing to put up permanent structures like metal silos. This was confirmed by **Conteh *et al.* (2015)** who investigated the determinants of post-harvest technologies in Sierra Leone. Farm size has affected choice either positively or negatively in various research. Some studies used larger farm sizes as a proxy for wealth and the ability to buy inputs and pay for labour **(Kimani, 2016b; Maboudou *et al.*, 2004b; Maonga *et al.*, 2013c)**. **Owach *et al.* (2017c)** explained that there is a possibility of increased yield when farm size was expanded and thus the need for better storage spaces to protect produce. A divergent effect was recorded in another empirical study by **Makana and Thebulo (2018)**. They reported that cheaper traditional storage structures were sought after to reduce the cost of storing larger harvests resulting from an increase in farm size.

Technical or Institutional Factors

Extension improved awareness of modern or more efficient technologies **(Maonga *et al.*, 2013a; Uaiene *et al.*, 2009b)**. The importance of extension in decision-making was corroborated by **Aidoo *et al.* (2014b)**, **Lwala *et al.* (2016)** and **Okorley and Bosompem (2014)**. Farmers with access to extension services adopted metal silos more than farmers who had limited extension contact in research in Malawi **(Maonga *et al.*, 2013a)**.

Membership of an association affected farmers' choice of modern food storage structures positively in a study by **Owach *et al.* (2017a)**. Some reasons given for the positive influence were that farmers were more organised and likely to have access to information about new technologies. Association membership is also likely to boost bargaining power through the collective acquisition of modern structures **(Owach *et al.*, 2017a)**. The associations become the mouthpiece of their members and can influence policy decisions **(Asante *et al.*, 2011)**. Membership in an association may lead to peer pressure, that is members would acquire modern structures to keep up with other members of the group **(Owach *et al.*, 2017a)**.

Credit increased the purchasing power of farmers or traders in acquiring new food storage technologies and hiring labour during construction **(Owach *et al.*, 2017a)**. Some research has shown a high correlation between credit access and productivity **(Awotide *et al.*, 2015; Diagne and Zeller, 2001; Foltz, 2004)**. Households with access to credit were able to acquire modern structures in research conducted in Uganda and Mozambique **(Gbénou-Sissinto *et al.*, 2018; Owach *et al.*, 2017a; Uaiene *et al.*, 2009b)**.

Perceptions About Storage Facility

The adoption perception paradigm states that the perceived characteristics of a technology influences adoption **(Uaiene *et al.*, 2009b)**. **Gbénou-Sissinto *et al.* (2018)** were of the view that user perceptions of the effectiveness of structure influenced their choice positively or negatively. A storage structure which was considered to provide the greatest protection against pests, fire and theft was selected. Thus, knowledge of end-user perception and preferences should inform product development and dissemination.

DATA AND METHODS

Data source and sampling procedure

The study was conducted in the Brong Ahafo region of Ghana, a region known to be the food basket of Ghana. Brong Ahafo is the largest maize-producing region in Ghana accounting for 24.23% of the overall national production in 2016 **(Ministry of Food and Agriculture, 2017)**.

A purposive sampling of eight districts/municipalities where maize seed sales were predominant in the Brong Ahafo region was made. The districts/municipalities selected were Atebubu Amantin, Kintampo South, Kintampo Municipal, Nkoranza North, Nkoranza Municipal, Techiman North, Techiman Municipal and Wenchi Municipal There were hundred (100) operational and duly licenced Agro-input dealers in the study area according to the records of the Plant Protection and Regulatory Services Directorate (PPRSD) in 2018. A total population sampling of the 100 agro-input dealers was done of which 82 of them were found to have sold certified maize seed during the planting season and hence these were interviewed.

Conceptual framework

Consider a risk-averse trader who purchases and sells a kilogram of maize seeds, Q, with options to utilize storage structures $S_c = (S_1, S_2, \dots, S_K)$, with their associated initial investment costs $N_c = (N_1, N_2, \dots, N_K)$ and operational and maintenance costs, $C_c = (C_1, C_2, \dots, C_K)$. Using the storage structure preserves the vigour and vitality of seeds, increases the quality and improves the storage duration. Let $q_s = (q_1, q_2, \dots, q_k)$ represent the improvements in the seed quality for using the respective structure, S_c. Thus, the quantity of seed traded, Q, is a function of the type of storage, expressed as $Q = f(S_c, e)$ where e captures all other factors that influence the quantity of seeds at any particular point in time. Given that seed buyers are willing to pay a premium price, P_q over and above the standard price $\overline{P}$, the premium P_q is ordered from 0, in which case the buyer pays the standard price, to P_{q_max}, the maximum the buyer is willing to pay above the standard price. Thus, the premium captures the value associated with quality, q_s.The total cost associated with seed storage structure, S_c, is given by the sum of the initial investment cost and the discounted operational costs, $N_c + \sum_{t=1}^{T} \frac{C_s}{(1+r)^T}$ Different seed storage structures are capable of safely storing seeds to different extents over time T, because of their varying duration of storage. The associated revenues from seed sale from storage structure are given by $Q\left(\overline{P} + \sum_{t=1}^{T} \frac{P_q}{(1+r)^T}\right)$ We assume that the trader maximizes her expected utility of the discounted profits, $E[U(\pi_c)]$, in the expression: $MaxE\left[U(\pi_s)\right] = \underset{s}{Max}\, E\left\{U\left[Q\left(\overline{P} + \sum \frac{P_q}{(1+r)^T}\right) - N_s + \sum \frac{C_s}{(1+r)^T}\right]\right\}$

(1)

Where the expression $U(\cdot)$ represents the von Neumann-Morgenstern utility, with a positive marginal utility, $\frac{\partial U(\cdot)}{\partial(\pi_c)} > 0,$ and a decreasing marginal utility, $\frac{\partial^2 U(\cdot)}{\partial^2(\pi_c)} < 0.$

The expectation operator is denoted by E and π_c represents the profit a trader obtains from her choice of the storage structure. The trader's profit is maximized when:

$$\bar{P}\frac{\partial Q}{\partial S} + P_q\frac{\partial Q}{\partial S} - \frac{\partial Q}{\partial S} = 0 \tag{2}$$

As previously indicated, a rational risk-averse trader will choose the storage structure that maximizes her expected utility, $E\left[U\left(\pi^{s^*}\right)\right] - E\left[U\left(\pi^{s}\right)\right] > 0$, which S^* denotes the alternative chosen by the trader, i over all others S. Given that the net utility of profit, y_i^*, associated with the choice of storage structure, is latent, we can express it as a function of some observables:

$$y_i^* = Z_i\beta_i + \varepsilon_i,\ \ y_i = 1 \text{ if } \ y_i^* > 0 \tag{3}$$

Where y_i is a binary indicator variable representing the household i, and is equal to 1, if a trader uses a concrete storage structure, and zero otherwise. Also, Z_i is a vector of explanatory variables, including age, years of experience in trading in maize seed, membership of trader association, and duration of seed storage, among others.
Likewise, β_i is a vector of parameters to be estimated, and ε_i is the error term assumed to be normally distributed with zero mean and constant variance.

Empirical specification
As previously indicated, seed traders are assumed rational and will make choices on the type of storage structure that maximizes profit. However, the utility associated with the choice of storage structure cannot be observed. In expressing the function of the latent variable of storage choice on some observables, several distributional assumptions are made. When the Bernoulli event of choosing either a concrete or a metal container to store seeds is repeated many times, its distribution may be approximated by a more manageable and easily estimated function. In particular, when we approximate this seed storage structure choice conditional on a normally distributed disturbance term, then a Probit model is estimated. On the other hand, conditioning on a logistic disturbance term calls for the use of the logistic model. The tendency for the logit model to conveniently handle extreme values makes it a preferred option **(Gujarati, 2004)**. In addition, the logistic model has the advantage of flexibility and ease of interpretation of dichotomous outcome variables **(Hosmer and Lemeshow, 1989)**.
The Logit probability is represented mathematically as:

$$P_i = \frac{1}{1+e^{-z_i}} = \frac{e^{z}}{1+e^{z_i}} \tag{4}$$

$f(z_i)$is the weight of the density function with respect to z_i.
The logit model takes the form;

$$\log\left[\frac{P_i}{1-P_i}\right] = \beta_0 + \sum_{j=1}^{n}\beta_{in}Z_i + \varepsilon_i \tag{5}$$

Where
P_i =probability of a trader using a concrete storage structure
B_0 = constant
$\sum_{j=1}^{n}\beta_{in}Z_i$ = vector of the independent variables and their associated coefficients
ε_i= disturbance term
Specifically, the model is expressed as:

$$\begin{aligned} STORAGE_i = \beta_0 &+ \underset{+/-}{\beta_1\left(AGE\right)_i} + \underset{+/-}{\beta_1\left(Experience\right)_i} + \underset{+}{\beta_3\left(TradeAssoc\right)_i} + \underset{-}{\beta_4\left(StoreDuration\right)_i} \\ &+ \underset{-}{\beta_5\left(AffordPerceptn\right)_i} + \underset{+}{\beta_6\left(QtyDiscard\right)_i} + \varepsilon_i \end{aligned} \tag{6}$$

Where $STORAGE_i$ is the storage structure used by seed traders with 1 = concrete structure, and 0 = metal, (wooden was excluded because of limited usage of this structure by respondents $\beta_0, \ldots, \beta_5$ are parameters to be estimated whiles capturing the disturbance term, ε_i .

RESULTS AND DISCUSSION

Descriptive statistics of maize seed traders

A typical maize seed trader is about 37 years old and has been trading in the commodity for about six years. About one in three of the interviewed traders belonged to a trader's association. Traders purchased and stored their maize stock for about four weeks before they sell. On their perception of the cost of rent, the results show that traders appear to be indifferent to the cost of rent for their storage structures. This, perhaps, could be indicative of their general satisfaction with the cost of renting the storage structures. In particular, neither do they perceive the cost to be exorbitant nor cheap. We present the descriptive statistics of the sampled traders in Table 1 below.

Table 1 Descriptive statistics on sampled seed traders

Dependent variable for Binary Model: Seed storage structure (1= Concrete, 0=Metal)			
Independent Variables	Definition	Mean	Std
Traders Characteristics:			
Age	Age of trader in years	36.98	11.23
Experience	Number of years selling maize seeds	6.11	6.11
Technical/Institutional			
Membership of Trader's Association	1=Member of Trader's Assoc. 0= Otherwise	0.29	0.46
Storage Duration	In weeks	4.16	2.86
Perception of Traders			
Perception of affordability of Cost of Rent	1= Very low, 2=Low, 3 =Average 4= High and 5= Very high	3.78	0.88
Perception of reduction in Quantity Discarded	1= Very low, 2=Low, 3 =Average 4= High and 5= Very high	4.94	0.29

Seed Storage Structures used by Maize Seed Traders

Eight different seed storage structure and container combinations categorised as concrete, metal and wooden were identified as being used by traders as shown in Table 2.

Concrete building refers to stores in the market centers, commercial warehouses or rooms in the dwellings of the trader. Concrete + Plastic sacks (68.30%) was the widely used seed storage structure-container combination. However, three traders (3.7%) emptied their packaged maize seeds into hermetic sacks during storage and sales. Four other traders stored theirs in boxes, metal drums and plastic receptacles during seed storage and sales. Their motive for storing seeds this way was to prevent rodents from destroying seeds. Structures built from metallic sheets or recycled shipping containers were also used by approximately 18% of those who stored in the generic plastic sack issued by Ghana Seed Inspection Division (GSID). Only one trader was found to use a wooden structure and so was treated as an outlier and removed from the model so further discussions focused on the usage of concrete or metal storage structures.

Table 2 Seed storage structure and container combinations used by traders

Type of seed storage structure	Frequency	Percentage
Concrete building + Hermetic sacks	3	3.7
Concrete building + Paper box	1	1.2
Concrete building + Metal drum	1	1.2
Concrete building + Plastic sacks	56	68.3
Concrete building + Plastic container	2	2.4
Metal container + Hermetic sacks	3	3.7
Metal container + Plastic sacks	15	18.3

Wooden structure + Plastic sacks	1	1.2
Total	82	100

Source: Field survey, 2019

A general observation of all the storage structures was that they were not solely used for seed storage. Traders who had separated structures for both vending and storing also stored other agro-inputs and equipment in the same structure. Ventilation in these stores was very poor whilst the main entrances to the stores and metal structures were shut at night. Ventilation is essential in seed storage stores as it is a requisite for effective convectional airflow that would enhance heat dissipation which would lead to a significant reduction in moisture content in the storage facility generated from seed respiration. Poor ventilation could lead to hot spots, caking or sprouting of seeds resulting in the eventual loss of seed viability **(McDonald and Copeland, 1997)**.

Relationship between socio-economic variables and seed storage structures

Table 3 summarises the socio-demographics of seed traders with respect to the type of storage structure used. There was no significant difference in age, years spent in formal education, household size, association membership, cost of storage as well as storage duration between users of concrete and metal seed storage structures. Conversely, differences in experience (years) and quantity sold were significant at 1%. Users of concrete storage structures were more experienced with a mean of 6.82 years compared to metal storage structure users with mean years of experience of 3.53 years.

Users of concrete storage structures sold significantly higher quantities than metal structure users, hence, are classified as large-scale operators. The average amount of seeds sold by concrete structure users was 748.96 kg whiles an average of 252.48 kg was sold by metal structure patrons. Concrete structure users also had greater access to credit. Differences in access to credit were significant at 10%. This can be attributed to the fact that financial institutions consider the type of infrastructure used by the business before granting loans to them (Fufa, 2016). Thus, fixed assets are a requisite for creditworthiness.

Table 3 Demographics of maize seed traders based on storage structure type utilised

	Concrete		Metal			
	Mean	Std	Mean	Std	Mean Diff.	T-test
Age (years)	37.02	12.07	36.41	9.42	0.61	0.22
Education (years)	11.36	3.26	10.5	1.97	0.86	1.31
Household Size	4.64	2.87	4.29	2.97	0.35	0.43
Experience (years)	6.82	4.84	3.53	2.12	3.29***	3.98
Number of Training	2.05	1.49	1.44	1.42	0.61	1.56
Access to Credit	0.64	0.48	0.39	0.5	0.25*	1.87
Association Membership	0.34	0.47	0.17	0.38	0.17	1.26
Quantity Sold (kg)	748.96	14.73	252.48	7.02	496.48***	3.74
Storage Cost/kg	0.27	0.29	0.26	0.23	0.01	0.13
Storage duration (weeks)	3.54	1.93	4.47	3.18	0.93	-1.43

Significance level: * $p<0.05$ ** $p<0.01$ *** $p<0.001$

Factors Affecting the Choice of Seed Storage Structures

The explanatory power of the model was determined by the Likelihood ratio (LR). The LR was statistically significant ($p<0.001$) and confirms that the model follows a Chi-square distribution. Therefore, this data is adequately explained by the logit model as presented in Table 4.

Table 4 Binary logit estimates of factors affecting the choice of seed storage structures

Variables	Coefficient	Marginal Effects
Age	-0.07*	-0.01*
	(-0.04)	-0.004
Experience	0.38***	0.04***
	(-0.16)	-0.014

Storage Duration	-0.33**	-0.03**
	(-0.16)	-0.017
Trader Association Membership	1.3	0.11
	(-1.05)	-0.073
Reduction in Quantity Discarded	1.11	1.11
	(-0.18)	-0.1
Affordability of Cost of Rent	-1.01*	-0.1*
	(-0.53)	-0.057
Constant	1.77	
	(-5.06)	
LR Chi^2	25.66***	
Pseudo R^2	0.302	
Log-likelihood	-29.56	

Significance level: * p<0.05 ** p<0.01 *** p<0.001.

The variable representing age was negative and statistically significant. This means that an increase in age decreases the probability of using concrete storage structures by one per cent. Which may be attributed to risk aversion associated with an increase in age **(Bokusheva *et al.*, 2012a; Maonga *et al.*, 2013a)**. Contrary to the findings of this research, **Thamaga-Chitja *et al.* (2004)**, **Adetunji (2007a)** and **Owach et al. (2017)** reported age to increase the probability of adoption of modern technologies. They further associated increased age with the likelihood of greater wealth accumulation to afford better technologies.

Experience or number of years for selling maize seeds influenced the choice of concrete storage structure positively and was significant at 1%. An additional year of experience in selling maize seeds increased the probability of using concrete storage structures by about four per cent. With an increase in years of experience, maize seed traders are better placed to appreciate the merits and demerits of the various storage structure options. This finding agrees with Maboudou *et al.* **(Maboudou *et al.*, 2004a)** on the use of improved clay storage facilities in Benin where a higher level of experience affected adoption. It also corroborates **Adetunji (2007)** who researched the economics of storage among farmers in Kwara State, Nigeria. With increased experience, it is also possible to acquire additional wealth to construct or rent more expensive seed storage structures **(Owach *et al.*, 2017a)**.

Another factor that significantly affected the choice of concrete seed storage structure negatively was the duration of storage which was significant at 5%. There was a negative marginal effect of 0.03 in using concrete structures as storage duration increased. An increase in seed storage duration is not compensated with price increases due to the relative stability of the price of maize seeds. Maize seed traders in the study area tend to use metal storage structures as storage duration increases and the cost of storage accumulates. These findings were underscored by **Ayedun (2018)** who also reported a negative impact on the use of PICS bags with increasing storage period. This was due to the relatively high cost of PICS bags so farmers resulted to cheaper options like chemicals to protect their stocks when storage duration increased. The findings however contradict the assertions made by **Gbénou-Sissinto *et al.* (2018)** in their research in Benin after investigating the relationship between the period of maize storage and storage alternatives.

Traders' perception of the affordability of rent charges for a storage structure affected their choice of concrete storage structures. There was a significant negative effect of trader perception of the cost of rent on the choice of concrete structures. An additional increase in the perception of the cost of rent will reduce the use of concrete storage structures by 10%. This is in line with the findings of **Maonga et al. (2013)**. In their study, farmer perception of the cost of metal silos was a deterrent to adoption although the farmers agreed it was more effective in reducing losses. Contrary to the finding of this study, **Gitonga *et al.* (2015)** found farmers' perceptions of the high cost of metal silos in Kenya to influence adoption positively. This was because the farmers linked higher costs to the effectiveness of storage facilities to protect their grains. They were of the view that they could recoup their investment in the long run when well-protected grains were sold. **Gbénou-Sissinto *et al.* (2018)** on the other hand reported a mixed effect on the perception of the cost of the storage structure. The positive or negative impact of the perception of cost on adoption was based on the segment of society they belonged to.

CONCLUSION AND RECOMMENDATIONS

The study investigated the types of seed storage structures used by maize seed traders in the Brong-Ahafo region of Ghana and the factors that determined their choice. A census of the population was taken and data from the survey was fitted using a logistic model. About 78% of the traders sampled stored their seeds in concrete structures with the remaining stored mainly in metal structures. Traders who stored in concrete facilities were more experienced and also sold larger quantities of maize seed than those who stored in metal structures. Additionally, concrete structure users had greater access to credit facilities than metal storage users.

The empirical logit results show that, with the increasing age of maize seed traders, metal structures were preferred whiles an increase in years of trading in maize seed led to the use of concrete structures. Also, storage duration and perception of higher rent cost of concrete structures negatively influenced its usage.
The study recommends that, in generating and disseminating seed storage technologies to seed traders, factors such as age, experience, storage duration and perception of rent charges are important factors to consider to promote adoption. Therefore, any strategies aimed at improving or introducing storage structures to traders should consider these factors in their implementation. To ensure that seed traders can obtain loans to support their business thereby enhancing seed availability, accessibility and seed security the promotion of concrete storage structures is required as users had greater access to credit.

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REGULAR ARTICLE

THE EFFECT OF WATER HYACINTH ON SMALLHOLDER RICE FARMER'S LIVELIHOOD: THE CASE OF LAKE TANA BASIN, ETHIOPIA

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ABSTRACT

Background: Invasive aquatic weeds like water hyacinth are of a great concern in Ethiopia, posing particular problems on aquatic biodiversity and fisheries in major water bodies and agricultural land in the surrounding water bodies. The study was aimed to analysis of the effect of water hyacinth on the livelihood of smallholder rice farmers around the Lake Tana, Ethiopia.
Methodology: Two districts and four Kebeles adjacent to Lake Tana and well known in rice production were purposively selected for the study. Individual interviews and key informants' checklists were used as data collection methods to achieve the desired objectives.
Results: The result showed that 48% of the rice cultivated land was infested by water hyacinth and 32.08% of rice farm area was not harvested totally due to Water hyacinth infestation in the study year. It showed a statistical significance mean difference on yield of rice between affected and non-affected plots, it could reduce by 1944 kg/ha. Moreover, households perceived that water hyacinth makes land preparation and crop production difficult, dehydrates farmland, reduces fish production, and contaminates water, destruction of animal feeds, causes disease on humans and animals. Smallholder rice-producing sampled households perceived that the rice production has been decreasing due to the spread of water hyacinth. Farmers by themselves implemented different adaptation strategies to resist the water hyacinth problem. The major adaptation strategies implemented by smallholder farmers are participating in water hyacinth removing campaigns or weeding, constructing a fence around their farm to defend the coming water hyacinth weed before invading their rice farms, and switching off from farm activity to other income-earning activities. The study results revealed that 73% and 91.5% of the sampled households received rice production extension services and information regarding water hyacinth, respectively.
Recommendation: To solve the problems of water hyacinth effects participatory approach to control water hyacinth, support farmers to produce crop in off season using irrigation, promote agricultural technologies and assist them to search other income earning activities.

Keywords: water hyacinth, rice, livelihood effect.
JEL Codes: Q15

INTRODUCTION

Invasive aquatic weeds are a growing threat worldwide, causing losses in biodiversity, changes in ecosystems, and impacts on economic enterprises such as fisheries, agriculture, forestry, power production, and international trade. Because of a wide range of adaptation to varying amounts of water, aquatic weeds are reaching alarming proportions in many parts of the world, especially in tropical water bodies where they have led to serious ecological and economic losses **(Xub, 2012)**. Water hyacinth is considered as one of the 10 top world's worst weeds invading lakes, ponds, canals, and rivers **(Ethiopian Biodiversity Institute, 2019; Wise *et al.*, 2007)**.
Due to its extremely fast growth, the weed has become the major floating water weed of tropical and subtropical regions. Africa has particularly been affected by the introduction and spread of water hyacinth, facilitated in part due to a lack of naturally occurring enemies. According to **(Mujingni, 2012)**, water hyacinth infestation in eastern, southern, and central Africa, was first recorded in Zimbabwe in 1937, Mozambique in 1946, and in Ethiopia in 1956.
Invasive aquatic weeds are of great concern in Ethiopia, posing particular problems on aquatic biodiversity and fisheries in major water bodies and agricultural land in the surrounding water bodies **(Firehun *et al.*, 2014)**. Since its introduction the infestation of water hyacinth appears in rivers like Baro, Gillo, and Akobo Rivers and lakes like Tana, Ellen Koka **(Rezene 2005; D Tewabe 2015; Ebro *et al.* 2017)**. The emergence of water hyacinth in Lake Tana has been reported and recognized as an ecologically dangerous and worst invasive weed in September 2011 **(Anteneh, 2015; Tewabe, 2015)**. In the year 2015, 18 *Kebeles* in the 5 districts bordering Lake Tana were infested by water hyacinth **(Anteneh 2015)**. According to Tana Lake and Aquatics resources Conservation and Development Agency, the water hyacinth infestation has been expanded to 7 districts and 28 *kebeles* in the Tana basin in 2020.

Even though efforts to remove water hyacinth in Lake Tana have been made by a number of institutions including government offices, universities, research centers, and local communities **(Anteneh, 2015; Anteneh *et al.*, 2014)**, the spread of the weed and its impact on the ecosystems in and around the lake are yet uncontrollable.

Most earlier studies have been emphasized the expansion of the weed, distribution, management option for water hyacinth, and perceptions on socioeconomic effects of water hyacinth in the Lake Tana basin**. (Damtie *et al.*, 2021; Yigrem, Mengist & Moges, 2019; Tewabe *et al.*, 2017; Getnet *et al.*, 2020; Minychel *et al.*, 2020).**

However, no prior research in the study area specifically addresses the impact of water hyacinth invasion on smallholder rice farming. Using a range of factors, this study aimed at analyzing the effects of water hyacinth on the livelihoods of smallholder rice-producing farmers in the Tana basin. This study could add to the body of literature by analyzing the effect of water hyacinth on rice producer farmers and providing greater insights to the responsible bodies so they can focus on water hyacinth mitigation and control strategies. Therefore, this study assesses the effects of water hyacinth invasion on smallholder rice farmers' livelihoods and rice farm households' perceptions regarding water hyacinth in Lake Tana basin, Ethiopia.

RESEARCH METHODOLOGY

Area description

Lake Tana is located in the highlands of northwestern Ethiopia. The Lake Tana Biosphere Reserve is located in the Amhara National Regional State; it is one of Africa's most unique wetland ecosystems and the source of 50% of the freshwater of the country. The average altitude of Lake Tana is approximately 1800m, and the area of the basin (including water surface area) is 15,096 km^2. The Lake has a surface area of 3111 km^2 and 284 km^3 volume. Gilgel Abay, Ribb, Gumera, and Megech are the most important rivers feeding into Lake Tana and contribute over 90% of the total water inflow **(Chuangye Song, Lisanework Nigatu, Yibrah Beneye, Abdurezak Abdulahi, Lin Zhang, 2018)**. The only out-flowing river is the Abay (Blue Nile) and it covers 20% of the surface area of the Lake Tana sub-basin.

The study was conducted in the Eastern part of Lake Tana in which rice crop is produced and invaded by Water hyacinth. The study was conducted in *Fogera* and *Libokemkem* districts which are two of the ten Woredas bordering Lake Tana and found in South Gondar Administrative Zone. Fogera district has 33 kebles, two of its kebles (Nabega and Wagetera) bordered by Lake Tana in the west and heavily affected by water hyacinth, The district has area coverage of 1,111.43 km^2 whereas *Libokemkem* district comprises of 34 *kebeles*. Out of these *kebeles*, four of them namely Tezamba, Kab, Agid & Kirgna are bordered by Lake Tana. The district has an area of 1,560 km^2.

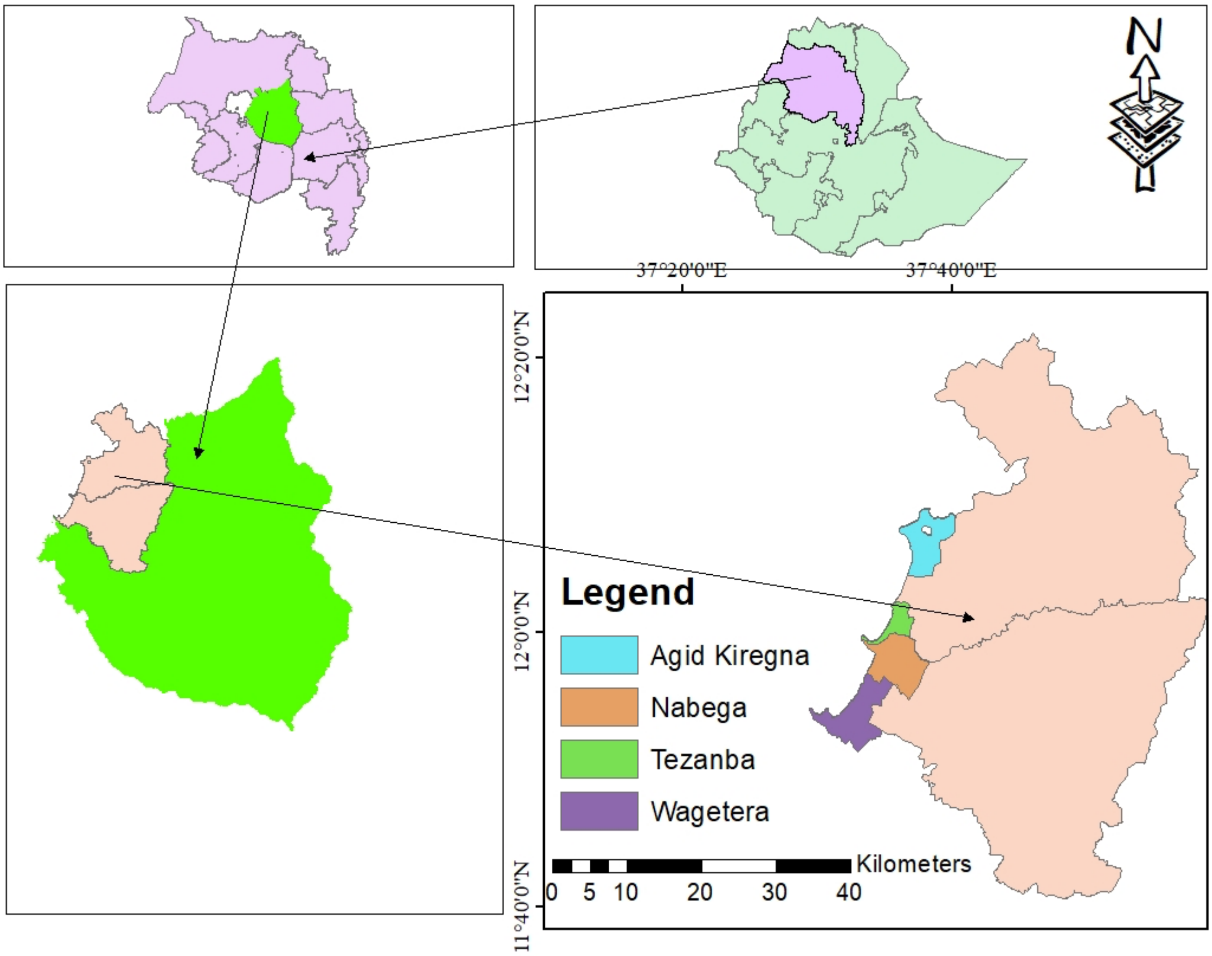

Figure 1 Map of the study areas
Source: Manipulated from Ethiopian map

Data and Survey design

The study was used primary and secondary data sources. Household and plot-level data were collected using structured questionnaires from randomly selected rice producing farm households in the study area. A community survey was also conducted to collect data through focus group discussion with community leaders, key informants with experts at district and Region level and direct observation. Through these methods, mainly qualitative data, focusing on the current status of water hyacinth infestation and its possible impact on rice production, controlling mechanisms done by different stalk holders was collected.

Additionally, data were also collected from secondary sources including journals, reports, conference proceedings, internet sources, and unpublished sources.

Based on the expansion magnitude of water hyacinth, the study uses purposive sampling techniques to select districts, accordingly, *Fogera* and *Libokemkem* districts were selected. First, numbers of rice producer *kebeles* that are affected by water hyacinth in each district were identified and then 2 *kebeles* in each district were selected purposively. A total of 189 households were selected randomly. The sampling distribution across each *kebele* is shown in Table 1 below.

Table 1 Sample distributions

District	*Kebele*	Sample size
Fogera	*Wagetera*	47
	Nabega	48
Libokemkem	*Aged- Keregna*	59
	Tezaamba	35
Total		189

Source: Own computation, 2019

Methods of Data Analysis

The study was used descriptive statistics and inferential statistics to analyze quantitative data. Descriptive statistics such as mean, frequency, percentage, t-test, and standard deviation were used to assess water hyacinth effect difference on crop yields. It is also used to explain the different socio-economic characteristics of the sampled households about their rice production status. On the other hand, some of the responses from the respondents were quoted directly in the analyses of qualitative data.

RESULTS AND DISCUSSION

Household Characteristics and Socioeconomic Factors

The average **age of household head was about 44 years (range 20 to 80 years). The average family size was 5.6 persons per household, with a minimum of 2 and a maximum of 12 members. A total of 54 % of the family members were of working age (15-64 years). In terms of farming experience, farmers had a mean of 23.78 years (Table 2). Regarding rice farming experience, the average was 14 years, and the younger respondent had one year and the older had 40 years of rice cultivation experience.**

The survey result depicted that males accounted for 92% of sample household heads, while females accounted for 8%. Nearly half of the household heads in the study area couldn't read or write (Table 2).

Table 2 Characteristics of the Household

Variable	Mean	Std. Dev.	Min	Max
Age of household head (years)	44.01	13.88	20	80
family size	5.61	2.02	2	12
Farming experience	23.78	13.74	3	61
Rice farming experience	14.30	6.73	1	40
Since when water hyacinth appeared on farm(years)	3.68	1.57	1	8
Own land holding size (ha)	0.89	0.55	0	4
Rented in land (ha)	0.05	0.13	0	0.5
Shared in land (ha)	0.13	0.24	0	1.75
Off/non-farm income (Ethiopian Birr/ETB)	3942.91	11649.93	0	126000
Farm income (ETB)	23668.31	20578.83	0	139350
Total Income (ETB)	27611.22	23953.20	0	147350
Land infested by WH (ha)	0.38	0.30	0	2
Nearest distance to lake Tana (kms)	2.73	2.47	0	12
Nearest distance to cooperatives (kms)	3.31	2.97	0	18
Nearest distance to extension office (kms)	3.05	2.47	0	12

Nearest distance to all weather roads(kms)	11.30	6.79	0	21
Proportion of family member between age 15 & 16 years	0.54			
Independency ratio	0.46			
Sex of the household head (male)	0.92			
Proportion of illiterate household head	0.51			
Proportion of literate household head	0.49			

Note: Average exchange rate in 2019: 1 USD=29.2123 ETB.
Source: Survey result, 2019

Access to roads that are reliably passable year-round is critical for many rural development processes, including access to inputs, markets, education, and campaigning services. Preferably, such roads should be paved to ensure all-season access for heavy vehicles. As observed in Table 3, in the study area households are far away from all-weather roads. This indicates road infrastructure is not accessible; this might prevent the easy control and monitoring of water hyacinth in the study areas. The average distance of farmers residence far from Lake Tana is 2.73 kms. The average own landholding size is estimated at 0.89 ha. In addition to this, farmers were used shared in, and rented in land for crops production, which is common in the study area. More than 45% of the land was devoted to an irrigation production system, mainly used lake Tana water source.

Major crops Produced
In the study area rice is one of the major crops produced; households on average allocated 0.876 ha of the land to rice crop, and were producing 2678 kg (Table 3). Rice contributed 55% of the area cultivated and 80% of production from all crops grown in the study area (Table 3). Teff is the second important crop, often produced through irrigation that it takes average land coverage of 0.46 ha per household. Finger millet, Maize, Grass pea, Chickpea, lintel, vegetables, and other crops were produced in the study areas to a limited extent. In the marshy lands near the lake coast **(Getnet *et al.*, 2020)** noted the dominance of rice, vetch, and chickpea farming.

Table 3 Major crops in the study area

Crops	Number of growers	Average area planted (ha)	Average production (kg)	Crop share	
				Area harvested (%)	Production (%)
Rice	189	0.88	2678	55.45	80.10
Teff	145	0.46	486	24.43	11.14
Grass pea	58	0.33	301	7.21	2.77
Chickpea	50	0.38	246	6.44	1.95
Maize	32	0.27	383	2.76	1.94
Finger millet	11	0.33	323	1.33	0.56
Lentil	10	0.19	188	0.73	0.30
Onion	2	0.09	150	0.07	0.05
Other crops(oat, garlic, etc	20	0.22	380	1.58	1.20

Source; survey result 2019

Rice is produced in the rainy season (*meher* season), generally planted in June and harvested in December while pulses (Grass pea, Chickpea, Lentil) are produced in residual moisture whereas teff, maize, and vegetables are produced using irrigation in the dry season.

Livestock resources
Cattle, sheep, donkey, goat, poultry, beehives are the common livestock types that the household is rearing in the study area. As it is observed in Table 4, out of the total interviewed households, 91.01% of them had owned at least an ox. To assess the livestock holding of each household, the tropical livestock unit (TLU) per household was calculated and an average livestock holding of sample households was 3.98 in TLU.

Table 4 Livestock ownership Status

Livestock Type	% of households owned	Mean	Min	Max
Oxen	91.01	1.70	0	4
Bulls	17.99	1.32	0	3
local cows	69.31	1.49	0	4

crossbreed cows	5.291	1.20	1	2
Heifers	46.03	1.32	0	3
Calves	52.91	1.29	1	3
Goats	2.65	2.40	0	4
Sheep	46.56	3.16	0	15
Poultry (chicken)	61.38	4.39	0	18
Donkey	51.32	1.16	0	2
Horse	0.529	2	2	2
Mule	1.587	1	1	1
Beehives	0.529	15	15	15

Source: Survey result, 2019`

Source of Income

Table 5, presents the amount of income earned from different sources by households in the study area. Households were engaged in different income-earning activities. The main income earnings are the income from crops, livestock, and non/off-farm activities. The main source of livelihoods income was from the sale of rice crops (41.31%), followed by livestock and livestock products selling (31.76%). This indicated that rice has been an important livelihood source of farmers even though it is affected by Water hyacinth.

The average total income of farmers in 2019 was ETB 27, 611.22 per year and the annual average off/non-farm income was ETB 3942 per household the maximum reached up to 126,000 ETB per year (Table 3). Close to 39% of the respondents took part in off/non-farm activities to supplement income from on-farm activities and it contributes 12.31% of the total household income. The main source of non/off-farm income activities was from petty trading. As connected with farmers living around lake Tana, a considerable proportion of farmers earned income from fishing activity (26.3%). This study is supported by the results in Malaysia rice producer district; non-farm activities contributed 12.47% the total respondent income whereas rice contributed 73.85% of their average income **(Ibrahim *et al.*, 2013).**

Table 5 Income from different sources

Income source	Share (%)
Sell from rice crop	41.31
Sell of livestock and its' products	31.76
Sell from other crops	14.56
Non/off farm income	12.36
Total income	100

Source; Survey result, 2019

The effect of Water hyacinth invasiveness

The average households' cultivated land infested by water hyacinth was 0.38 ha. The devastated season is usually from August to October, when the water hyacinth is pushed by a wave and rests in the rice fields. Just as rice is grown in the *meher* season, the worst damage has occurred on rice crop. In the study area, 48% of the rice cultivated land was infested by water hyacinth. The extent of invasiveness becomes worsening, 32.08% of rice farm area which was planted was not harvested totally due to Water hyacinth infestation (Table 6). During floods and waves, a mat of water hyacinth completely covers the rice field, made rice production difficult **(Dereje Tewabe *et al.*, 2017)**.

Table 6 Extent of Water hyacinth invasiveness on rice farms (%)

Water hyacinth invasiveness	Area of planted farm	Area of Harvested farm	Area of unharvested farm
Infested rice farm	48.50%	39.73%	32.074%
Non infested rice farm	51.50%	60.27%	2.97%
Total	100%	100%	17.09%

Source; Survey result, 2019

Water hyacinth has been imposed great effect on rice production than other crops. As observed in Table 7, the average productivity of farms which infested by water hyacinth was 2122 kg/ha while the average yield goes up to 4066 kg/ha in non-infested farms. Water hyacinth brought a significant difference in rice yield at a 1% level of significance. The result indicates that water hyacinth reduces rice production by two-fold. Though there were no statistically significant differences in other crops, water hyacinth reduces the yield of other crops too. Previous research in the same study area found that rice farmers whose rice fields were damaged by the weed's dense mats did not grow chickpea, grass pea, or vegetable crops of land due to the difficulty of clearing the mats from rice fields, with a loss value of up to USD 21,333 in chickpea and grass pea production **(Getnet *et al.*, 2020)**.

Table 7 Mean yield (kg/ha) comparison water hyacinth infested and non-infested farms

Crops	Yield in infested farm		Yield in non- infested farm		Combined		T Value
	Mean	SD	Mean	SD	Mean	SD	
Rice	2122	2308	4066	2320	3222	2506	-9.73***
Teff	1096	1011	1320	1055	1235	1042	-1.61
F.Millet	660	631	660	631	1634	1991	-1.23
Maize	2471	2772	1379	1944	1942	2433	1.30
Grass pea	860	582	1041	862	1014	825	-0.64
Lentil	3973	5258	1104	1093	1965	2977	1.49
Check pea	527	422	802	775	752	729	-1.13
	2600	2143	2177	2455	2292	2331	0.37

Source; survey result, 2019

According to data from regional office expert, rice production in 4 districts (Dera, Fogera, Lebkombek & Denbiya districts) has been affected by water hyacinth. In the study ditricts (Fogera and Libokekem) the affected farmland estimated that 1774 ha of the land in the year 2019. As seen in the Table 7 above Water hyacinth could reduce rice productivity by 1944 kg/ha. This has led to the loss of rice production in these districts by 3,448,655 kg and the value 38,073,162.24 birr per year by taking the nominal market price of rice (1774 ha*1944 kg/ha*11.04 ETB/kg), and if it continues in the present trends cause damage to previously untouched areas could totally distract rice production in this districts surrounding lake Tana.

Rice production trend over five years

The trend of rice production has been decreasing over the last five years. Farmers also perceived the reduction of rice crop production, out of the interviewed households 83.07% of the households confirmed the rice production reduction. There might be contributing factors for the production decrease; limited use of fertilizers, poor agronomic management, unable to afford improved rice seeds, flooding of rivers like *Rib* & *Gumara* put sedimentation on land and other factors. But no one can take a more share beyond water hyacinth. Because production showed decreasing trend since 2015, where water hyacinth was started to invade the farm lands in most of the study areas.

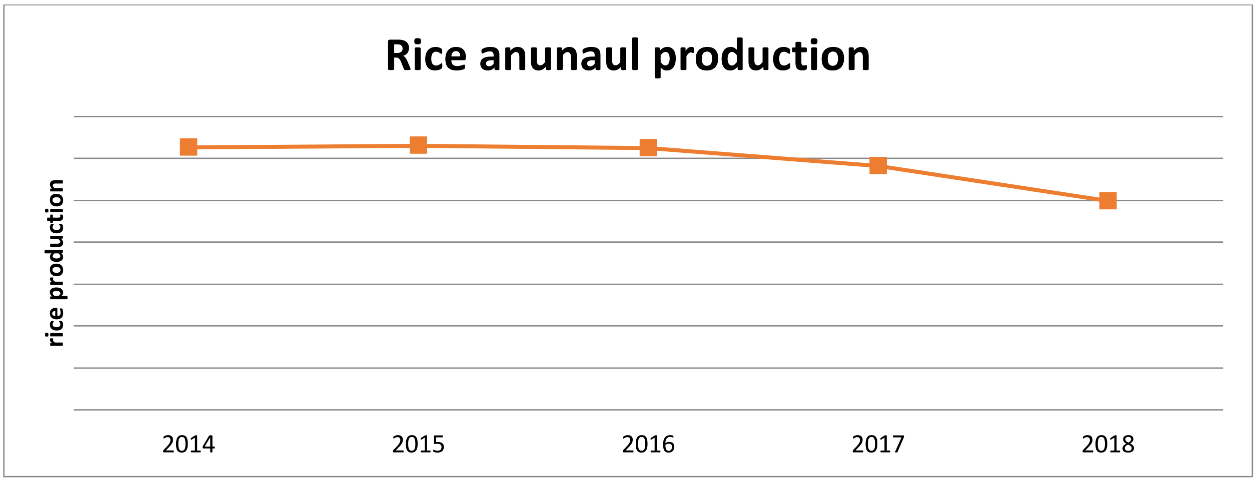

Figure 2 Trends of Rice production over the last five years
Source; survey result 2019

According to data from farmers, rice production has been declining over the past 4 years from 2015, primarily due to the water hyacinth. Although the weed is mainly grown in the rainy season, it also indirectly causes moderate damage to crops that were produced in the dry season through irrigation. Farmers replied that various diseases and insects were observed on the farm fields of teff, maize, and other crops, which are irrigated in dry season, resulting in a reduction in the quality and quantity of produce. Interviewed farmers added that in addition to crop production reduction, there are other side effects, such as when animals use it for food, it also affects the quality of cow milk, it is a waste of grazing land, and it creates a favorable environment for various insects that harm human beings. It also demands a great deal of energy and time of labor and it causes skin itching for humans during removal of water hyacinth. Various studies have shown that it has positive effects mainly used for animal feeds, soil conservation & fertility, fuel production, **used as a raw material to make items that include baskets, cupboards, tablemates, seats, handbags, earnings, bangles, necklaces, trays, chairs and coffins** and other uses **(Osoro, 2014; Balasubramanian *et al.*, 2013; Agengo, 2013),** but farmers were not utilizing it in usable form in the study area. Even though different researches showed that water hyacinth has a positive contribution, the comminute in the study area almost nothing reported that water hyacinth is important for animal feed, soil fertility, and as a raw material to produce finished goods. However, according to a key informant interview with an expert from the Lake Tana and Aquatics Resources Conservation and Development Agency, water hyacinth has many positive effects in addition to its negative ones.

"Before 2019, the top priority was to eradicate the water hyacinth outbreak on Lake Tana," the expert said. To eradicate the weed, it will take longer periods. The Agency are collaborating with relevant governmental and non-governmental organizations on a pilot project to control and manage the water hyacinth by using it as a raw material to create finished goods for human use. Among those who have success with this, for instance, is an international NGO, NABU project. According to his observations from prior studies, water hyacinth is utilized to produce biofuel, soil fertilizer, charcoal, handicrafts, biogas, and ethanol, as well as animal feed.

There is good beginning charcoal production from water hyacinth in Lake Tana, which are run by international NGOs. The Agency intends to scale up the effective methods and include more products made from water hyacinth. Knowing that water hyacinth is a natural resource that can be utilized for a variety of purposes to create the aforementioned finished goods could be taken as an opportunity.*"*

Furthermore, previous studies show that paper hand sheets are made from a blend of water hyacinth pulp and bamboo pulp **(Goswami & Saikia, 1994)**. **Tham (2012)** evaluated water hyacinth was used as animal feed has potential as feed for livestock due to high crude protein content and high dry matter, which may be improved by the addition of molasses or rice bran.

Households Perceptions and the effect of water hyacinth

In the study area water hyacinth affected the farmers around Lake Tana in many ways. As observed in Table 8, sample households perceived that water hyacinth makes land preparation and crop production difficult, dehydrates farmland, reduces fish production and contaminates water, destruction of animal feeds, cause disease on humans and animals.

Table 8 The effect of water hyacinth

Effects	Freq.	Percent
Makes land preparation and crop production difficult	172	91.01
Dehydrates farm land	125	66.14
Makes fishing difficult	123	65.08
Contaminates water	107	56.61
Others(Cuase disease on humans and cattle)	12	6.35

Source; Survey result, 2019

Since 2014, fishing in the study area becomes tiring due to the expansion of this invasive weed **(Asmare, 2017).** According to this source water hyacinth impose a negative impact on fishing activity in Lake Tana, it affected catch rates, increasing fishing costs and blocked many fishing grounds.

Water hyacinth negatively affected fish catch rates, reduce crop production where water hyacinth mate covering fields during wave time, collected water hyacinth (heap) makes the farm land fragile, also affects diversity, distribution and abundance of life in aquatic environments **(Dereje Tewabe *et al.*, 2017, Damtie, Mengistu & Meshesha, 2021)**. It also created a favorable breeding environment for mosquitoes, adversely affects aesthetic and recreational value, Excessive water loss from the river has been regarded as a threat to food security especially in the face of climate change of the river to the communities along Shagashe River in Zimbabwe **(Chapungu, OC & B, 2018).** Due to this weed**, s**mallholder farming along River Tano and Tano Lagoon in Ghana perceived that in the future their living conditions will be worse off if it continues to remain at a level **(Honlah *et al.*, 2019).**

Of the total farmers interviewed, 84.13% of them think that the government/other organizations are recognizing the problem and working against the problem. The government is also providing various supports, including training on how to control the weed, on adaptation strategies and removing water hyacinth using improved technologies, financial support and supplying of oil and soap. A majority of farmers aware that water hyacinth removal using machines practiced in other parts of the area in which water hyacinth invading the lake should also be done alongside with manual control of the weed to improve the prevention work.

Table 9 Farmer's participation and access to information

Particulars	Freq.	Percent
Adapting a strategy to resist the water hyacinth problem	175	92.59
Participation in campaign of removing water hyacinth	169	89.42
Information access regarding water hyacinth	173	91.53

Source: Survey result, 2019

As observed in Table 9, 92.59% of the households used adaptation strategy to resist the water hyacinth problem by themselves. Mostly they participate in removing water hyacinth in campaign or individually by weeding, collect and burn. Few farmers locally constructed fence around their farm to defend the coming water hyacinth before invading their rice farms. Others switch-off from farm to other income earning activities (off/non-farm type). Most of the farmers in the study areas were participated in Watter hyacinth removal campaign. It is coordinated by governmental office experts at *kebele*, *woreda*, *zone* and Region level. Communities contribute as labor to remove water hyacinth.

From the interviewed households 89% of the farmers were willing to participate in removing water hyacinth in community water hyacinth removal campaign. In the campaign different stalk holders were participated like farmers, DA, environmental experts from *woreda*, *Zone* and Regional level. Farmers contribute their labor and time to remove water hyacinth, DAs' and experts at different level create awareness to mass campaign to remove water hyacinth, government organizations supply materials like oil, soap to those participants. The campaign mostly done in months of November to December. The water hyacinth removal activity has been continuing and done by hiring daily labourer till month of May.

Farmers replied that different problems were happened during removing water hyacinth. Some of the difficulties encountered during WH removal were: Bitten by different types of insects (*Alekit*, snake, etc.), cause human skin sick, difficult for movement on water body, weeding is time and energy consuming, and bad smell, cause human disease

The survey result revealed that 91.5% households had access to information regarding water hyacinth in different sources like from Extension workers (43.39%), own experience, fellow framers, mass media and training/workshops.

Trainings about water hyacinth were given to the communities in different times. It was organized by government. The environmental conservation office at different levels; regional, zonal and woreda level was mainly responsible to provide formal training on water hyacinth. There are responsible persons at each level who are experts with environmental in addition to training; they are following up the removal of water hyacinth. The training topics was focused on removing water hyacinth and its' effect on farming and human health.

CONCLUSION AND RECOMMENDATION

Most the population in the study area was found in productive age category, between 15 to 64 years. Half of the household heads were able to read and write. Rice cultivation has been started log years ago. Farmers are very close to the lake and far away from the year-round road, it makes it extremely difficult for the institutions/ individuals/communities to enter the area and avoid water hyacinth.

Since rice is their main crop, more land has been allocated to this crop, and in addition, they can supplement their livelihoods by producing other crops and raising livestock. If the water hyacinth effect continues, they may turn their faces toward rice. Farmers could get difficulty in sustain their life unless donations would be given. Even though tef, lentil, rice and chick pea were the crops produced for market in the study areas, the livelihood of the community decreasing from time to time. As compared with other source of income, farmers still get more income from sell of rice. It is important to work against the water hyacinth effect since it is imposing higher damage. If the proper management strategies are not designed to reduce/eradicate the effect of water hyacinth that could be obtained from rice would lead to risk because it affects not only rice crops but other crops, grazing lands, fishing, and livestock.

Water hyacinth affected the farmers around Lake Tana in many ways, affected negatively crop, fish and livestock production, and contaminates the lake water that could be used for drinking and irrigation and cause animal and human diseases. One third of the planted rice farm was not harvested totally due to Water hyacinth infestation. This led to loss of more than 38 million ETB per year. On the other hand, different findings indicated that it has benefits like the use as animal feed, producing of fertilizer and other finished goods.

Based on the study results, we recommend the following:

The farming communities along *Fogera* and *Libokemkem* districts largely depends on lake Tana water body to access the sources of their livelihood, their quest to sustain themselves economically should be easily made possible through interactive participatory management approach involving the farmers, district authorities, newly established Agency named Lake Tana and Aquatics resources Conservation and Development Agency, local community leaders and rural development agencies to ensure the control of the water hyacinth. Smallholder farmers should be made to participate in joint analysis of the problems created by water hyacinth invasion and the possible solutions, with concerned bodies. This will lead to action plans and the strengthening of existing local institutions whose mandate it is to address the water hyacinth invasion problem.

Water hyacinth significantly reduces income obtained from rice crop mostly and other crops which are produced in irrigation system even though its effect is relatively lower. There needs supporting of farmers whose livelihood affected by water hyacinth in many ways, we suggest the government/ NGOs and individuals to support directly and strength the irrigation development in the study area alongside with this promote of agricultural technologies (crops and livestocks technologies) to these areas. Further to this, creating enabling environment to switch the livelihoods of farmers to other income earning activities that could sustain their life. In addition to weed removal, local residents in the surrounding should be made aware of the possibility of using the weed as a raw material to produce various goods, more research on the use of water hyacinth for social benefits is also essential.

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REGULAR ARTICLE

ASSESSING THE TECHNICAL EFFICIENCY OF IMPROVED TOMATO PRODUCTION IN GHANA: A TWO- STEP METASTOCHASTIC FRONTIER APPROACH

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ABSTRACT

Purpose of the Article: This study examines the technical efficiency of tomato farmers in Ghana.
Methods: Using cross-sectional data for the 2019 cropping season and through a multi-stage sampling technique, 508 farmers from three agro-ecological zones were selected and used for the study. Using Metafrontier analysis and a translog functional form, we examined the mean levels and the determinants of Metatechnical efficiencies.
Findings, Value Added and Novelty: The findings of group-specific metafrontier technical efficiencies (MFTEs) and ecological gap ratios (EGRs) showed that tomato farmers in Ghana produced below the group frontier due to limited and inefficient utilization of the available technologies. Farmers in Forest Savannah Transitional Zone (FSTZ) achieved higher mean technical efficiency than those in the Coastal Savannah Zone (CSZ) and the Guinea Savannah Zone (GSZ).respectively. Conventional inputs such as land, seeds, insecticides, and tractor services positively influenced tomato production in GSZ, FSTZ and CSZ while farmers who were: male; formally educated; belonged to an FBO; and had access to extension services, were technically efficient in GSZ and FSTZ. In CSZ, female farmers and farmers producing tomato as a secondary occupation were more technically efficient. The study recommends that the private sector, including financial institutions, value chains, and NGOs as well as the government through MoFA should invest in FBOs, and also assist tomato farmers to access extension services and education to help eliminate technical inefficiencies in tomato production. Government should also help ease farmers 'access to production inputs such as tractor, fertilizer, pesticides, and seed so as to increase tomato production in Ghana.

Keywords: Metafrontier, Ecological zones, Technical Efficiency, Tomatoes, Ghana
JEL Codes: Q15

INTRODUCTION

Tomato (*Lycopersicon esculentum*) is one of the popular and major income-generating vegetables cultivated by small-scale and medium-scale commercial farmers globally **(Aidoo-Mensah D 2018; Naika *et al.,* 2005; Osei et al., 2010; Ayandiji *et al.,* 2011; Singh *et al.,* 2018).** Tomato has a relatively shorter maturity period and a longer production period (usually up to a year), making it economically attractive to many farmers **(Naika *et al.,* 2005).** It flourishes from temperate to hot and humid tropical weather under different crop systems and climatic conditions, **(Naika *et al.,* 2005).** Compared to other vegetables, tomatoes are the most consumed vegetable in Ghana. It is consumed in large quantities daily by most households in various dishes such as soups, sauces and salads **(Aidoo-Mensah D,2018 ; Attoh *et al.,* 2014).** Tomato is an essential source of minerals (iron, phosphorus), lycopene, beta-carotene, vitamins (A and C), large amounts of water, and low calories **(Naika *et al.,* 2005; Abdulai et al., 2017).** Tomatoes help prevent aging-related illnesses such as dementia and osteoporosis **(Freeman and Reimers, 2010),** and can also improve fertility in men by improving sperm quality and swimming speed by reducing the amount of abnormal sperm in men due to their high lycopene content **(Innes, 2014).**

In Ghana, tomato cultivation is a thriving agricultural activity in the savanna and forest-savanna transition zones. Differences in rainfall patterns, access to tractor services and land makes tomatoes production highly seasonal and bring about variation in harvest periods **(Robinson and Kolavalli, 2010).** Two periods (period of abundance and period of scarcity) is created due to seasonality and this reflects in market prices **(Amikuzuno and Ihle, 2010).** In addition, high production costs, poor seed distribution, poor adaptation of a variety to temperature, inadequate use of irrigation water when needed, sub-optimal and/or untimely application of inputs such as fertilizers, lack of access to credit and inadequate control of pests and diseases contribute to low yields and inefficiency of tomato production in Ghana. It is believed that a farmer can obtain the maximum attainable yield levels by using the recommended quantity of fertilizer, improved seeds and other relevant inputs in tomato production **(MoFA, 2010).**

Despite the increase in tomato production, national demand for tomatoes has long outstripped domestic supply, a situation that attracts large imports from neighbouring countries **(Dapaah and Konadu, 2004; Melomey *et al.,* 2022).** In 2017 for instance, some 75,000kg of tomatoes was imported to meet domestic demand. The supply shortfalls are attributed to low yields **(Attoh, 2017),** which are on average between 63,500kg to 65,500kg. Low agricultural productivity is partly due to resource-used inefficiency in agricultural production and low adoption of improved agricultural technologies including crop varieties **(Owusu *et al*, 2016).** The use of local and poor seed variety limits productivity **(Mohiuddin *et al*., 2007)** and the quality of tomato, which in turn affects pricing **(Horna *et al.,* 2007; Clottey *et al.,* 2009).** Although the crop has many benefits, most developing countries, particularly those in Africa, face many challenges in cultivating it, rendering it unprofitable to produce.

Increasing tomato productivity will not only involve the transformation of some institutions such as the land tenure systems and input and credit provision, but will also require farmers to adopt improved technologies **(Donkoh *et al.,* 2013).** In recent times, the introduction of advanced agricultural technologies has become the focus of the political interests of developing countries. The introduction of improved tomato varieties provides a significant increase in yields by reducing post-harvest losses, which can lead to the creation of processing and export industries, thereby promoting economic development, **(Aidoo *et al.,* 2014).**

Efficiency measurement is continually an area of significant research in the developing countries owing to the inefficiencies in the production processes of developing countries **(Betty 2005).** For instance, some studies **(e.g., Attoh, 2011)** have delved into options for increasing tomato production in Ghana and others (**e.g., Ahmed and Anang, 2019)** have unraveled the drivers of efficiency performances of tomato farmers. However, less of these studies did a country-wide analysis, let alone investigated the effect of improved seed adoption on production efficiency. It is also worth knowing that, efficiency study is location and crop specific, hence results from existing studies elsewhere cannot be generalized.

This study is aimed at identifying the metafrontier technical efficiency, ecological gab ratios (EGRs) and its drivers. Specifically, the study sought to determine the levels and the factors influencing the technical efficiency of tomato farmers and the factors influencing tomato production output in the selected agro-ecological zones of Ghana. The study contributes to filling the gab of regional interventions as a conduct to improving the performance of smallholder farmers. The remaining section of the study in structured as follows: Section 2 literature review, section 3 contains the methodology, which consists of the material and methods and, sections 4 and 5 is devoted to results and discussions and conclusions and recommendations

LITERATURE REVIEW

Efficiency concepts and measurement

Farrell (1957) introduced efficiency measurement, which **Kumar and Gulati (2010)** defined as a measure of operational excellence in the resource utilization process. Productivity is closely related to efficiency. In its most basic form, productivity is calculated by dividing the output by the total physical inputs or resources (land, labor, seed, etc.) used in production. In other words, productivity is simply production efficiency **(Syverson, 2011).** Single factor productivity measures or reflects output units produced per unit of a specific input. When a company fails to maximize its potential output, it is said to be inefficient. A company in the manufacturing process is likely to experience some aspects of productive efficiency, such as technical, allocative, and economic efficiencies. Farmers' output differences can be explained by differences in efficiency. Thus, the production frontier describes the highest attainable output given the smallest number of inputs required to produce a specific output. In other words, the production frontier depicts the maximum attainable output for each input mix. Technical inefficiency refers to a farmer's or firm's failure to achieve the frontier level of output given the level of inputs **(Kumbhakar, 1994).** As a result, inefficiency occurs when the observed output falls below the frontier. Allocative efficiency refers to a company's or farmer's ability to use inputs optimally given their respective prices **(Uri, 2001).** Allocative inefficiency or resource misallocation occurs when a farmer fails to allocate inputs at the lowest possible cost, given the relative input prices. The implication is that misallocating resources will result in higher production costs and, as a result, lower output. Again, a firm or farmer is said to be allocatively inefficient if the marginal rate of technical substitution between any two inputs is not equal to the resulting proportion of factor prices. This could be due to a slow response to price changes and regulatory challenges (**Atkinson & Cornwell, 1994).** In the manufacturing process, a company can be technically efficient but allocatively inefficient, allocatively efficient but technically inefficient, both technically and allocatively efficient, or, at worst, both technically and allocatively inefficient. Economic efficiency attempts to combine technical and allocative efficiencies to depict a firm's or farmer's ability to produce at the lowest possible cost, given an input price and a set of inputs. As a result, attaining technical or allocative efficiency is a necessary but not sufficient condition for achieving economic efficiency. To achieve economic efficiency, a firm or farmer must achieve both technical and allocative efficiencies.

Tomato Production in Ghana

Tomato varieties developed in Ghana have varying levels of resistance to pests and diseases. Resistant varieties have an inherent resistance to pests and diseases that is present in the seed. Varieties of resistant seeds are capable of preventing certain unique diseases, meaning that it is very difficult or unlikely for a plant with these resistant features to get the particular disease. Resistance may be attributed to different characteristics of the plant. A densely covered leaf with hairs prevents certain insects from sitting on such improved trees. Again, some colours are unattractive to certain insects which give such plants resistance ability. Most of these characteristics are noticeable, while features leading to fungal and virus resistance are invisible **(Minot & Ngigi, 2004).** Tomato is a food as well as a cash crop in Ghana. Increasing competitiveness of tomato production can enhance economic growth in Ghana **(Anang *et al.,* 2013).** Despite its potential, tomato production continues to decline, while imports of tomato paste surge at high levels **(Robinson *et al.,* 2012).** The country is ranked as the second largest importer in Africa with about 7,000 Mt of fresh tomatoes and 27,000 Mt of processed tomatoes from the European market **(MoFA, 2017).** Again despite the fact that, tomatoes is one of the most important vegetables produced and consumed in the country, its production shows a pronounced seasonal trend with prices typically varying substantially even within a week.

RESEARCH METHODOLOGY

Study settings

This study was carried out specifically in the Guinea Savannah, Forest Savannah Transition and the Coastal Savannah zones of Ghana. The reason for the selection of these three agro-ecological zones was motivated by a study by **IFPRI (2013)** which identified these zones as having the potential to grow enough tomatoes to meet domestic demand and supply and even have excess for export to the neighboring countries. The study was cross-sectional and employed mainly primary data obtained from farmers using semi-structured questionnaires through a multi-stage sampling technique: the study purposively selected the Guinea Savanna, Forest Savanna Transition and Coastal Savanna based on the aforementioned **(IFPRI, 2013)** study. A simple random and the stratified sampling technique were used in the selection of both the municipality and the communities in each municipality. A proportion-to-size sampling technique was then used to select twenty households from each community, to avoid selectivity bias a simple random technique was employed in the last stage in the selection of individual respondents from each household that engages in tomatoes farming. We employed the Slovin's formula used by **Rivera (2007)** to determine the sample size for the study. It is expressed as:

$$n = \frac{N}{(1 + Ne^2)} \tag{1}$$

Where n is the sample of farmers to be included in the study, N is the population size (number of potential farmers in Ghana, according to $MoFA(2016) = 2503006$) and e is the margin of error. We used 4.4% as the margin of error also known as precision level. From the above formula a total of 516 farmers regardless of acreage were obtained. Data was collected from the 516 respondents and was later cleaned to arrive at 508 farmers. We employed quantitative techniques in the analysis. The Stata software version 16 was used to provide descriptive statistics, such as the mean, standard deviation and variance of the respondents.' and to also estimate the maximum likelihood estimates.

Analytical framework

Given that the study involves different ecological zones with differences in rainfall pattern, tractor services and land, we employed Metafrontier stochastic model in determining the drivers of meta-technical inefficiency and the translog production function in determining the factors influencing tomato output. **Barnes and Revoredo (2011)** stated that a metafrontier production function is suitable for studies under different technologies and environmental conditions.
Specifically we employed the two-step stochastic metafrontier model since the sample consists of different ecological zones. The two-step metafrontier, the pooling stochastic metafrontier and the two-step mixed methods all assume that the deviations between the frontier and the observed output are caused by both factors under and beyond the control of the firm (farmer). Unlike the pooling stochastic metafrontier model whose estimates are not exact and the two-step mixed approach also violating the standard regularity property, the new two-step approach to estimating metafrontier technical efficiencies is accurate and exact and meets all the standard regularity conditions **(Haung *et al.,* 2014).**

The New Two-Step Stochastic Metafrontier Models

The proposed new two-step stochastic metafrontier by **Huang et al. (2014)** is the current estimation method for production efficiency analysis. Both the group specific stochastic frontier and the stochastic metafrontier regressions are used. The group specific stochastic frontier regression is specified as:

$$y_i^k = f(x_i, \beta_i^k)\ell^{V_i^k - U_i^k} = \ell^{x\beta_i^k + V_i^k - U_i^k} \tag{2}$$

Where y^k is group k output, x is the vector of inputs, v_i^k and u_i^k are the error terms for firms in group k, β^k is

a vector of unknown parameters for group k firms.

From the above model [eq2], the group specific stochastic frontier will be first estimated and the estimated parameters and error terms pooled together for the estimation of the stochastic metafrontier model. This is expressed as:

$$y_i^k = f(x_i, \beta_i^k)\ell^{V_i^k - U_i^k} = y^* = f(x_i, \beta_i{*})\ell^{V_i^{*} - U_i^{*}} = \ell^{x_i\beta_i^* + V_i^* - U_i^*} \quad (3)$$

The variables are as defined in (Eq. 2). On the contrary, y^* is metafrontier output and v_i^* and u_i^k are error terms for metafrontier and β^* is the vector of metafrontier parameters.

From equation [2.0] above the group technical efficiency can be derived by dividing the observed output by the frontier output. Both the frontier output and the observed outputs can be used in estimating production performance of a firm. Therefore, the technical efficiency (*T.E (1))* of a group (1) is expressed c as:

$$TE_A^1 = \frac{Observed - output - of - eco\log ical - zone1}{Frontier - output - of - group(1)eco\log y} = \frac{y_A^1}{y^1} = \frac{f_A^1(x, \beta^1)e^{v^1 - u^1}}{f^1(x, \beta)e^{v^1}} = -u^1 \quad (4)$$

For output-oriented efficiency, the ecological gap ratio of farmers in eco1ogical group1 (GSZ) can be estimated as:

$$EGRs(1)\frac{Frontier - output - of - firms - eco\log ical - zone1}{metafrontier - output} - \frac{y^1}{y^*} \quad (5)$$

Finally, the metafrontier technical efficiency *(TE*)* can be measured using the equation

$$TE^* = \frac{Observed - output - of - eco\log ical - zone1}{metafrontier - output} - \frac{y_A^1}{y^*} \quad (6)$$

From the viewpoint of **Huang *et al.* (2014)**, the exact nature of any estimated metafrontier efficiency $MFTE_i^k$ justifies the definition of metafrontier as an envelope of individual frontiers. Hence, the estimated metafrontier is given as:

$$MFTE_i^k = EGR_i^k \times TE_i^k \quad (7)$$

Where $0 \le MFTE_i^k \le 1, 0 \le TE_i^k \le 1 and 0 \le TGR_i^k \le 1$ while $MFTE_i^k$, are all predicted.

For a farmer to be technically efficient or inefficient will depend on some characteristics that are directly or indirectly associated with the farmer. These characteristics could be farmers' socioeconomic or demographic characteristics, farm specific location (FSD), institutional-policy variables (IPV), seed variety adoption (SVA) and the border town effect (BTE). Thus, technical inefficiency of the farmers in *k-th* agro-ecological zone is expressed theoretically as:

$$TI_i^k = U_i^k = \{\delta_o^k + \sum_{m=1}^{m=6}\delta_m^k FSD_{mi}^k + \sum_{m=7}^{m=10}\delta_m^k IPV_{mi}^k + \sum_{11}^{13} SVA_{mi}^k + \sum_{14}^{14}\delta_m^k BTE_{mi}^k + \delta_i^k\} \quad (8)$$

Empirical estimation of the New-Two Step Stochastic Metafrontier Translog Model

Following the new two-step stochastic metafrontier model used by **Huang et al. (2014)**, we first estimated the group specific stochastic translog models. Each of these estimated group specific stochastic translog models are then used in the prediction of tomatoes outputs. The group estimates of tomatoes output (T_i^*) are then pooled together and used for further estimation of the metafrontier model. Also, to obtain a metafrontier technical efficiency ($METE_i$ or TE_i^*), the metafrontier technical inefficiency is subtracted from one (1). Where a metafrontier technical inefficient is given as:

$$TI_i^k = U_i^* = \{\delta_o^* + \sum_{m-1}^{m-6}\delta_m^* FSD_{mi}^* + \sum_{m-7}^{m-10}\delta_m^* IPV_{mi}^* + \sum_{11}^{13} SVA_{mi}^* + \sum_{14}^{14}\delta_m^* BTE_{mi}^* + \delta_i^*\} \quad (9)$$

Implies ($METE_i = TE_i^* = 1 - U_i^*$).

The likelihood ratio test was used in testing for the right functional form while the one-step maximum likelihood estimation procedure was used in the determination of the relationship between tomato output (dependent variable) and input use (socio economic variables influencing tomato output). The generalized likelihood-ratio test was expressed as:

$$K = -2[\ln\{L(H_A)\}/\ln\{L(H_0)\}] = -2[\ln\{L(H_A)\} - \ln\{L(H_0)\}] \quad (10)$$

Where the values of the likelihood function under the alternative and Null hypothesis are $L(H_A)$ and $L(H_0)$. Also, the value of K has a chi-square (χ^2) or the mixed chi-square distribution with the value of degrees of freedom equal to the difference between the number of parameters involved in H_A and H_0.

Table1 Definition of variables
Table1 below shows the variables used in this study and their measurements

Variable	**Description**	**Measurement**
Improved Tomato Seed Variety	Tomato Variety	Categorical: Pectomer 1, Power Roma 2 , Pectomer/power roma 3.
Sex	Sex of the farmer	Dummy; 1 if the respondent is male, 0 if otherwise
HH_Size	Household size	No. of people eating from the same pot
Education	Education of the farmer	No. of years in school
Primary_Occupation	Main occupation of the farmer	Dummy; 1 if tomato farming is the main occupation, 0 if otherwise
Income	Annual household income	Ghana cedi
Ext_Access	Access to extension service	Dummy; 1 if the respondent had extension visit (s), 0 if otherwise
Credit_Access	Access to credit	Dummy; 1 if the respondent had credit, 0 if otherwise
Cropping_Type	Type of cropping	Dummy; 1 if the respondent practices mono-cropping, 0 if otherwise
Potential_Yield	Perception about yield	Scale; ranked from 1-7
Availability_Mkt	Perception about market access	Scale; ranked from 1-7
Seed_Access	Perception about access to seed	Scale; ranked from 1-7
Resistance_Pest	Perception about resistance to pest	Scale; ranked from 1-7
Early_Maturity	Perception about early maturity	Scale; ranked from 1-7
Storage_Ability	Perception about good storage ability	Scale; ranked from 1-7
Resistance_BadWeather	Perception about weather condition	Scale; ranked from 1-7
GSZ	Guinea Savannah zone	Dummy; 1 if the respondent is located in GSZ, 0 if otherwise
FTSZ	Forest Transition Savannah zone	Dummy; 1 if the respondent is located in FTSZ, 0 if otherwise
Instrumental variables		
FBO	Membership in FBO	Dummy; 1 if the respondent belonged to an FBO, 0 if otherwise
Insurance	Membership in insurance program	Dummy; 1 if the respondent participated in insurance program, 0 if otherwise

RESULTS AND DISCUSSION

FARMER AND FARM-SPECIFIC CHARACTERISTICS

Table 2 shows the descriptive results of the farmer and farm-specific characteristics, as well as institutional and environmental factors used in the study. As shown in the table, the respondents have a mean age of 40.53 years with a minimum of 22 years and a maximum of 77 years. The mean ages of farmers in GSZ, FSTZ, and CSZ are 41.09 years, 40.97 years, and 39.367 years respectively. These statistics imply that tomato farmers are within their active and economical years and this has the tendency of increasing tomato production in the country. This finding is consistent with **Dasmani *et al.'s* (2020)** study which showed a mean age of 40 years. Also, 89.6% of the respondents are male while the remaining 10.4% are females. The gender distribution in GSZ (73.4%), FSTZ (87.0%), and CSZ (84.1%) also suggest that tomato production is dominated by males. The findings are consistent with **Owusu (2016)**, **Wongnaa and Awunyo-Vitor (2019),** and **Dasmani *et al.* (2020)** who revealed male dominance in farming in the coastal, forest and savannah zones in Ghana. It was also revealed that males (82.10%) domnate cormmercial tomato farming with only a few females (17.90) also into commercial tomato faming. However in the case of small-scale farming majority (91.29%) are female with the remaining (8.71%) being male. This finding does not meet the *a-priori* expectation. Also, the survey results show that 36% of the sampled respondents in the selected agro ecological zones are illiterate while the remaining 64% are literate. The mean formal education is 2.23 years with a minimum of zero and a maximum of seven. The mean educational years also indicate that the highest level of education a respondent has attained on average is primary education (approximately Primary 3). The result is consistent with the **GSS (2016)** finding which indicates that approximately half of Ghana's adults have obtained primary education or completed middle school/JHS. In terms of technology adoption and understanding of market dynamics, this could have some negative influence on agriculture. **According to Minot *et al.* (2006),** education is also a means of accessing extra employment activities, especially in the non-farm sector. Moreover, majority (90%) of the family heads of the selected farmers in the agro ecological zones are without formal education and this may mean that most of these people would not be able to engage in any formal employment except agriculture. The findings are consistent with **Dasmani *et al*. (2020).**

The mean farming experience is 13.01 years. This high level of expertise in farming can be an essential factor for improving the efficiency of resource use in tomato production.

The mean household size is 7.58 persons per household with a minimum of one and a maximum of twenty-three respectively. This average size is slightly above the average of 7 members in Ghana's household **(GSS, 2010)**. **Al-Hassan (2008)** argues that large families enable members of household to earn additional income from non-farm activities and can help minimize marketable surplus through consumption. Furthermore, majority (83.9%) of the farmers are engaged in tomato production as their primary occupation. Table 1 further reveals that the mean land size is 2.51 ha for the pooled sample and 2.95 ha, 2.44 ha, and 2.38 ha in CSZ, FSTZ, and GSZ. Labour is another important variable that is required through the production process. The mean labour for the pooled sample is approximately 133.41 mandays/ha, with a minimum of 10 and a maximum of 1200 mandays. The average quantity of seed planted to one ha was estimated at 18.94 kg for the pooled sample. The mean herbicide and insecticide application rates are 4.654 litres/ha and 3.207 litres/ha for the entire farmers respectively. The average cost of tractor services is GH¢214.03/ha for the pooled sample. The mean output of tomato for the entire sample is estimated at 98.32 crates per ha. A crate was evaluated at 72kg. The table reveals that about 96.5% of the farmers belong to FBOs. Furthermore, about 63.2% of tomato farmers have access to extension services. Also, less than 5.0% of the entire sample belongs to an insurance program.

Hypotheses Tests for the use of Stochastic Frontier and Metafrontier Models

The results of the generalized likelihood ratio (LR) chi-squared tests for determining the appropriate functional form, existence of inefficiency, and the effects of exogenous factors on technical inefficiency are presented in Table 3. The stochastic metafrontier model is estimated using the stochastic production frontier (SPF) estimates of the individual agro-ecological zones (GSZ, FSTZ, and CSZ). According to the table, the null hypothesis that the Cobb-Douglas production function is suitable for the data is rejected at 1% significance level. The transcendental (translog) functional form is used to represent the production structure since the chi-square calculated values are greater than the chi-square critical values. Several recent studies on the production efficiency of farmers also applied the translog SPF model to estimate technical efficiency **(Owusu *et al.,* 2016; Asravor *et al.*, 2019; Wongnaa and Awunyo-Vitor, 2019).** Besides the LR test, the translog production function is adopted because it is said to be flexible and imposes no restrictions on both production (demand) elasticities and elasticities of substitution, compared to the Cobb-Douglas production function which assumes constant returns-to-scale **(Battese and Coelli, 1995).** Also, the null hypothesis that technical inefficiency is absent is rejected at 1% significance level for each of the translog stochastic frontier production (SPF) models. This result generally indicates that the total variation in output or deviation of actual output from the frontier is in part, explained by farmers' inefficiencies **(Belotti *et al.*, 2013; Kidane and Ngeh, 2015).** The presence of technical inefficiency in the data provides a strong justification for the use of the stochastic production frontier model, rather than the Ordinary Least Squares (OLS) or average production response model (APR) which would have produced biased and inefficient estimates **(Onumah *et al.*, 2013 as cited in Mabe, 2018).**

Furthermore, the null hypothesis that none of the exogenous explanatory factors has a significant effect on technical inefficiency is rejected at 1% significance level. Also, the stochastic metafrontier model is used to estimate technical efficiencies of tomato farmers in the three agro-ecological zones on the basis that farmers in each zone operate under different technologies **(Aravindakshan *et al.*, 2018).** To justify the use of the stochastic metafrontier model, the LR chi-squared test was conducted to test the null hypothesis that tomato farmers in the three selected agro-ecological zones operate with similar or homogenous production technologies against the alternative hypothesis that they operate with heterogeneous production technologies. According to the results, the null hypothesis is rejected at 1% significance level, confirming that tomato farmers in the three agro-ecological zones operate with different production technologies. However, by using the stochastic metafrontier model, all potential biases in technical efficiency due to differences in production technologies and capacity imposed by tomato seed variety have been corrected **(Villano *et al.*, 2010)**. The differences in ecological zones production are evident in the results since the translog SPF model for GSZ is nested into translog SPF models for FSTZ and CSZ, whereas at the same time, the translog SPF model for FSTZ is also nested into the translog SPF models for GSZ and CSZ respectively.

Maximum Likelihood Estimates of the New-Two Step Stochastic Metafrontier Translog Model

The dependent variable, output, and the input variables are all mean-corrected to zero and log-transformed, which implies that the first-order coefficient estimates of the model represent the corresponding elasticities. This study interprets partial output elasticity as the percentage change in output as a result of a one-percent change in an input.

The result is presented in table 4 and shows that the estimated returns-to-scale (RTS) is greater than one in GSZ (1.5111) but less than one in FSTZ (0.1194) and CSZ (-6.6092), indicating that farmers in GSZ are operating at increasing returns to scale (IRTS) while farmers in FSTZ and CSZ are operating at decreasing returns to scale (DRTS). The quantity of seed planted by farmers is significant and positive in the GSZ and FSTZ but negative in the CSZ. The coefficient of land, labour, herbicides, and tractor services are also significant in GSZ. Land, herbicides, and tractor services are positive and significant at 1%, 10%, and 1% levels respectively, while labour is negative and significant at 1% level. The positive effect of land and seed agrees with **Asravor et al. (2019)** and **Wongnaa and Awunyo-Vitor (2019)** who reported a positive and significant effect of land and seed on rice and maize production in some selected agro-ecological zones in Ghana. However, the negative effect of labour in this study contradicts **Asravor *et al.* (2019)** but agrees with **Owusu (2016)** and **Wongnaa and Awunyo-Vitor (2019). Owusu (2016)** further found a negative effect of land on maize production in some selected agro-ecological zones in Ghana.

The results show that land has the largest positive (0.4407) impact in tomato production, followed by seed (0.2731), fertilizer (0.1089), tractor services (0.0868), and herbicide (0.0678). In contrast, labour has the largest negative (0.0594) impact on tomato production, compared to insecticide (0.0439). The positive effect of land, fertilizer, and seed is consistent with **Dessale (2019)** in Ethiopia and Oyetunde-Usman and Olagunju in Nigeria who found a positive and significant relationship between farm size and farm output. In addition, the sources of technical inefficiency (TI) of tomato farmers in the various agro-ecological zones were determined and presented in Table 3. Here, TI is the reverse of technical efficiency (TE). This implies that factors that positively influence TI also reduce TE while factors that negatively influence TI also increase TE. The results reveal that the education of farmers, farming experience, membership of FBOs, and access to extension services are found to be significant factors of TI of tomato farmers in GSZ. The coefficient of education is negative (-0.9169) and significant at 1% significance level. This finding is consistent with **Narala and Zala (2010**), **Cramon-Taubadel and Saldias (2014),** in Chile and **Ngango *et al.* (2019)** in Rwanda, but contradicts the findings of **Donkoh et al. (2013)** and **Anang et al. (2016)** in Ghana who found a positive and significant effect of education on TI of small-scale maize farmers. Membership of FBOs was also significant and negative. The finding is consistent with A**nang et al. (2016) and Wongnaa and Awunyo-Vitor (2019)** in Ghana who found that farmers who belong to FBOs are more technically efficient than those who do not belong to FBOs. The results also found that access to extension services reduces TI by 1.1916 and 0.0633, in GSZ and FSTZ respectively. The finding is consistent with previous literature **(Wongnaa and Awunyo-Vitor, 2019).** Contrary to expectation, highly experienced farmers are less efficient, compared to less-experienced farmers. The finding contradicts **Narala and Zala (2010)** in Central Gujarat who found that highly-experienced farmers are more efficient than less-experienced farmers. The coefficient of gender is significant and negatively related to TI in FSTZ, but positively correlated with TI in CSZ. The negative effect of gender on TI is consistent with **Donkoh *et al.* (2013) and Anang *et al.* (2016)** while the positive effect of gender on TI is in agreement with **Wongnaa and Awunyo-Vitor (2019).** Furthermore, farmers whose primary occupation is tomato farming are less technically efficient compared to those who engage in tomato production as their secondary occupation. This result is contrary to expectation.

Determinants of Technical Inefficiency across the Agro-Ecological Zones

Having examined the determinants of TI of tomato farmers, we proceed to estimate the determinants of metafrontier inefficiency. Table 5 presents the results on the determinants of the metafrontier inefficiency. Results from the estimation revealed education, farming experience, and farming type positively and significantly influence TI while access to extension negatively and significantly influences TI of tomato farmers in Ghana. The results show that the educated, highly-experienced farmers and farmers who practice mixed cropping are less technically efficient while farmers who have access to extension services are more technically efficient.

Summary Statistics of Metafrontier Technical Efficiencies and Ecological Gap Ratios

The study further looked at the ecological gap ratio (EGRs) on farm metafrontier technical efficiency. The results of on-farm metafrontier technical efficiency (MFTE) and ecological gap ratio (EGRs) of tomato farmers are presented in Table 5. MFTE scores are calculated by taking the ratio of actual output to the frontier output. The mean MFTE of the stochastic metafrontier is 77.19%, with a minimum of 15.76% and a maximum of 96.47%. The MFTEs for farmers in the FSTZ range from 4.69% to 100.00% with a mean of 98.17%. Also, MFTEs for tomato farmers in GSZ range from 23.49% to 99.61% with a mean of 77.44% whereas MFTEs for tomato farmers in the CSZ range from 17.29% to 99.99%, with an estimated mean of 86.51%. The findings imply that on average, tomato farmers in GSZ, FSTZ, and CSZ produce at 22.56%, 1.83%, and 13.49% below their respective frontiers. However, the MFTE scores indicate that farmers in FSTZ perform better than their colleagues in GSZ and CSZ. Also, a MFTE score of 100% was recorded among the farmers in FSTZ. In rice production, **Mabe (2018)** also reported that TE scores of rice farmers in GSZ and CSZ are lower when compared with MFTE scores of farmers in FSTZ.

EGRs is estimated to show the productivity potential and gap between each agro-ecological zone frontier and the metafrontier given that all farmers in any of the agro-ecological zone have the potential access to the best available technology for tomato production. EGRs of 1 implies that each group-specific frontier is tangential to the metafrontier whereas EGRs <1 implies that each group-specific frontier is not tangential to the metafrontier. EGRs> 1 indicates better returns from technology. The results in Table 4.6 reveal a mean EGRs of 81.14% (16.48), ranging from 37.77% to 146.54%. This indicates that on average, tomato farmers in Ghana achieve 81.14% of the potential output given the technology available to overall tomato production. The mean EGRs for farmers in GSZ is 86.89% (11.69), ranging from 53.33% to 152.17%. The mean EGRs for farmers in FSTZ is 75.26% (18.45) with a minimum of 15.76% and a maximum of 104.45% whereas EGRs for farmers in CSZ is on average 76.05% (18.51), ranging from 37.77% to 146.54% respectively. The findings imply that, on average, about 13.11%, 24.74% and 23.95% of the EGRs in GSZ, FSTZ, and CSZ are farther below the metafrontier.

Table 2 Descriptive statistics of the sample's characteristics

	GSZ (n=250)		FSTZ (n=158)		CSZ (n=100)		Pooled (n=508)	
Variables	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
Farmer characteristics								
Sex (dummy)	0.896	0.306	0.734	0.443	0.870	0.338	0.841	0.366
Age (years)	41.092	11.054	39.367	8.554	40.970	11.854	40.532	10.522
Household size (count)	7.488	3.662	6.677	10.693	9.250	4.774	7.583	6.874
Education (years)	2.208	2.426	2.741	1.130	1.500	1.806	2.234	2.027
Farming experience (years)	14.060	9.809	11.285	7.451	13.090	10.744	13.006	9.406
Primary occupation (dummy)	0.848	0.360	0.930	0.255	0.670	0.473	0.839	0.368
Policy variables								
Membership in FBO (dummy)	0.984	0.126	0.962	0.192	0.920	0.273	0.965	0.185
Membership in insurance policy (dummy)	0.080	0.272	0.050	0.219	0.000	0.000	0.049	0.217
Extension service (dummy)	0.436	0.497	0.816	0.388	0.830	0.378	0.632	0.483
Access to credit (dummy)	0.184	0.388	0.038	0.192	0.100	0.302	0.122	0.328
Production variables								
Land size (ha)	2.375	1.693	2.441	1.534	2.946	2.382	2.508	1.814
Farming type (dummy)	0.252	0.435	0.481	0.501	0.500	0.503	0.372	0.484
Labour (mandays/ha)	86.400	66.374	207.278	217.504	134.200	90.265	133.406	145.583
Seed (kg/ha)	23.956	97.998	14.430	4.879	13.500	4.263	18.935	68.936
Tractor service(GH¢/ha)	278.720	600.017	74.057	177.951	273.456	603.349	214.029	516.3036
Fertilizer (kg/ha)	252.204	251.348	410.127	404.149	239.010	381.616	298.724	340.120
Herbicides (litres/ha)	6.562	12.035	3.425	4.155	1.824	0.975	4.654	8.973
Insecticides (litres/ha)	3.847	4.155	3.134	2.618	1.725	0.907	3.207	3.376
Output (crates/ha)	94.060	70.524	98.070	67.778	109.350	89.909	98.317	74.005

Environmental factors								
Annual rainfall (mm)	984.1	870	1150	1000	841.3	800	1024	800
Annual temperature (ºC)	28.5	27.8	26.7	26	24.6	24	27.1	24

Source: Authors' Constract, 2020

Table 3 Hypotheses Tests for the use of Stochastic Frontier and Metafrontier Models

Null hypothesis	**(n)**	**Df**	**Chi-Square Test**		
Cobb-Douglas functional form is appropriate			$\chi^2 - Cal$	$\chi^2 - Crit$	$\rho - Values$
GSZ	250	21/49	114.54	34.39	0.000
FSTZ	158	21/49	43.62	34.39	0.0012
CSZ	100	21/49	40.11	34.39	0.0016
Metafrontier	508	21/49	230.37	34.39	0.0000
No inherent inefficiency					
GSZ	250	38/39	128.37	29.41	0.0000
FSTZ	158	38/39	58.76	29.41	0.0000
CSZ	100	38/39	53.95	29.41	0.0005
Metafrontier	508	38/49	117.54	29.41	0.0000
Homogeneous Ecological Zones					
There are no differences in ecological	508	38/49	121.12	65.81	0.0002

Source: Authors' Constract, 2020

Table 4 Maximum Likelihood Estimates of the New-Two Step Stochastic Metafrontier Translog Model

Variables	GSZ Model		FSTZ Model		CSZ Model		Metafrontier Model	
	Coeff.	SE	Coeff.	SE	Coeff.	SE	Coeff.	SE
lnLand	0.4979***	0.1623	-0.1269	0.2851	-0.3311	0.6931	0.4407***	0.0467
lnLabour	-0.6396***	0.0219	-0.0273	0.0741	-0.6299	0.7131	-0.0594***	0.111
lnFertilizer	0.1284	0.1197	0.0965	0.1040	-0.5287	0.5057	0.1089***	0.248
lnSeed	1.3840**	0.5060	0.1477**	0.0616	-3.4764*	6.4874	0.2731***	0.0731
lnHerbicide	0.0712*	0.0387	0.1095	0.6493	-0.9949	0.7429	0.0678***	0.0185
lnInsecticide	-0.0257	0.0403	-0.0925	0.8210	-0.8538	0.5700	-0.0439**	0.0206
lnTractor	0.0949***	0.0322	0.0124	0.1217	0.2056	0.1444	0.0868***	0.0154
$\ln Land^2$	0.1726	0.1931	0.2181	0.1738	0.0906	0.2206	0.2956***	0.0495
$\ln Labour^2$	0.0145	0.0226	0.0784	0.0752	0.1727	0.1222	0.0259***	0.0078
$\ln Fertizer^2$	-0.0533	0.0499	-0.0421	0.2663	-0.0844	0.1054	-0.0244*	0.0139
$\ln Seed^2$	0.0732	0.1715	0.0814	0.2675	-1.4432	1.0007	0.0089	0.0619
$\ln Herbicid^2$	0.0073	0.0726	0.1048	0.9760	-1.6352*	0.8491	0.0453	0.0387
$\ln Insecticide^2$	0.1213	0.0922	-0.2545	1.2279	-0.7336	0.7743	0.0884**	0.0437
$\ln Tractor^2$	0.0256***	0.0068	-0.0088	0.0237	0.0281	0.0246	0.0204***	0.0032
lnLand×Labour	0.2530**	0.0957	-0.0996	0.1873	0.0702	0.1728	-0.0536*	0.0297
lnLand×Fertilizer	0.1479*	0.0794	0.2710	0.1773	0.2465*	0.1455	0.1824***	0.0276
lnLand×Seed	-0.3893**	0.1546	0.0187	0.3322	-0.5451	0.5721	-0.0246	0.0611
lnLand×Herbicide	-0.0112	0.0889	-0.8811*	0.5311	0.1466	0.4816	-0.0308	0.0369
lnLand×Insecticide	-0.1336*	0.0773	1.0159*	0.5844	-0.6699	0.4558	-0.0421	0.0372
lnLand×Tractor	-0.0143	0.0141	-0.0105	0.0233	-0.0315	0.0333	-0.0067	0.0052
lnLabour×Fertilizer	-0.1252*	0.0727	0.0056	0.1719	-0.6516***	0.1538	-0.1007***	0.0204
lnLabour×Seed	-0.2856**	0.1323	0.2399	0.4762	-0.9347**	0.4428	-0.2482***	0.0506
lnLabour×Herbicide	-0.0115	0.0732	0.0098	0.4832	-0.0745	0.2363	-0.0115	0.0296
lnLabour×Insecticide	0.1478*	0.0874	-0.2419	0.4930	0.7013**	0.3004	0.1223***	0.0342
lnLabour×Tractor	-0.0019	0.0171	0.0405	0.0438	0.0798**	0.0298	0.0191***	0.0054
lnFertilizer×Seed	0.2735*	0.1553	0.4277	0.2863	-0.3029	0.3955	0.1076**	0.0498
lnFertilizer×Herbicide	-0.0279	0.0752	0.5146	0.4681	0.2584	0.2442	0.0509*	0.0295
lnFertilizer×Insecticide	-0.0784	0.0786	-0.5348	0.4681	-0.9198**	0.3369	0.0713**	0.0298
lnFertilizer×Tractor	0.0197	0.0132	-0.0396	0.0271	0.0006	0.0239	0.0069*	0.0036
lnSeed×Herbicide	-0.0376	0.1228	0.2308	0.5953	-0.4629	0.6514	0.0140	0.0539
lnSeed×Insecticide	0.1155	0.1411	-1.1960	0.9271	-1.9599*	1.1544	0.1175*	0.0604
lnSeed×Tractor	-0.0134	0.0108	0.0468	0.0379	-0.0306	0.0602	0.0157**	0.0068
lnHerbicide×Insecticide	-0.0772	0.0773	0.0711	1.1257	0.3766	0.3617	-0.0157	0.0357
InHerbicide×Tractor	0.0134	0.0108	0.0300	0.9517	0.0039	0.0345	-0.0233***	0.0042
InInsecticide×Tractor	-0.0065	0.0117	-0.0431	0.1111	0.0744	0.0538	0.0058	0.0045
Constant	-0.0327	0.2499	-0.5494	0.9459	-2.7645*	1.6365	0.0340	0.0872

RTS	1.5111	0.1194	-6.6092	
Log-Lik	139.7159	104.9329	74.4009	79.0894
Wald $\chi^2(35)$	193.46***	67.60***	78.92***	795.22

Note: ***, **, and * indicate significance levels at 1%, 5%, and 10% respectively
Source: Authors' Constract, 2020

Table 5 Determinants of Technical Inefficiency across the Agro-Ecological Zones

Variables	**GSZ Model**		**FSTZ Model**		**CSZ Model**		**Metafrontier Model**	
	Coeff.	**SE**	**Coeff.**	**SE**	**Coeff.**	**SE**	**Coeff.**	**SE**
ln (σv^2)	-2.0953***	0.1844	-1.6448***	0.1291	-1.4744***	1.6193	-3.3802***	0.2192
Sex	-1.1111	0.6940	-2.4081**	1.0461	5.8368**	2.7453	0.0105	0.2377
Age	0.0275	0.0203	0.0790	0.0492	-0.1074	0.0741	-0.0081	0.0092
Education	-0.9169*	0.5256	2.8475	1.9228	1.5353	2.1419	0.3597*	0.2172
Household size	-0.5399	0.8289	3.6567	2.5807	-1.3413	2.8821	0.2720	0.4069
Marital status	-0.0874	0.0729	3.4863	4.2894	-2.2479	1.4213	0.0182	0.5953
Occupation	0.5019	0.4541	-3.7965	3.4559	3.3556*	2.0218	-0.0174	0.2349
Farming experience	0.3737**	0.1589	-0.0631	0.3389	-0.22750	0.6491	0.2291***	0.0658
Farming type	-0.0736	0.4264	-1.4818	1.0661	1.3671	1.3867	0.7663***	0.1994
Membership in FBO	-1.7440**	0.6522	2.0110	2.5760	-3.0353	5.1542	-0.6399	0.4170
Access to credit	0.4102	0.5427	0.4087	2.5760	-0.4888	4.7024	-0.1059	0.4031
Access to extension	-1.1916**	0.5127	-0.0633***	0.0188	2.8829	1.8977	-0.7404**	0.2753
Constant	-0.3929	1.4224	-5.2248	3.7797	-6.6865	5.7682	-2.0111**	0.7718

Legend: ***, **, and * indicate significance levels at 1%, 5%, and 10% respectively
Source: Author's construct, 2020

Table 6 Summary Statistics of Metafrontier Technical Efficiencies and Ecological Gap Ratios

Central Tendencies	GSZ		FSTZ		CSZ		Metafrontier	
	MFTE	**EGRs**	**MFTE**	**EGRs**	**MFTE**	**EGRs**	**MFTE**	**EGRs**
Mean	0.7744	0.8689	0.9817	0.7526	0.8651	0.7605	0.7719	0.8114
St. Deviation	0.1731	0.1167	0.0939	0.1845	0.1729	0.1851	0.1446	0.1648
Minimum	0.2349	0.5333	0.0469	0.1576	0.2298	0.3777	0.1559	0.1576
Maximum	0.9961	1.5217	1.0000	1.0445	0.9999	1.4654	0.9647	1.5217
Sample Size	250		158		100		508	

Source: Authors' Constract, 2020

CONCLUSION AND RECOMMENDATION

This study sought to determine the levels and the factors influencing the technical efficiency of tomato farmers in selected ecological zones of Ghana using the metafrontier model and a translog functional form. The findings of the study revealed that land, seeds, insecticides, and tractor services significantly increased tomato output in FSTZ and CSZ while decreased tomato output de GSZ. Also, education, membership in FBOs, and access to extension services significantly reduced technical inefficiencies while farming experience significantly increased technical inefficiencies in GSZ. Females and farmers with access to extension services had higher technical inefficiencies in FSTZ. In addition, farmers who engaged in tomato production as their primary occupation in CSZ were found to be technically inefficient compared to FSTZ and GSZ. Metafrontier technical efficiency (MFTE) and ecological gap ratios (EGRs) of tomato farmers of the stochastic production metafrontier were estimated to be above 80%. However, farmers in FTSZ achieved the highest mean MFTEs and EGRs, followed by CSZ and GSZ. Similarly, farmers in FTSZ achieved the highest mean technical efficiency, compared to farmers in CSZ and GSZ.

Tomato farmers in Ghana produced below the group frontier due to limited and inefficient utilization of the available technologies. There were also technical inefficiencies in tomato production, especially in GSZ and CSZ compared to FSTZ whose farmers were the most technically efficient.

The policy implication of the study is that government should also help ease farmers' access to production inputs such as tractor, fertilizer, pesticides, and seed so as to increase tomato production in Ghana Also, the private sector, including financial institutions, value chains, and NGOs as well as the government through MoFA should invest in FBOs, and also assist tomato farmers to access extension services and education to help eliminate technical inefficiencies in tomato production

Conflict of Interest: Competing Interests Disclaimer

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge.

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REGULAR ARTICLE

IT IS TOO LATE TO REGRET AND TAKE RISK: FARMERS' ADOPTION DECISION FOR STALL-FEEDING (SF) IN TIGRAY, ETHIOPIA

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ABSTRACT

Research background: Despite a growing interest in the role of time and risk preferences in explaining technology adoption, empirical studies that investigate this behavior are scant. Numerous studies have attempted to identify the determinants of adoption of new technologies. However, those studies failed to capture the duration of time farmers will take to adopt a given technology using a proper model such as duration model.
Purpose of the article: This study developed a technology adoption theoretical model that incorporates time and risk preferences in addition to household level characteristics. Using this model, we tested whether impatience and risk aversion delays or expedites stall-feeding adoption or not.
Methods: Using cross sectional data of 518 sample farmers from Ethiopia, both semi-parametric (Cox PH) and parametric (Weibull PH and Weibull AFT) models have been applied to estimate the conditional probability of SF adoption. This enables us to convey information not only on why a farmer adopted, but also on the timing of the adoption decision.
Findings: As expected, our results indeed show that, the time of stall-feeding adoption increases with discount rate. Individuals who are patient and risk loving adopt stall-feeding sooner than individuals who are impatient and risk averse. Likewise, farmers who are more less-averse adopt SF technology latter compared to farmers who are risk neutral. The estimated results also revealed that economic incentives (i.e. prices) was found to be the most important determinants of the time farmers wait before adopting new technologies. While higher output price significantly accelerates SF adoption, higher input price decelerates the adoption period. The expected milk yield (first moment) had a positive significant effect on the adoption decision, indicating that higher expected mean, on average decreases farmers' time to adopt.
Findings in this study suggest that, land and labor endowment shorten the time to adopt SF. However, market distance delay the adoption of SF. Moreover, access to information, education of household head, breed cow ownership, and location of the farmer, accelerated the likelihood of early SF adoption. To the best knowledge of the authors, this is one of the first adoption studies to have incorporated time and risk preference in its parametric and semi-parametric adoption analysis.

JEL Code: Q1, Q5, O16, Q57
Key words: Stall-Feeding; duration model; hazard rate; time discounting model; Ethiopia

INTRODUCTION

In both theoretical and empirical literature, time preferences is coming to the center stage in explaining technology adoption behaviors. Households with present-biased preferences (impatience) are more likely to have low technology adoption especially in the fields of agriculture and this in turn, will leave them in a cycle of poverty traps **(Banerjee *et al*., 2010; Duflo *et al*., 2011; Le Cotty *et al*., 2014; Tucker, 2006)**. Decision-makers tend to devalue future rewards for which they must wait so that the value of future reward is discounted to equate the present flow benefits (see **Frederick *et al*., 2002; Tucker**, **2006**). The discount rate, hence shows how individuals weigh current versus future rewards which are crucial to understand technology adoption dynamics.
Theory suggests that individuals with higher discount rates are less likely to adopt new technologies with benefits that only occur in the future but that require relatively large up-front investment costs. Farmers may discount seriously the delayed advantages and thereby show that they prefer the immediate gains (traditional technology and input investment) rather than of investing in modern agricultural inputs and harvesting higher yield in the future. Time preference refers, as how a decision-maker subjectively values the tradeoff between the current benefit versus deferred benefit flows **(Duquette *et al*., 2013; Duflo *et al*., 2011; Le Cotty *et al*., 2014: Tanaka *et al*., 2010, Ashraf, 2009)**.

In the past three decades, studies aimed to understand how individual preferences condition agricultural investment decisions have proliferated **(Duflo *et al*., 2011; Le Cotty *et al*., 2014: Tanaka *et al*., 2010, Ashraf, 2009; Liu and Huang, 2013; Ray *et al*., 2018; Kijima, 2019)**. Using a study from Western Kenya **Duflo *et al.* (2011)** found a result which proved present-biased or impatient farmers postpone fertilizer adoption; and **Le Cotty *et al.* (2014)** confirmed that impatience decreases the likelihood of improved grain storage technology adoption in Burkina Faso. Likewise, the work of **Yesuf (2004)** indicated that higher discount rate was correlated with low adoption of soil conservation technology in Ethiopia. Similar result was echoed by **Tucker (2006)** using a study conducted in Madagascar. However, none of the stated studies have touched, how individual risk preference affects farming decisions in the process of technology adoption **(Chavas et al., 2010)**.
Interestingly, several studies **(Feder *et al*., 1985; Liu and Huang, 2013; Ray *et al*., 2018; Kijima, 2019)** have also recognized the importance of capturing the effect of risk and individual preferences on the technology adoption decision. Farmers are expected to select the technology that offers the maximum expected utility, given their level of risk preference **(Foster and Rosenzweig, 2010; Barham *et al*., 2014)**. Findings indicate that risk preference affects farmers' willingness to try new practices **(Greiner *et al*., 2009)**. The state of risk preference, affects the adoption of new technologies in many ways and has been found to reduce the adoption of new technologies/practices **(Ghadim *et al*., 2005)**. Especially if farmers perceived the new agricultural technology as an uncertain proposition, then the individual subjective risk preferences tend to play a major role in technology adoption **(Holden, 2015)**. In line to this, **Ward and Singh (2015**) found that risk averse and loss averse farmers are more likely to switch to new rice seeds in India. Besides, a recent findings by **Liebenehm and Waibel** (2018) proved that a loss averse and impatient farmer is less likely to adopt prophylactic drugs leading to losses of higher and sustainable returns, thereby deteriorates risk management abilities and likely perpetuates poverty.
This paper aims to establish whether individual time and risk preferences play an important role in the adoption of stall-feeding technology in Ethiopia. Though few studies **(Garcia *et al*., 2008; De Cao *et al*., 2013; Klitzing *et al*., 2014; Hadush, 2018)** showed that benefits from modern stall-feeding, if properly implemented, however, its pace of diffusion in practice is slower than anticipated **(Lenaerts, 2013; Bishu, 2014; Hadush, 2018)**. Given the financial constraints **(Cole *et al*., 2013),** state of available information on the benefits **(Gine and Yang, 2009)** and level of social connectivity of the potential adopter **(Conley & Udry, 2010)**, the hypothesis that differences in adoption decisions are explained by individual time and risk preferences need to be tested **(Duflo *et al*., 2011; Le Cotty *et al*., 2014: Tanaka *et al.,* 2010; Liu and Huang, 2013; Ray *et al*., 2018; Kijima, 2019)**. It might be the case that if farmers have a strong preference for immediate rewards, the higher return of stall-feeding may be subjectively discounted, to below the more immediate value of traditional free grazing so that free grazing is preferred and vice versa. Thus, the lag in the benefit realized from the investment may suggest, the potential influence of farmers' time preference to explain their adoption.
Knowing time consistent behavior of our respondents', and using time-consistent discounting model, this paper aims to provide an evidence based explanation in the stall-feeding adoption variation among farmers. We claim that even in cases of, where farmers are not financially constrained and aware of the benefit of stall-feeding, differences in stall-feeding adoption intensity may suggest difference in individual preferences. Therefore, it helps us to establish a causal relationship between the discount rate and stall-feeding adoption in a framework where farmers are time-consistent using a simple protocol to elicit discount rates. Accordingly, individuals are asked to choose between a small immediate reward and a delayed large reward in two-time term frames; which enables to generate an average monthly individual discount factors **(Ashraf *et al*., 2006; Meier and Sprenger, 2010; Bauer *et al*., 2012; Meier and Sprenger, 2013)**.
While a small number of studies attempted to assess the extent to which individual preferences drive individual decisions in saving or borrowing, this study claims to be a pioneer work in providing evidence that time-consistent model of discounting explains the variation of technology (stall-feeding) adoption and expected to contribute to the tiny stall adoption literature. More importantly, in most cases during the introduction of new technology, planners either assume that farmers will assign a discount rate similar to farmers in other parts of the world (bench mark discount rate), or completely ignore time discounting factor at all. Our analysis enables us to provide evidence based policy input in this regard. If our analysis provides us causal relationship between time and risk preferences and adoption, it will be instrumental in helping in predicting how individuals will behave with new technology adoption process and show how discount factor and risk vary in the individual's behavior; which can help explain why low levels of adoption of socially desirable technologies in the future.
In this case, we hypothesized that individuals with high discount rates will be less likely to adopt beneficial technologies and are less likely to favor long-term payoff; implying that as impatience increases it decreases stall-feeding adoption and vice versa. Second, we also hypothesize that stall-feeding adoption decreases with increasing risk aversion behavior. Third, we expect loss adverse individuals have adoption difficulties. We further propose that SF adoption positively and directly respond to output price but negatively respond to input cost of adoption.
The rest of the paper is organized as follows; Section 2 discusses the existing literature on factors that influence household stall feeding adoption decisions with particular emphasis on time and risk preference. The next section explains deeply the relevant theoretical model. Section 4 presents a description of the survey data and experimental design while its sub-section deals on empirical model for estimating stall feeding adoption. Results and discussions are presented in section 6 while section 7 presents conclusions and suggestions.

LITERATURE REVIEW

Livestock farming relies on a number of decisions which includes among other things; feeding rations, breed type selection, and pasture management. For instance, as the decision to adopt stall feeding, entails both short-term costs and long-term benefits in terms of greater livestock productivity and ecological sustainability **(Ghadim *et al*., 2005; Lenaerts, 2013; Bishu, 2014; Hadush 2018)**. A plausible reason for the slow and/ low adoption of some technologies is the timing of benefits and costs associated with new technologies. Risk aversion will be less likely to adopt new technologies with benefits that occur in the future but that require relatively large up-front investment costs **(Duquette *et al*., 2013; Le Cotty *et al*., 2014)**. Following the seminal works of **Fisher (1930)** and **Paul Samuelson (1937)**, many economists have started to a better understanding of time preferences as conditioning factor in individuals 'decision making. **Samuelson** in his constant discounted utility model, noted that individuals with a hyperbolic discount function are more patient in the near future and grow more patient as the delayed rewards get further and further away, which indicates present bias. **Luhmann (2013)** in his work, comparing hyperbolic and exponential discounting models, concluded that, exponential discounting models do not allow for present bias, whereas hyperbolic discounting models do. Few studies which focus on the existence of present bias itself rather than the shape of the discount function which tried to examine the association of present bias with undesirable behaviors, such as procrastination, lack of savings, and a higher probability of quitting job **(Burks *et al*., 2012)**.

Despite the apparent importance of discounting behavior, there is little supporting evidence in its role in the technology adoption of farmers and, more particularly, to stall feeding decisions **(Chavas *et al*., 2010)**. Some directly related studies includes the work of **Duflo *et al*. (2011)** who argued that, those present-biased farmers may procrastinate fertilizer purchases until later periods, and fail to make profitable investments in fertilizer in Western Kenya. **Le Cotty *et al.* (2014)** using hypothetical questions about risk aversion and time discounting in Burkina Faso, showed that impatience decreases grain storage adoption, whereas risk aversion increases storage level. Similarly, **Tucker (2006)** stated that farmers discount future harvests sufficiently and thereby prefer the immediate gains from foraging rather than the delayed advantages of investing additional agricultural inputs using time preference in Madagascar. Another related work in the subject is of **Yesuf (2004)** whose study highlighted the relationship between time preference and adoption of soil conservation technology using elicited discount rates. In his study, higher discount rates were found to be significantly correlated with low adoption in Ethiopia.

Sullivan *et al.* (2010) using survey and field experiment data, from China stated that households with higher discount rates used less labor for applying inputs and spent less on forest inputs in response to forest plot certification. Empirical studies in developing countries have also identified different factors in relation with technology adoption. Accordingly, they found that poor farmers may be credit-constrained **(Cole *et al*., 2013)**, lack information on future benefits of the technology **(Gine and Yang, 2009)**, and may be too risk averse to experiment with new technology **(Liu and Huang, 2013; Conley and Udry, 2010)**. In that **Liu and Huang (2013)** using TCN[1] approach with cotton farmers in China found that more risk-averse and more loss-averse farmers adopt Bt cotton later. Meanwhile, social network facilitates adoption of new technology by enabling farmers to learn about benefits of new technologies from their peers, imitate their peers' decisions, or respond to their peers' experience **(Conley and Udry 2010)**.

However, **Ray *et al.* (2018**) found that risk averse farmers and farmers who overvalue smaller probabilities adopt technology sooner than others. Farmers are expected to be motivated to adopt new technology whenever it promises them higher return i.e. the first moment-predicted mean is positively related to adoption **(Kassie *et al*., 2009; Juma *et al*., 2009; Ogada *et al*., 2014)**. Economic factors relating to output and input prices are important factors to influence the adoption process **(Martínez-García *et al*., 2016)**. A higher input cost delayed SF adoption **(Hadush *et al*., 2019; Martínez-García *et al*., 2016)**. Hence, **Liebenehm and Waibel (2018)** recommended that further research is needed to assess the role of behavioral factors (time preference, loss aversion and risk aversion) on technology adoption.

THEORETICAL MODEL

Why farmers in developing countries who face similar financial constraints and agro-ecological conditions differ in technology adoption such as, fertilizer, recommended agronomic practices and stall-feeding adoption behavior which is the focus of this paper. A hypothesis to be tested is that other things remaining constant, differences in agricultural decisions are explained by individual preferences. If farmers are too impatient, they may be reluctant to use new technologies such as stall-feeding technology.

This section tries to develop a theoretical mode which is used to test that impatience decreases stall-feeding adoption whereas individuals with low discount rate are likely to adopt stall-feeding sooner. Consider a farmer who produces milk or drought power under the inter-temporal decision by dividing the production season into the lean and the harvest season produce h_t, consumes $h_t - c_t \geq 0$ and keeps c_t up to the next lean season. Assuming there is no uncertainty on the milk or milk product price nor on harvest level, the farmers will have a fixed milk price $\underline{p}$ in the harvest period.

The farmers in the lean season decides to feed his/her cow/ox x_t under stall-feeding practice at unit price (k),[2] and consumes the remaining value of his/her harvest, $\bar{p}c_t - kx_t \geq 0$, where $\bar{p}$ is the price of milk or milk product at the lean season. The farmer expects an increase in production under the new investment (improved feeding scenario) and production h_t increases as the number of stall-fed cows increases, x_{t-1}. More precisely, $h_t \equiv h(x_{t-1})$ and $h' > 0$ while $h'' \leq 0$. The model assumes that farmers have no access to credit nor can save any amount of valuable good between the lean season and the next harvest season, implying that the whole harvested amount is supposed to be self-consumed or sold before the next harvest season. In rural farm households, it is logically true that the price of milk or milk product falls from the period of harvest to the lean period. Then we assume that $\bar{p} > \underline{p}$.

Denoting u as the utility function of the farmer (with $\mathrm{u}' > 0$ and $\mathrm{u}'' \leq 0$) and $\sqrt{\rho}$ represents the discounting factor between the two seasons, the discounted sum of the utility of the farmer starting from the harvest season is given by

$$U_t = \sum_{r=1}^{+\infty} \rho^{\frac{r-1}{2}} u\left(\underline{p}(h(x_{r-1}) - c_r)\right) + \rho^{\frac{r-t+1}{2}} u(\bar{p}c_r - kx_r) \tag{1}$$

Farmers maximize their discounted sum of utility by choosing the number of stall feed cows under, x_t, and the stock , c_t, for all t. Following the above expression, the necessary condition for an interior solution ($x_t > 0, c_t > 0, h_t - c_t > 0, \bar{p}c_t - kx_t > 0$) are:

$$-\underline{p}\mathrm{u}'\left(\underline{p}(h(x_{t-1}) - c_t)\right) + \bar{p}\sqrt{\rho}\,\mathrm{u}'(\bar{p}c_t - kx_t) = 0$$

And

$$-k\mathrm{u}'(\bar{p}c_t - kx_t) + \underline{p}h'(x_t)\sqrt{\rho}\,\mathrm{u}'\left(\underline{p}(h(x_t) - c_{t+1})\right) = 0$$

Dealing on the stationary solution i.e., $x_t = x$ and $c_t = c$, the necessary condition for these expressions become:

$$\frac{\mathrm{u}'(\bar{p}c - kx)}{\underline{p}\mathrm{u}'\left(\underline{p}(h(x) - c)\right)} = \frac{1}{\sqrt{\rho}\bar{p}}, \tag{2}$$

and $\frac{\sqrt{\rho}h'(x)}{k} = \frac{\mathrm{u}'(\bar{p}c - kx)}{\underline{p}\mathrm{u}'\left(\underline{p}(h(x) - c)\right)}$

This expression reduces to

$$h'(x) = \frac{k}{\rho\bar{p}} \; or x = h'^{-1}\left(\frac{k}{\rho\bar{p}}\right) \tag{3}$$

From this expression, the model shows that the adoption of stall-feed cows is a decreasing function of the price or the cost of stall feed (k) but an increasing function of the annual discount rate (patience) ρ, price of milk and milk product at the lean season, $\bar{p}$. Furthermore, it does not depend on the utility function i.e. risk aversion and on the price of price of milk and milk product at the harvest season, $\underline{p}$.

In order to take price and harvest uncertainty into account, we further assume that the price of milk in the lean season is unknown in the time of harvest season but it is distributed according to cumulative distribution M. Besides, future harvest is not also certainly known at the time of lean season and assumed to be τh_t, where τ is distributed according to cumulative distributing N. The harvest $\tau h_t(x_{t-1})$ is known at the harvest season of year t, and then the farmer chooses c_t that maximize

$$U_t = \sum_{r=1}^{+\infty} \rho^{\frac{r-1}{2}} u\left(\underline{p}(\tau h(x_{r-1}) - c_r)\right) + \rho^{\frac{r-t+1}{2}} \int u(pc_r - kx_r)\, dM(p)$$

Then the first order condition is given by;

$$-\underline{p}\mathrm{u}'\left(\underline{p}(\tau h(x_{r-1}) - c_r)\right) = \sqrt{\rho}\int \mathrm{u}'(pc_r - kx_r)\, dM(p)$$

Since price is known (p) at the lean season of year t, the farmer chooses x_t that maximize

$$U_t = \sum_{r=1}^{+\infty} \rho^{\frac{r-1}{2}} u(pc_r - kx_r) + \rho^{\frac{r-t+1}{2}} \int u\left(\underline{p}(\tau h(x_r) - c_{r+1})\right) dN(\tau)$$

The first order condition is then given by;

$$k\mathrm{u}'(pc_t - kx_t) = \sqrt{\rho}\underline{p}\, h'(x_t) \int \tau\mathrm{u}'\left(\underline{p}(\tau h(x_t) - c_{t+1})\right) dN(\tau)$$

Rearranging the two first order conditions result in

$$\underline{p} \int \tau\mathrm{u}'\left(\underline{p}(\tau h(x_{t-1}) - c_t)\right) dN(\tau) = E(\tau)\sqrt{\rho} \int \mathrm{pu}'(pc_t - kx_t)\, dM(p)$$

and

$$k \int \mathrm{pu}'(pc_t - kx_t)\, dM(p) = E(p)\sqrt{\rho}\underline{p}\, h'(x_t) \int \tau\mathrm{u}'\left(\underline{p}(\tau h(x_t) - c_{t+1})\right) dN(\tau)$$

or

$$\frac{\underline{p}}{E(\tau)\sqrt{\rho}} = \frac{\int \mathrm{pu}'(pc_t - kx_t)\, dM(p)}{\int \tau\mathrm{u}'\left(\underline{p}(\tau h(x_{t-1}) - c_t)\right) dN(\tau)}$$

and,

$$h'(x_{t-1}) = \frac{k}{E(p)\sqrt{\rho}\underline{p}} \frac{\int \mathrm{pu}'(pc_t - kx_t)dM(p)}{\int \tau\mathrm{u}'\left(\underline{p}(\tau h(x_t) - c_{t+1})\right) dN(\tau)}$$

Focusing only on the stationary solution, the stationary number of stall feed cows are given by;

$x = h'^{-1}\left(\frac{k}{E(\tau)E(p)\rho}\right)$, for all t

In summary, the model presents that the adoption of number of stall feed cows is a decreasing function of the price or the cost of stall-feed (k)but an increasing function of the annual discount rate (patience) ρ, expected price of milk and milk product at the lean season, $E(p)$ and expected yield, $E(\tau)$. Furthermore, as in the case no uncertainty, the adoption of stall fed cows does not depend on the utility function i.e. risk aversion and on the price of price of milk and milk product at the harvest season, $\underline{p}$. This model rules out that adoption of stall feeding is an independent of risk aversion

MATERIALS AND METHODS

Study Area and Survey Design

The study is conducted in the Tigrai region in the northern part of Ethiopia by randomly selecting 632 farm households. The Rural Household Survey dataset collected (cross sectional) in 2018 run by MU research project[3]. To capture the systematic variations among the different agro-climatic zones in terms of, agricultural potential, population density and market access conditions, four communities were selected from each of the four zones and three communities that represent irrigation projects. Likewise, one with low population density and one with high population density were strategically selected from each zone among communities to reflect far distance market **(Hagos, 2003)**.

The study was conducted in five zones (the next lower administration unit to region) covering 11 districts and 21 *Tabias* (lower administrative units to district) so as to yield 632 sample size. A cross-sectional data set for the year 2017/2018 was extracted from the survey since some variables used in this paper were only added in the last wave. The estimation of stall-feeding adoption further reduced the sample size to 518 farmers, including those who only own cattle during the study year. The descriptive statistics of the important variables used in the study are presented in Table1 and are discussed there.

Measuring Time Preferences

In order to test whether heterogeneity in individual time preferences affects stall feeding adoption, we measure individual time preferences using a hypothetical question **(Ashraf *et al*., 2006; Meier and Sprenger, 2010; Bauer *et al*., 2012; Meier and Sprenger, 2013)** to link the state of impatience to stall feeding adoption. In particular, we investigated whether individuals who exhibit present-biased preferences and impatience have higher or lower stall-feeding adoption decision. Individuals under two multiple price lists were asked to make a series of choices between a smaller reward (X) in period t_0 and a larger reward (Y>X) in period t_1 keeping Y constant by varying X in two-time frames. In time frame 1, t_0 represents the present (t = 0) and t_1 is one month (τ =1); and in time frame 2, t_0 is six months from the study date (t_0 = 6) and t_1 is seven months from the study date (t_1 = 7) indicating that the delay length, d, is one month in both time frames. In both frames, the value of X varies from ETB 75 to ETB[4] 40 while Y is held constant to ETB 80.

Employing monetary rewards and multiple price lists as a preference elicitation mechanism enables us to identify differences in patience and present bias between individuals similar to time preference measures derived from other methodologies **(Chabris et al., 2008)**. Time preference measures obtained from price lists at the individual level have been shown to be stable over time (see **Meier and Sprenger, 2010)**. Using information from both price lists allows us to measure individual discount factors (IDF) and present and future bias. Individual discount factor (δ) is measured by taking the point in a given price list, X^* at which individuals switch from opting for the smaller (earlier payment) to opting for the larger (later payment). That is, a discount factor is taken from the last point at which an individual prefers the earlier smaller payment, assuming that $X^* \approx \delta^d \times$Y, where d represents the delay length **(Meier and Sprenger, 2010; Bauer et al., 2012; Meier and Sprenger, 2013)**.

As the delay length, d, is always one month for both time frames, $\delta \approx (X/Y)^{\frac{1}{d}}$. Since our procedure produce two discount measures,$\delta_{0,1}$ and $\delta_{6,7}$, we use the average of these calculated monthly discount factors as the discount factor in the main analysis. Besides we are able to measure present bias and future bias to identify dynamic inconsistency. An individual is present-biased if he is more impatient when presented with a choice with a shorter delay and more patient with longer delays and if the individual is future biased, more patient with a shorter delay and impatient with longer delays **(Bauer et al., 2012)**. We classify an individual as present-biased if $\delta_{0,1}<\delta_{6,7}$, and as future-biased if $\delta_{0,1}>\delta_{6,7}$. For our primary analysis, we use dummy variables Present Bias (=1) and Future Bias (=1).

In order to validate our result cautiously, our elicitation design enables us to reduce the effect of seasonality on time preferences, as the future choice is shifted forward by exactly one month. In the long-term frame, we avoid proposing a choice between an amount now and a higher one a month from now. Instead, the choice is made between six months from now and seven months which involves front-end delay, in the sense that no reward is ever obtained without some minimal delay, allowing us to compare two uncertain choices and to avoid a possible bias toward the present and certain option as proposed by **Frederick et al. (2002**). The format used in this elicitation is presented in appendix A.

Measuring Risk Preferences

Although our intention in this paper is not to estimate risk preference, we include risk preference in order to test the link between risk aversion and patience in our time preference estimation. Exploring people's risk preference through field experiment in developing countries are mostly derived from the types of instruments developed by **Binswanger (1980)** or **Holt and Laury (2002**).While the **Holt and Laury (2002)** approach uses choices from a list of binary lotteries that differ in expected payoffs and variance to infer parameters for risk-aversion, the instrument we employed in this paper instead is similar to the approach of **Noussair *et al*. (2013)** and **Drouvelis and Jamison (2012)** asking respondents to directly compare declining present choices with constant future choices.

A simple hypothetical risk elicitation instrument was presented to our respondents using similar approach of **Noussair *et al.* (2013)** and **Drouvelis Jamison (2012)** who measured risk aversion by counting the number of safe choices made by the individual in five and seven list choices respectively. In order to elicit risk preferences, participants were shown a table with seven rows and asked to choose between a safe option and a lottery option in each row where the safe option is held constant in each row, but the amount in the lottery option increase from row to row. More precisely, in the first-row subjects choose to receive 60 ETB with certainty, or they choose to play the lottery and have a 50 percent chance of receiving 0 ETB and a 50 percent chance of receiving 110 ETB. The amount in the lottery row increases from110 ETB to120, 130, 140, 160, 180, and 200 ETB. Our measure of individual risk aversion is the number of instances in which a respondent chose the certain row. Thus, our *risk aversion* measure ranges from a lowest possible value of 0 to a highest possible value of 7. Then respondents revealed their risk preferences by switching from option 1 to option 2.

A choice of zero safe option, out of seven choices indicates risk preferring individual and a risk neutral individual would make either one or two safe choices, out of the seven choices, and more than two safe choices indicate risk aversion. More safe choices indicate greater risk aversion according to **Noussair *et al*. (2013).** Consulting the work of Drouvelis and Jamison

(2012) as a measure of loss aversion, we used the frequency with which a subject chose the safe option. A detail elicitation table is presented in an Appendix B.

Empirical Model Specifications

To estimate the hazard rate, the time required to adopt SF, duration model was applied. Duration model has its origin in survival analysis, where the duration of interest is the survival of a given subject. While in economics this model is used in labor market studies, where unemployment spells were analyzed **(Verbeek, 2008)**. More recently, **Hannan and McDowell (1984, 1987)** and **Burton *et al.* (2003)** have used it to capture dynamic aspects of adoption processes of agricultural technologies. Since this study intends to estimate the survival, hazard rate and the factors affecting the probability that the farmer adopt SF, in the next short time interval given that it has lasted to that period.

Survival function

Coming to the model specification, T is a non-negative continuous variable representing the duration of stay in a given state measured in years and the probability of a farmer stays in the same state until or beyond time (t) is given by the survival function.

$$S(t) = \Pr(T \geq t) = 1 - F(t) \quad (4)$$

Where t is the age of an enterprise, the survivor function reports the probability of surviving beyond time t.

Hazard function

The hazard function is defined as the limiting value of the probability that T lies between t and t+Δt, conditional on T being greater or equal to t, divided by the interval Δt, as Δt tends to zero.

$$h(t) = \frac{f(t)}{S(t)} = \lim_{dt\to 0} \frac{\Pr(t \leq T < t+dt | T \geq t)}{dt} \quad (5)$$

Where $F(t) and f(t) = dF(t)/dt/$ are the corresponding cumulative distribution and probability density function, respectively. In technology adoption study, the hazard function, therefore, represents the probability that a farmer will adopt SF at time t, given that the farmer has not adopted before t. Given a vector of explanatory variables x_ix, the hazard function (Lancaster 1990) may be redefined as,

$$h(t, X_i) = h_0(t) e^{\sum_{i=1}^{N} \beta_i X_i} \quad (6)$$

The hazard function $h(t, X_i)$ h(t) gives the instantaneous potential per unit time for the event to occur, given that the farmer has not adopted SF up to time t given the set of explanatory variables denoted by X_i. Equation (6) the $h(t, X_i)$ represents Cox model at time t- is the product of $h_0(t)$ which is the baseline hazard and the exponential expression e to the linear sum of $\beta_i X_i$.

The two most popular ways of specifying hazard function are the proportional hazard (PH) and the accelerated failure time models (AFT).

The PH Specification

The hazard rate in all proportional hazard models can be written as follows:

$$h(t, X_i) = h_0(t) e^{\sum_{i=1}^{N} \beta_i X_i} = h_0(t)\lambda \quad (7)$$

Where, $h_0(t)$ is the baseline hazard and depends on t but not X_i; indicating the pattern of time dependence that is assumed to be common to all units; $\lambda = e^{\sum_{i=1}^{N} \beta_i X_i}$ on the other hand is a unit-specific (non-negative) function of covariates (which does not depend on t) which scales the baseline hazard function common to all units up or down. Once we recognize the time dependency, the three hazard parameterization models which specify a particular shape for the hazard rate can be specified as follows **(Cleves *et al.*, 2010; Jensen, 2008)**.

i) Exponential Model: assumes a flat hazard which implies the risk of an event occurring is flat with respect to time.

$$h(t, X_i) = \lambda_i = e^{\sum_{i=1}^{N} X_i \beta_i} \quad (8)$$

ii) Weibull Model: assumes a monotonic hazard

$$h(t,X) = \lambda p(\lambda t)^{p-1} = \exp(\beta_0 + X_i\beta_i)pti^{p-1} \tag{9}$$

Where $\lambda = e^{Xi\beta i}$ and p is a shape parameter

iii) Gompertz Model: follows monotone hazard rates that either increase or decrease exponentially with time**.**

$$h(t) = \lambda e^{\gamma t} = \exp(\gamma t)\exp(\beta_0 + X_i\beta_i) \tag{10}$$

Where $\lambda = e^{X_i\beta_i}$ and γ is a shape parameter

The AFT Specification

The word "accelerated" is used in describing AFT models, assumed for $T_i = \exp(-X_i\beta_i)t_i$ and $\exp(-X_i\beta_i)$ is called the acceleration parameter **(Cleves *et al.,* 2010)**. Moreover, the AFT model assumes a linear relationship between the log of (latent) survival time T and characteristics of the units X: $\ln(T) = X\beta + z$; where β is a vector of parameters and z is an error term. This may be rewrite as:

$$Y = \mu + \sigma u = Y - \mu/\sigma = u \tag{11}$$

Where $Y = \ln(T)$, $\mu \equiv X\beta$, and $u = z/\sigma$ is an error term with density $f(u)$ and σ is a scale factor which is related to the shape parameter of the hazard function.

Having the above AFT model specification, the distributional assumptions about u determine which sort of AFT model describes the distribution of the random variable T. With this regard, five parametric AFT models (time parameterization models) have been specified; to analyze the risk of an event occurring (SF adoption) over time T and the set of covariates, and thereby the best model was selected using appropriate model selection criteria. The models include; Weibull distribution, Exponential distribution, Log-logistic distribution, Lognormal distribution and Gamma distribution. Accordingly, the AFT models functional form are presented below **(**see **Cleves *et al*., 2010; Jensen, 2008)**.

i) Exponential Model

$$h(t, X_i) = \lambda_i = e^{\sum_{i=1}^{N} -X_i\beta_i} \tag{12}$$

Thus, the key note is that $\lambda i = e^{X_i\beta_i}$ in the PH format and $\lambda i = e^{-X_i\beta_i}$ in the AFT format (the change in signs).[5]

ii) Weibull Model

From the AFT specification such that:

$$\ln(T) = X\beta + \sigma u \tag{13}$$

The relationship between PH and AFT Weibull metric given as:

$$\beta_{AFT} = \frac{-\beta PH}{p} \quad \text{or } \beta_{PH} = \frac{-\beta AFT}{\sigma} \tag{14}$$

Hence, the AFT Weibull metric is written as:

$$h(t, \lambda i, \gamma) = \gamma\lambda i t^{\gamma-1} \tag{15}$$

Where $\lambda i = e^{-Xi\beta i}$; and the effect of the covariates is to accelerate time by a factor of $\exp(-Xi\beta i)$

iii) Lognormal Regression Model

It assumes a non-monotonic hazard with an inverted U-shaped hazard function. Its hazard function is given as:

$$h(t) = \frac{\frac{1}{t\sigma\sqrt{2\pi}}exp\left[\frac{-1}{2\sigma^2}\{Ln(t)-\mu\}2\right]}{1-\Phi\left\{\frac{Ln(t)-\mu}{\sigma}\right\}} \tag{16}$$

Where Φ is the standard Normal cdf; $\mu = X\beta$ and σ is a shape parameter

iv) Log Logistic Regression Model

This model is appropriate for data with non-monotonic hazard rates and where the error term follows the Log-Logistic Distribution. It has an inverted U-shaped with the following hazard function:

$$h(t, X) = \frac{\lambda \frac{1}{\gamma} t\left[\left(\frac{1}{\gamma}\right)-1\right]}{\gamma\left[1+(\lambda t)^{\left(\frac{1}{\gamma}\right)}\right]} \tag{17}$$

Where$\lambda i = e^{-(Xi\beta i)}$; λ is the location parameter and γ is the shape parameter,

v) Generalized Gamma Regression Model

It has two shape parameters (ρ and κ) and possessing a highly flexible hazard function that allows for many possible shapes. The density of the generalized gamma distribution is:

$$f(t) = \frac{\lambda\rho(\lambda t)^{\rho k-1} e^{-(\lambda t)^{\rho}}}{\Gamma(\kappa)} \tag{18}$$

Where $\lambda i \ = e^{-(Xi\beta i)}$ and includes special cases/ shape parameters:
If κ = 1, then the Weibull distribution is implied
If κ = p = 1, the exponential is implied
If κ = 0, the log-normal is implied
p = 1, the gamma distribution is implied

An important issue in the duration analysis is the issue of duration dependence, thus "true" duration dependence or "state dependence" versus spurious" duration dependence. Following Lancaster (1979), the problem is addressed by introducing a multiplicative random effect in the PH specification shown in equation 3 above.

$$h(t, x_i, v) = h_0(t) e^{\sum_{i=1}^{N} \beta_i X_i} v \tag{19}$$

Where v is a real positive random variable with mean one and varianceθ, and θ is estimated from the data **(Cleves *et al.*, 2010; Lancaster, 1979)**. Therefore, given the different parametric model specification, the Akaike's Information Criterion (AIC) was conducted to pick the right distributional function ('right' shape for the time dependency). The choice of independent variables was guided mainly by our theoretical model and previous studies, economic theory and the characteristics of the practice under consideration.

RESULTS AND DISCUSSIONS

Descriptive Results

The study was conducted in the Tigrai region in the northern part of Ethiopia by randomly selecting 632 farm households. This study used a cross-sectional data from Tigrai Rural Household Survey dataset collected in 2018 run by MU. To control the systematic (if any) variation in agro-climatic conditions, agricultural potential, population density and market access conditions, four communities were selected from each of the four zones and three communities which are considered irrigation potentials. Furthermore, one with low population density and one with high population density were strategically selected from each zone among communities to reflect far distance market **(Hagos, 2003)**. The study was conducted in five zones covering 11 districts and 21 Tabias so as to yield 632 sample size. A cross-sectional data set for the year 2017/2018 was extracted from the survey since some variables used in this paper were only added in the last wave.

Table 1 Descriptive Statistics

VARIABLES	(1) Mean	(2) SD	Description	Prior
Family size	5.873	2.413	Family size in number	+
Age	56.83	15.20	Age of household head in years	?
Discount factor	0.498	0.404	Average individual monthly discount factor	?
Lasttime	4.793	3.277	Average survival /lasting time to adopt stall feeding	?
Risk Aversion	4.411	2.120	Number of safe choices from risk field experiment	?

Loss Aversion	4.622	2.132	Number of safe choices from loss field experiment	?
Log labor time	4.747	1.435	Adult labor allocated to cattle rearing in hours	?
Expected mean	1.160	0.696	First moment derived from milk production	?
Information	0.583	0.494	Information access via radio and mobile (1/0)	?
Location	0.936	0.244	highland =1 if altitude >2500masl	?
Farm size	1.391	1.225	Total cultivated land in hectare	?
Own cow	0.332	0.471	Ownership of milking local cow (1/0)	?
Log Input Exp	5.370	0.521	Log of modern animal input expenditure (ETB)	?
Gender	0.264	0.441	Sex of household head (Male=1)	?
Lndistmkt	5.062	1.677	Log of distance to market in minute	?
Log milk price	2.523	0.564	Village milk price in Ethiopian currency (ETB)	?
Education	0.481	0.500	Household head education (1= literate)	?
Improved	0.334	0.472	Household breed cow ownership (1/0)	?
ADP	0.556	0.497	Seasonal adoption of stall-feeding	?
FADP	0.363	0.481	Full year adoption of stall-feeding	?
Lasttime	4.793	3.277	Average lasting time to adopt stall feeding	?

Source: Own Survey, 2015

The estimation of SF adoption further reduced the sample size to 518 farmers, excluding those who did not own cattle during the study year. Duration analysis treats the length of time to adopt (or adoption spell) as the dependent variable unlike discrete choice models. The start of the duration spell was set either at the year the practice was first introduced in the village or the year the households in the village started farm adoption decision (the potential year of first adoption).

The sample consisted of 518 households: 187 (36.10%) adopted stall feeding in a full year scale; and 331 (63.9%) are those who are non-adopters until the survey period. However, farmers practicing SF at least in single season are 288 (55.6%), whereas those of non-adopters are 230 (44.4%) in the study area. The specific variables hypothesized to influence the speed of adoption are presented in Table 1 and their expected direction of influence are indicated respectively.

Based on the descriptive analysis, the average time to adopt was found to be 3.7 years. The average age of the sampled farmers was 56.8 years and had an average 5.87 family size at the time of the survey, which is common in rural Ethiopia. Likewise, an average individual monthly discount factor, AVIDR[6], is 0.5. This discount factor is low, but consistent with **Meier and Sprenger (2010)** and **Meier and Sprenger (2013)**, whose result reveals an average individual monthly discount factor of 0.84 in Boston using the same experimental design and **(Bauer *et al*., 2012)** in which the average individual monthly discount factor is 0.6 in India using the same design. An average discount factor of 0.5 was also reported by **Yesuf and Bluffstone (2008)** in Ethiopia.

We found average of 4.4 and 4.6 safe choices in risk/loss field experiment, suggesting that farmers in the sample in general are risk and loss averse. The average log labor time allocated to stall feeding is 4.7 hours per day implying this practice takes a large share of farmers' daily time. On the production risks, the average first moment (expected mean) is around 1.16. From the total 518 households, 302 farmers or close to 58% reported to have access to information via radio, TV or mobile, and of these 302, 80% had adopted it. The farmers in this region are having an average land holding of 1.4 hectares and close to 93% households live in the highlands, of which 67% are SF adopters. This is because the highland is attributed to low land holdings due to population pressure which forces farmers to invest in output-increasing or feed -saving practices in the study area.

On average, farmers who owned an improved breed cow and local milking cow are about 33% and 36% respectively with a mean of 1.8 local milking cows. The average log animal input expenditure (including salt, brewery, bi-product and veterinary services) of the farmers is 5.37 ETB (Ethiopian Currency) with an average log milk price value of 2.5 ETB per day. Of the farmers contacted, the proportion of male headed farmers is higher (74%) than female headed farmers which is 26%. Among the sample farmers, 51% have a literacy education, which on average constitutes half of the sample farmers. Similarly, the average log distance to the local market in the sample is found to be 5.06 walking minutes.

Semi-Parametric and Parametric Estimation Results

While estimating the probability of adoption, both fully parametric and semi-parametric duration models are estimated and the models are compared in terms of fit, magnitude, sign and significance of the estimated coefficients. A semi parametric proportional hazard regression, Cox- proportional model is estimated for the sampled farmers. In this model, the relationship between the probability of an event/failure occurrence and various covariates have been analyzed. In this case, no assumptions are necessary to be made about the shape of the baseline hazard rate **(Cleves *et al*., 2010)**. In order to check the robustness of the estimation and compare results across alternative estimates, three hazard parameterization models have been estimated. From the proportional hazard (PH) family models, exponential, Weibull and Gompertz were estimated but Weibull proportional hazard was favored based on the Log likelihood-ratio, AIC and BIC test statistics. Hence, the discussion and analysis is based on mainly the Weibull metric estimated results, which assumes a proportional relationship between the baseline hazard and the influence of respective covariates reported in Table 2. For the brevity, hazard ratios are reported for the Cox PH and PH models rather than coefficients.

A hazard ratio greater (less) than one denotes that the variable has a positive (negative) effect on the likelihood of the spell ending, that is on SF adoption. A unity hazard ratio implies no effect of the variable on adoption. The shape parameter, ρ is 4.79 for seasonal adoption indicating a positive duration dependence. That is, the probability of farmers' adoption increases with time.

AFT models are also alternatively estimated and presented in Table 3, so as to check the robustness of the effect of the specified covariates on SF adoption's waiting time. Thus, the effect of the covariates is to accelerate time by a factor of exp $(-X_i\beta_i)$. Standard coefficients are reported for the AFT Weibull model. The parameter estimates for this model is reported in accelerated failure-time metric and represent the effect of an explanatory variable on the conditional probability of adoption at time period t.

A negative coefficient indicates a shorter pre-adoption spell (that is the relevant variable speeds up the adoption process) and increases the probability of adoption, while a positive coefficient reflects longer pre-adoption spell and lower probability of adoption. A positive (negative) coefficient would indicate a factor that would delay (accelerate) adoption; and vice versa. Table 3 presents estimated results of AFT Weibull selected from the five AFT models.

Table 2 Estimates of Proportional Hazard Models

	(Seasonal-SF)		**(Full-SF)**	
VARIABLES	**PH Weibull**	**CoxPH**	**PHWeibull**	**CoxPH**
Average discount factor	0.587***	0.632**	0.656*	0.662*
	(0.111)	(0.117)	(0.142)	(0.141)
Risk Aversion	0.870**	0.884**	0.897**	0.900**
	(0.0491)	(0.0495)	(0.042)	(0.042)
Loss Aversion	0.887**	0.897**	0.924*	0.925*
	(0.046)	(0.046)	(0.041)	(0.040)
Expected Mean	1.370**	1.354*	0.625***	0.663**
	(0.220)	(0.212)	(0.113)	(0.119)
Log Milk price	1.257*	1.194	1.422**	1.344**
	(0.167)	(0.160)	(0.203)	(0.194)
Log Input Expenditure	0.885*	0.880**	0.661***	0.680***
	(0.057)	(0.056)	(0.096)	(0.098)
Farm size	1.071*	1.062	1.081	1.051
	(0.038)	(0.040)	(0.066)	(0.068)
Log Labor Time	1.284***	1.201**	1.183**	1.170**
	(0.100)	(0.095)	(0.089)	(0.088)
Information	1.482***	1.410***	1.437**	1.371**
	(0.193)	(0.183)	(0.230)	(0.218)
own cow	1.536***	1.419**	1.939***	1.694***
	(0.229)	(0.212)	(0.346)	(0.301)
Age	0.998	0.997	1.001	1.002
	(0.004)	(0.004)	(0.006)	(0.005)
Family size	1.034	1.020	1.107***	1.089**
	(0.031)	(0.031)	(0.039)	(0.038)
Gender	0.563**	0.604**	0.609**	0.635**
	(0.142)	(0.153)	(0.139)	(0.144)
Education	1.509**	1.383*	1.415*	1.464*
	(0.290)	(0.263)	(0.281)	(0.292)
Improved	1.344**	1.392**	2.260***	1.837***
	(0.197)	(0.200)	(0.404)	(0.325)
Location	5.144***	3.269***	3.247***	2.155**
	(1.521)	(0.985)	(1.081)	(0.686)
Lndistmkt	0.862*	0.874*	1.445***	1.335***
	(0.066)	(0.065)	(0.126)	(0.113)
Lnp	2.632***		2.249***	
	(0.120)		(0.127)	
Constant	0.001***		0.001***	

	(0.001)		(0.001)	
LR chi2	0.000	0.000	0.000	0.000
AIC	399	2755	624	1948
BIC	480	2827	705	2020
Observations	518	518	518	518

NB: ***, **,*Implies that the estimated parameters are significantly different from zero at 1, 5, and 10% significance level respectively; Figures in parentheses are standard error

Tables 2-3 exhibits consistent results from both estimates. Results showed that, the hypothesized variables such as expected mean of milk, price of milk, farm size and family labor time, access to information, agro-ecology location, literacy rate, ownership of breed and milking local cows significantly and positively influenced SF adoption. However, variables such as log input (bi-product, salt, brewery and vaccination) expenditure, individual monthly discount factor, risk aversion, loss aversion and distance to service road, and female household headship delayed early SF adoption. Against our expectation, age of household head appears to have no influence on the adoption process of seasonal and full model estimates.

The standard economic theory stated that the tendency to adopt new practice is driven by the individual time preferences of the decision makers. It has been argued that a high level of impatience may prevent farmers from making long-term investments **(Duflo *et al*., 2011; Le Cotty *et al*., 2014; Tucker, 2006: Tanaka *et al*., 2010, Ashraf, 2009)**. Our result showed a negative association between SF's hazard rate and individual monthly discount factor; implying that impatient farmers have a lower probability of adoption than those patient counter partners. The AFT model, has also gave similar results, a farmer with a high discount factor increase time to adopt, other variables held constant, by 20% on average. This concurs our prior expectation and earlier findings **(Yesuf, 2004; Le Cotty *et al*., 2014; Duflo *et al*., 2011)**. Inline to this, **Duflo *et al.* (2011)** stated that present-biased or impatient farmers postpone fertilizer adoption in Western Kenya while **Le Cotty *et al.* (2014)** confirmed that impatience decreases grain storage adoption in Burkina Faso. Another related work is of **Yesuf (2004)** whose result indicated that higher discount rate was correlated with low adoption of soil conservation technology in Ethiopia. This is also similar to the behavior of Malagasy farmers; whose loss aversion significantly reduces their rice intensification **(Takahashi, 2013)**.

In many developing countries, rural farm is considered as a risky activity given its dependence on environmental factors that are beyond farmer's control. Farmers will, given their level of risk preference, select the technology that offers the maximum expected utility **(Foster and Rosenzweig, 2010; Barham *et al*., 2014)**. Risk aversion describes observed behavior that demonstrates a fear of variance in outcomes **(Tanaka *et al*., 2010; Brick and Visser, 2015; Di Falco, 2014)**. Farmers perceive any new agricultural technology as an uncertain proposition, which allows individual subjective risk preferences to play a major role in technology adoption **(Holden, 2015)**. In connection to this, **Liu and Huang (2013)** and **Ward and Singh (2015)** are the only pioneer studies that inclusively examine the role of expected utility theory (EUT) and prospect theory (PT) for adoption of BT cotton seeds in China. The finding of **Liu and Huang (2013)** indicated that more risk averse and loss averse farmers adopt the BT cotton seed later, while **Ward and Singh (2015)** found that risk averse and loss averse farmers are more likely to switch to new rice seeds in India. At the same time, **Liebenehm and Waibel (2018)** proved that a loss averse and impatient farmer is less likely to adopt prophylactic drugs in West Africa.

Earlier findings indicate that risk preference affects farmers' willingness to try new practices **(Greiner *et al*., 2009)**. It affects the adoption of new technologies in many ways and has been found to reduce the adoption of new technologies/practices **(Ghadim *et al*., 2005)**. It has been documented that risk averse farmers are expected to adopt practices more slowly than risk-loving farmers to avoid the cost of uncertainty and the cost of learning a new technology **(Sassenrath *et al*., 2008)**. Our result revealed a negative association between SF's hazard rate and risk aversion; implying a farmer with a high-risk aversion, found to have a lower probability of SF adoption than those with risk-loving. The AFT model, has also provided similar results, a farmer with a high-risk aversion, on average, increases time to adopt SF, other variables held constant, by 5.3%. This is consistent with the finding of **(Liu and Huang, 2013; Sassenrath *et al*., 2008; Ghadim *et al*., 2005)**. However, **Ray *et al.* (2018)** found that risk averse farmers and farmers who overvalue smaller probabilities adopt his technology sooner than others.

Another variable which was considered to affect SF's adoption is loss aversion **(Liu and Huang, 2013; Ray *et al*., 2018; Kijima, 2019)**. It is found that loss-averse household adopt SF latter. Higher loss aversion, holding other variables constant, reduces the estimated hazard of SF's adoption to 88.7% of its starting value. The results from the AFT model, revealed that loss aversion, on average, decreased the time to adopt for a SF, other variables held constant, by 4.5%. This is in contrast with most of the literature which finds that loss aversion delays the adoption of new technologies **(Liu and Huang, 2013, 2013; Ray *et al*., 2018; Kijima, 2019).**

Farmers are expected to be motivated to adopt new technology whenever it promises them higher return i.e. the first moment-predicted mean is positively related to adoption **(Kassie *et al*., 2009; Juma *et al*., 2009; Ogada *et al*., 2014)**. The expected milk yield (first moment) had a positive significant effect on the adoption decision, indicating that the higher the expected return, the greater the probability of adopting SF. From the AFT model (Table 3), higher expected mean, on average decreases farmers' time to adopt, other variables held constant, by 12% in the case of seasonal and 21% in the case of Full year respectively. Economic factors relating to output and input prices are important factors to influence the adoption process **(Martínez-García *et al.*, 2016; Ghadim *et al.*, 2005)**. One possible reason for the relatively slow adoption of the new practice has been probably due to the relative advantage it offers **(Ghadim *et al.*, 2005)**.

Adoption of SF by smallholders is mainly driven by the objective of increased milk production, for both home consumption and sale **(Klitzing *et al.*, 2014; Lenaerts, 2013; De Cao *et al.*, 2013; Hadush, 2018)**. Inline to our expectation, higher milk price induces faster SF adoption. A one unit increase in milk price, holding other variables constant, induced the estimated hazard of SF graduation to 25.7% of its starting value. An addition of similar result was also portrayed by AFT model, where farmers of higher milk adopt SF faster (8.5%) than farmers with less milk output. This agrees with the finding of **Hadush (2018)** and **Dadi *et al.* (2004)** in which milk price was positive and significant factor SF adoption. This result suggests that economic incentives are more important influences on the speed of adoption than any environmental, institutional or personal factors.

Table 3 AFT Models' Estimation

VARIABLES	(Seasonal) AFT- Weibull	(Full) AFT- Weibull
Average discount factor	0.202***	0.187**
	(0.072)	(0.096)
Risk Aversion	0.0531**	0.048**
	(0.021)	(0.021)
Loss Aversion	0.045**	0.035**
	(0.019)	(0.019)
Expected Mean	-0.120*	0.209***
	(0.061)	(0.079)
Log Milk price	-0.087*	-0.156**
	(0.050)	(0.063)
Log Input Expenditure	0.047*	0.184***
	(0.025)	(0.065)
Farm size	-0.026*	-0.035
	(0.013)	(0.027)
Labor Time	-0.095***	-0.0749**
	(0.029)	(0.034)
Information	-0.150***	-0.161**
	(0.049)	(0.072)
Owncow	-0.163***	-0.295***
	(0.056)	(0.078)
Age	0.001	-0.001
	(0.002)	(0.002)
Family size	-0.013	-0.045***
	(0.011)	(0.015)
Gender	0.218**	0.221**
	(0.096)	(0.102)
Education	-0.156**	-0.154*
	(0.073)	(0.089)
Improved	-0.112**	-0.363***
	(0.056)	(0.077)
Location	-0.622***	-0.524***
	(0.108)	(0.145)
Lndistmkt	0.056*	-0.164***
	(0.029)	(0.038)
ln_p	0.968***	0.810***
	(0.045)	(0.057)
Constant	3.140***	3.316***
	(0.311)	(0.482)
LR chi2	0.000	0.000
AIC	399	624
BIC	480	705
Observations	518	518

NB: ***, **,*Implies that the estimated parameters are significantly different from zero at 1, 5, and 10% significance level respectively; Figures in parentheses are standard error

However, a higher input cost delayed SF adoption. Our result from Table 2 revealed a negative association between SF' hazard rate and input expenditure; implying that farmers with a high input cost, found to have a lower probability of SF adoption than those with low input cost farmers. The AFT model, has also shown similar results, increasing input expenditure increases time to adopt seasonal and full SF, other variables held constant, by 4.7% and 18.4% respectively. This result finds a favor from the findings of **Hadush *et al.* (2019)** and **Martínez-García *et al.* (2016)**, whose result indicate higher expenditure on salt, brewery and veterinary services discourages SF adoption.

Land owned and labor supply are posited to decrease time to adoption **(Newbery and Stiglitz, 1981)**. It is hypothesized that large farm size increases the probability of the adoption of new practices. This makes adoption more feasible since larger farm size is associated with greater wealth, high availability of capital, and high-risk bearing ability to invest in new technology **(Norris and Batie, 1987)**. There is strong evidence, in Table 2, that farmers with more land size labor availability take shorter to adopt seasonal and full SF. The estimated coefficients for land size and labor time in Table 3 suggest that increasing land size and availability of labor decreases the time to adopt SF by 2.6% and 9.5% respectively. As it is expected, farmers with larger farms adopt earlier, and this was borne out by the analysis. This corroborates recent finding of **Murage *et al.* (2011)** where farm size increased the speed of adoption of weed control in Kenya.

As we hypothesized, variables associated with access to information and milking cow ownership, lead to shorter time to SF adoption. Considering the magnitude and significance of the coefficients in both models, information and breed cow had similar influence on adoption of full and seasonal SF. If the farmer had any access to information and milking cows, his/her probability of SF adoption increased its hazard rate by 1.48 and 1.54 times higher. Consistent with this result, the AFT model revealed that a farmer with access to information and milking cow adopted SF 15% and 16% earlier than a farmer without information and cows. This result mirrors results for static adoption analysis of SF in East Africa **(Turinawe *et al.*, 2011; Hadush, 2018** and **Gunte, 2015)** who stated that adopters of improved forages had higher access to a mobile telephone and milking cows. The less important influence on the SF adoption process appear to be age of household head and family size, except that family size shortens the time to full SF adoption by 4.5%.

Contrary to the previous findings of **(Gunte, 2015; Hadush, 2018)** female household head shortens the time to SF adoption. Female head farmers adopted earlier, on average, than male head farmers. This is a fascinating result as it corroborates the past debates in the context **(Kaliba *et al.*, 1997)** that female-headed households usually tend to be poor, and thus prefer to have few breed cows under stall feeding practice in Kenya. Of the remaining variables, farmer's literacy and breed cow ownership, appear to be the most important influences on the speed of adoption; their coefficients all have the expected signs and are significant. The hazard increases by 46-51% (SSF and SFSF) if a farmer is literate compared to not having any, *ceteris paribus.* From the AFT model, the farmer's time to adopt SF decreases by almost 15 percent compared to a farmer not having any literacy, which is similar to that in PH models. Consistent with this study, previous studies provide evidence that education is indeed important in the choice and adoption of different practices **(Abdulai and Huffman, 2005; Hadush, 2018)**.

A hazard ratio of 1.34 and1.84 (SSF and FSF) of improved cow ownership indicates that a Farmer with breed cow is 34 and 84 percent more likely to adopt SSF and FSS at time *t* than a farmer without breed cow. Based on the AFT model, a farmer with breed cow adopted SSF and FSF 11% and 36% earlier than a farmer without breed cow. This result was expected and in line with the findings of **Hadush (2018)** who found a positive relationship between a number of breed cattle and adoption of SF. Interestingly, a greater elevation of the farm household has the effect of shortening the time to SSF and FSF adoption. If a farmer is located in the highland, the farmer showed a 5.144- and 2.155-times higher hazard rate than a farmer located in the lowland. Likewise, the AFT models indicated that highland location decreases the log of time to failure (time to adopt) by 0.622 for SSF and 0.524 for FSF. That is, location in a highland decreases the waiting time to adopt SSF and FSF by 62% and 52% respectively. This finding is consistent with **Hadush (2018)** and **Hadush *et al.* (2019)** on the adoption of SF in Ethiopia

The evidence regarding the importance of the distance variable in the adoption decision is reasonably strong. A one walking minute increase in distance from the local market, *ceteris paribus*, reduces the estimated hazard of SSF adoption to 86% of its starting value. The farther the farmer lives from a local market; the more time it takes to adopt SSF. Considering the magnitude and significance of the AFT coefficient, a farmer living a mile farther from the local market increases her time to adopt, other variables held constant, by 9 percent on average which is consistent with our expectation and findings in the literature **Dadi *et al.* (2004) and Hadush (2018)** who showed that distance to market significantly retarded the adoption of fertilizer and SF in rural Ethiopia.

CONCLUSION AND POLICY IMPLICATIONS

A number of studies have dealt on identifying the determinants of adoption of new technologies. However, those studies use probit models to explain why a farmer adopted but fail to capture the farmer's time to adoption using a proper model such as duration model. Moreover, many scholars believe that time preference explain individual decision-making behavior as it captures the patience of individuals, in addition to risk aversion. Despite there is an increasing interest in the role of time and risk preferences in explaining technology adoption, empirical adoption studies that investigate this behavior are scant. In this paper, we develop a simple theoretical technology adoption model that incorporates time and risk preferences to test that impatience and risk aversion delays stall-feeding adoption whereas individuals with low discount factor and risk aversion are likely to adopt stall-feeding sooner.

Using survey data from Ethiopia, Cox PH, Weibull PH, and Weibull AFT models have been estimated. Both parametric and semi-parametric models are applied to estimate the conditional probability of SF adoption, in which the full parametric models include the Weibull PH model and the Weibull AFT model, and the Cox PH model is the semi-parametric model. This enables us to convey information not only on why a farmer adopted, but also on the timing of the adoption decision, using cross sectional data of 518 sample farmers in Ethiopia, which cannot be portrayed by discrete probit models. In this paper, we try improve our understanding of the process of technology adoption over time and enhance our ability to predict the effect of time-varying variables on adoption using duration analysis.

The main conclusion of this study is that it is not only the economic or individual characteristics of the farmer that are important influences in the timing of the adoption decision but factors related to information, location, discount factor, attitudes toward risk and loss. The main findings have shown that indeed the time of stall-feeding adoption increases with increasing discount rate. This is to imply that impatience lengthens the time to adopt stall-feeding whereas patient individuals are likely to adopt stall-feeding sooner. Likewise, farmers who are more risk averse a loss averse adopt this technology latter compared to farmers who are risk neutral/loving and loss-loving. This is one of the first adoption studies to have incorporated time and risk preference in its parametric and semi-parametric adoption analysis.

The estimated models suggest that economic incentives (i.e. prices) are the most important determinants of the time farmers wait before adopting new technologies. While higher milk price significantly induces faster SF adoption, higher input price increases the time to adoption period. The expected milk yield (first moment) had a positive significant effect on the adoption decision, indicating that higher expected mean, on average decreases farmers' time to adopt. Findings in this study suggest that land and labor endowment shorten the time to adopt SF However, market distance and male headship were found to delay the adoption of SF in the study area. In addition, the findings in this study suggest that risk age is not a significant factor. Access to information, education of household head, breed and local cow ownership, and location of the farmer, accelerated the likelihood of early SF adoption. As a result, it can be argued that the decreased time to adoption due to living in highland is related to population pressure and resource scarcity.

The main limitation of this paper is that the measure of time and risk preferences is based on hypothetical experimental design. In this case, it is possible that individuals may tend to be risk–lover than they are in the case of incentivized experimental design. This affects individual decision making in the case of technology adoption. The second point worth that this paper used a cross-section data which does not capture the dynamic nature of the state of adoption. Thus, the authors call for a further study with an incentivized experimental design and panel data in the study area.

Endnotes:

[1]Tanaka, Camerer, and Nguyen (2010) (hereafter TCN) developed a method to measure PT parameters: risk aversion, loss aversion, and nonlinear probability weighting by presenting Vietnamese respondents with 35 pairwise lottery choices, seven of which contain gains as well as losses, and use farmers' choices in these pairs to estimate the three PT parameters. TCN incorporates PT but does not reject EU outright particularly, prospect theory converges to the standard expected utility model when α=1and λ=1. This approach is applicable to our study since its design is simple to less educated respondents.

[2]Assuming that there is a one-to-one correspondence between number of milking cows treated under stall − feeding and the amount of improved inputs used, then k can also be interpreted as the per cow cost under stall-feeding practice.

[3] Mekelle University. This dataset has been initially used by Holden et al. (2011) and Hagos (2003) for their PhD study

[4] ETB refers to Ethiopian currency where 1USD≈24 ETB during the study year, 2015

[5] The change in sign makes sense because the PH format uses covariates to model the hazard rate whereas the AFT format uses covariates to model the survival times. The AFT metric gives a more prominent role to analysis time.

[6] For a similar approach (see Ashraf et al. 2006; Meier & Sprenger 2010; Bauer et al. 2012; Meier & Sprenger 2013), and see the appendix for the full explanation of the field experiment.

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Appendix A. Choice Experiment for Time Preference

Individual discount factor (δ) is measured by taking the point in a given price list, X^* at which individuals switch from opting for the smaller (earlier payment) to opting for the larger (later payment) using a hypothetical questions[1]. That is, a discount factor is taken from the last point at which an individual prefers the earlier smaller payment, assuming that $X^* \approx \delta^d \times$Y, where d represents the delay length. As the delay length, d, is always one month for both time frames, $\delta \approx (X/Y)^{\frac{1}{d}}$ .Since this procedure produce two discount measures,$\delta_{0,1}$ and $\delta_{6,7}$, the average monthly discount factors is used as the discount factor in the main analysis. The author classify an individual as present-biased if $\delta_{0,1} < \delta_{6,7}$, and as future-biased if $\delta_{0,1} > \delta_{6,7}$ to use in the analysis.

Instruction: Please indicate for each of the following 12 decisions, whether you would prefer the smaller payment in the near future (A) or the bigger payment later (B). Switching from option A to option B is possible at any point.

S/N	**Option A: Today (t_0 = 0)**	**Decision: A or B**	**Option B: 1 Month (t_1 = 1)**
1	ETB 75 guaranteed today		ETB 80 guaranteed in a month
2	ETB 70 guaranteed today		ETB 80 guaranteed in a month
3	ETB 65 guaranteed today		ETB 80 guaranteed in a month
4	ETB 60 guaranteed today		ETB 80 guaranteed in a month
5	ETB 50 guaranteed today		ETB 80 guaranteed in a month
6	ETB 40 guaranteed today		ETB 80 guaranteed in a month
	Option A: six month (t_0 =6)		**Option B: 7 Month (t_1 = 7)**
7	ETB 75 guaranteed in 6 month		ETB 80 guaranteed in 7 month
8	ETB 70 guaranteed in 6 month		ETB 80 guaranteed in 7 month
9	ETB 65 guaranteed in 6 month		ETB 80 guaranteed in 7 month
10	ETB 60 guaranteed in 6 month		ETB 80 guaranteed in 7 month
11	ETB 50 guaranteed in 6 month		ETB 80 guaranteed in 7 month
12	ETB 40 guaranteed in 6 month		ETB 80 guaranteed in 7 month

Appendix B. Hypothetical Risk

A simple hypothetical risk elicitation instrument was presented to the respondents[2] to measure risk aversion by counting the number of safe choices made by the individual in a five and seven list choices respectively. A choice of zero safe option, out of seven choices indicates risk preferring individual and a risk neutral individual would make either one or two safe choices, out of the seven choices, and more than two safe choices indicate risk aversion.

Instruction: choose either option A, which gives you a certain 60 ETB or option B with 50% chance of getting 0 and 50% chance of getting the specified ETB amount. You can switch from option A to option B at any point you want to switch.

Risk				
Option A		A or B	Option B	
1	100 % of 60 ETB		50 % 0 and 50% 110 ETB	
2	100 % of 60 ETB		50 % 0 and 50% 120	
3	100 % of 60 ETB		50 % 0 and 50% 130	
4	100 % of 60 ETB		50 % 0 and 50% 140	
5	100 % of 60 ETB		50 % 0 and 50% 160	
6	100 % of 60 ETB		50 % 0 and 50% 180	
7	100 % of 60 ETB		50 % 0 and 50% 200	

[1] See for more details (Ashraf et al. 2006; Bauer et al. 2012)
[2] See for similar approach (Noussair et al. 2012; Drouvelis et al. 2012; Meier and Sprenger 2013)

REGULAR ARTICLE

FACTORS INFLUENCING FARMERS' WILLINGNESS-TO-PAY FOR BIOFORTIFIED MAIZE IN THE FEDERAL CAPITAL TERRITORY, NIGERIA

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ABSTRACT

Research background: Biofortified maize are products of modern biotechnology and genetic engineering, which produce crops with special traits of interest resistance to pests and diseases, tolerance to the herbicide, high yield, salt tolerance, submergence, nitrogen efficiency, etc. It is not just about technological advances and the development of a new product, ascertaining the factors that could stimulate demand, and creating awareness about the benefits of biofortified crops are crucial for this new enhanced variety of maize to make an impact.
Purpose of the article: The research was conducted to determine the factors influencing farmers' willingness-to-pay for biofortified maize in Gwagwalada Area Council, of the Federal Capital Territory (FCT), Nigeria, to identify the stimulating factors and challenges confronting farmers' willingness-to-pay for biofortified maize.
Methods: The multistage sampling technique was adopted for the study and used to select a total of 100 maize farmers for this study. Primary data were collected from the respondents using a well-structured questionnaire. The data were analyzed using descriptive statistics and the Two-limit Tobit Model, which was used to identify the factors influencing farmers' willingness-to pay for biofortified maize.
Findings, value-added & novelty: The study found that the majority of the maize farmers in FCT, Nigeria were willing-to-pay for biofortified maize, while the result from the Two-limit Tobit analysis revealed that sex, extension contact, access to land, the number of literate in the farmers' households, and maize farming training were the factors that influenced the maize farmers' willingness-to-pay for biofortified maize, while non-availability of credit facilities was a major constraint militating against their willingness to pay for biofortified maize. The study recommends that stakeholders should ensure to make credit facilities more accessible to maize farmers to enhance the adoption of biofortified crops, especially maize, and advocated for regulatory land-use acts that will make maize farmers participate more inland ownership systems that are more secured should be put in place for land tenants to benefit so that they can be able to invest and use sustainable maize production strategies to maximize benefits.

Keywords: *biofortification; Two-limit Tobit; maize; willingness-to-pay.*
JEL Codes: R52; R58; D1.

INTRODUCTION

Maize (Zea mays) is one of Nigeria's most important cereals, both in terms of the number of farmers that cultivate it and in terms of its economic importance. Maize, which began as a subsistence crop in Nigeria, has evolved into a commercial crop on which many agro-based industries rely for their raw materials, owing largely to the fact that maize is a versatile crop that allows it to grow across a range of agro-ecological zones of the country, costing less than other cereals, high yielding and easy to process **(Iken & Amusa, 2004)**. The animal feed sector consumes about half of the total maize produced in Nigeria, with poultry accounting for up to 98% of the total feed. There are nearly 870 million people who are chronically undernourished **(Food and Agriculture Organization [FAO], 2012)**, and according to **United Nations Children's Fund** [**UNICEF] (2017)**, 22.9% of underage five children worldwide are stunted, with one-third of these stunted children living in Sub-Saharan Africa, with West and Central Africa accounting for 33.5%.
Maize's richness lies in its enormous genetic diversity, which has allowed breeders to improve it using traditional breeding methods. Maize is the most extensively consumed staple food in Africa, providing over 30% of total calories to over 4.5 billion people in developing countries. Poor-quality diets dominated by dietary staples are typically lacking in minerals and vitamins, but maize can supply enough amounts of Provitamin A (proVA), which the body converts to Vitamin A. According to **Nilupa *et al.*, (2019)** the first commercial biofortified crop was Quality Protein Maize (QPM), which is a group of maize varieties established by traditional plant breeding methods to produce grains with higher protein quality. The maize breeding target was set at 15 g/g beta-carotene, to provide an additional 50% of the estimated average Vitamin A requirements in maize-eating regions. Maize containing these quantities of beta-carotene would be an effective contributor to reducing Vitamin A deficiency.

Biofortification is the process of biologically enriching food crops with macro or micronutrients by agronomic methods, traditional plant breeding, or genetic engineering **(Bouis & Saltzman, 2017)**. Biofortification tries to boost nutrient levels in crops while they're still growing, rather than after they've been harvested. According to the World Health Organization (WHO), vitamin A deficiency affects 5.2 million preschool-age children worldwide. The International Maize and Wheat Improvement Center have partnered with several agencies in recent years to develop provitamin A maize to reduce vitamin A deficiency in children. The first zinc-enriched maize varieties were launched in Honduras and Colombia in 2017 and 2018, respectively, as a result of the collaborative efforts. Biofortified maize consumption has been shown to boost total body Vitamin A deposits as effectively as supplementation **(Gannon *et al.*, 2014)**, as well as considerably improve visual performance in children who are Vitamin A deficient **(Palmer *et al.,* 2016)**.

The International Institute for Tropical Agriculture (IITA), the Institute of Agricultural Research (IAR), and the Nigerian university's agriculture faculties are also involved in breeding initiatives that assist maize stack nutrients. For biofortified maize to have an impact, research institutes must collaborate with maize farmers, this entails much more than simply technology advancements and generating new products; it's also about enabling legislation, encouraging demand, and raising knowledge about the advantages of various kinds.

Despite the fact that biofortified maize has been identified as one of the key staple crops that can be used to reduce hunger and combat malnutrition in Africa, it is yet to be fully accepted by farmers in Nigeria and this can be attributed to numerous factors. Farmers' willingness-to pay (a measure of their acceptance) for biofortified maize depends largely on the farmer's attributes and agronomic traits' including its nutritional values. Currently, the perceived agronomic traits of biofortified maize by smaller holder farmers in Gwagwalada Area Council of the FCT, have not been explored. This and many more drawbacks necessitated this study to assess the factors influencing farmers' willingness-to-pay for biofortified maize in the FCT, Nigeria. Specifically, the study would assess the willingness-to pay for biofortified maize by the respondents in the study area, identify the factors influencing farmers' willingness-to pay for biofortified maize in the study area, and assess the perceived constraints facing farmers in acceptance of biofortified maize in the study area.

The null hypotheses that aided the study to achieve the specific objective of identifying factors influencing farmers' willingness-to-pay for biofortified maize in Gwagwalada Area Council, FCT were: (i) H_{01}: There is no significant relationship between socio-economic characteristics of the farmers and their willingness-to-pay for biofortified maize in the study area; (ii) H_{02}: There is no significant relationship between the willingness-to-pay for biofortified maize and the farm and institutional factors in the study area.

LITERATURE REVIEW

Biofortification is derived from the Greek word "bios" which means "life" and the Latin word "fortificare" which means "making strong". It's the process of improving the nutritional quality of food crops through agronomic practices, traditional plant breeding, or modern biotechnology **(Meena *et al.,* 2017)**. Biofortification is defined as "the enhancement of micronutrient levels of staple crops through biological processes such as plant breeding and genetic engineering". Biofortification of staple crops, according to **Meenakshi *et al.,* (2010)**, is a major technique to combat micronutrient insufficiency and increase the availability of vitamins and minerals for individuals whose diets are dominated by low-nutrient foods.

Biofortification employs advanced technology (breeding and genetic engineering) alone or in combination with crop selection to increase the nutritional value by increasing micronutrient content, the bioavailability of nutrients, and cost-effectiveness. Because of its long-term cost-effectiveness in delivering micronutrients once incorporated into plant food varieties, biofortification has been identified as an advantageous approach. It has the potential to make micronutrients available to underserved rural populations who cannot afford other forms of fortification and micronutrient sources and rely more on staples **(Bovis, 2003)**. Biofortification is aimed at the rural poor, who produce and consume staple food crops in large quantities and may lack access to other nutrition interventions such as fortification, which are primarily aimed at urban populations who consume processed foods **(Birol et al., 2015)**. If fully adopted and accepted, genetically modified crops could provide food-based interventions to remote populations with micronutrient deficient diets **(Onyeneke *et al.,*2019)**. According to **Mwiti *et al.,* (2015)**, biofortification, particularly in staples, can help to reduce the prevalence of vitamin A deficiency and food insecurity. Creating new products from these biofortified crops can help to increase acceptability and utilization, and thus increase dietary intake of provitamin A carotenoids **(Nkhata, *et al.,* 2020)**. Biofortification may thus provide a means of reaching populations where supplementation and traditional fortification activities may be difficult to implement and/or limited **(World Health Organization [WHO], 2019)**.

Maize (Zea mays) belongs to the grass family (gramineae). It originated in South and Central America and was introduced to West Africa in the 10th century by the Portuguese. Maize is a major cereal and one of Nigeria's most important food crops. Dent corn, flint corn, pod corn, popcorn, flour corn, and sweet corn are the six major types of maize **(Franklin, 2013)**. Sweet corn varieties are typically grown for human consumption as kernels, whereas field corn varieties are used for animal feed, and various corn-based human food uses (such as grinding into cornmeal or masa, pressing into corn oil, and fermentation and distillation into alcoholic beverages such as bourbon whiskey), and as chemical feedstocks. Maize is also used in the production of ethanol.

Maize has grown in importance over the years, displacing traditional crops such as millet and sorghum. In 2018, Nigeria produced 10.2 million tons of maize from 4.8 million hectares, making it Africa's largest producer **(FAO, 2018)**. Because of its genetic plasticity, it has become the most widely cultivated crop in the country, ranging from the wet evergreen climate of the forest zone to the dry ecology of the Sudan savanna. Maize has become a staple food in many parts of the world, with total maize production exceeding wheat or rice. Maize is used for corn ethanol, animal feed, and other maize products in addition to being consumed directly by humans (often in the form of masa).

Willingness to pay (WTP) is the highest price a consumer is willing to pay for a commodity, product, or service. The concept of WTP assists economists in determining aggregate consumer demand. Businesses set the price points for their products based on information about consumer demand. According to **Vernazza *et al.,* (2015)**, "willingness-to-pay" (WTP) is a systematic and reliable monetary method. WTP attempts to quantify an individual's preference strength for any desired intervention by calculating the maximum amount of money they would be willing to sacrifice **(Matthews *et al.,* 2002)**. **Donaldson (2011)** saw this as an example of "direct democracy" in public policymaking.

WTP can be measured in two ways, according to **Carson & Hanemann (2005)**: first, the "revealed preferences" approach, which focuses on farmer behaviour in the market and can be measured based on information obtained from actual real market purchases of individuals, and second, "stated preferences," an indirect technique in which farmers are asked to explicitly state their WTP. WTP can be elicited through an interview or a questionnaire, but **Calder (2004)** recommended a face-to-face interview method for a more valid result.

The two-limit Tobit model can be used to isolate factors that influence willingness-to-pay for biofortified maize. The two-limit Tobit model is a special case of the censored model; this model class is known as limited dependent variable models or latent variable models. Censoring occurs when the values of the dependent variable are restricted to a narrow range of values, i.e., we see Yi=0 and Yi>0. When data is censored, the distribution that applies to the sample data is a hybrid of the discrete and continuous distributions. The total probability is 1, as expected, but instead of scaling the second part, we simply assign the full probability in the censored region, in this case, 0, to the censoring point.

Tobit models are a type of censored regression model in which a model captures variation in a specific direction where variables are only observable under certain set conditions. When it assumes a value greater than zero, it is frequently defined as equal to the latent variable; otherwise, it is defined as zero. The relationship between a non-negative dependent variable and independent variables is statistically described by Tobit models. Heckman's two-step, or correction method, is a popular alternative to the maximum likelihood estimation of the Tobit model.

Zhou and Li (2015) used the Tobit model to examine the factors that influence residents' willingness to pay for watershed services, and the results show that residents' heterogeneity is significantly related to residents' willingness to pay. **Zheng et al. (2010)** used the Probit model to investigate the factors that influence residents' willingness to pay for the Jinhua River Basin, and the empirical results show that education levels and income levels have a significant correlation with residents' WTP. Literature has shown that previous studies primarily used Tobit **Zhou and Li (2015)**, Probit **Zheng *et al.,* (2010)**, logistic **(Ge *et al.,* 2009)**, or structural equation models **(Li *et al*., 2012)** to analyze the factors influencing willingness to pay. But none specifically used the two-limit Tobit model that is characterized by censoring from the two extremes. This study adopted a two-limit Tobit model to examine the factors that influence the willingness-to-pay for biofortified maize.

DATA AND METHODS

Study Area

The study was carried out in Gwagwalada Area Council of Federal Capital Territory Abuja, Nigeria. It is located at the extreme South-west near the flood plain of River Gurara which transverses the territory from North to South at an elevation of 70m above sea level. The area lies between latitude 07^0.57̀N and longitude 07^0.7̀E. There are ten (10) wards within the Gwagwalada Area Council, they are Dobi, Ikwa, Tungan Maje, Gwagwalada center, Kutunku, Zuba, Paiko, Gwako, Ibwa, and Staff quarters. The vegetation in the area combines the best features of the southern tropical rain forest and guinea savanna of the North. This reflects the full transitional nature of the area between the Southern-forest and Northern grassland which have the woods and shrubs respectively. The soil is reddish with isolated hills filled with plains and well-drained sandy clay loams which support the farming of the major crops such as sorghum, millet, melon, yam, soybean, benniseed, cassava, and rice cultivation **(Federal Capital Territory Agricultural Development Programme [FCTADP], 2004)**.

Sampling Technique and Sample Size

This study made use of the multistage sampling technique that includes the purposive and simple random sampling techniques for sample size selection. In the first stage, the purposive sampling technique was adopted and employed in choosing Gwagwalada Area Council as the study area. The criteria for the selection of Gwagwalada Area Council as the study area was based on the high maize production activities in the council areas. In the second stage, simple random sampling techniques were employed for the selection of five (5) wards out of the ten (10) wards within the Gwagwalada Area Council. The third stage involves the random selection of two (2) villages per ward to give a total of 10 villages in all. The fifth and final stage involves the random selection of ten (10) smallholder maize farmers from each selected village, thus giving a total of 100 respondents, but 94 were finally used after data cleaning and removal of questionnaires that were not filled.

Method of Data Collection

The primary data used for this study were collected using a well-structured questionnaire. The questionnaires were administered to selected farmers in the selected areas through personal interviews.

Econometric Model Specification: Two-limit Tobit Model

Two-limit Tobit Model was adopted for this study and used to identify the factors influencing farmers' willingness-to pay for biofortified maize in the study area. This was purposely chosen because the objective being investigated involves two limits of zero and any positive categorical value of the respondent on willingness-to-pay for bio-fortified.

$$Y^* = \beta_0 + \beta_i X_i + \varepsilon_i \quad (1)$$

Where = Y^* is a continuous latent variable, X is a matrix of explanatory variables, β is a vector coefficient to be estimated, and ε_i is a vector of normally distributed error terms with variance σ^2, if we denote the observed dependent variable as Y, then

$$Y = 0 \; if \; Y^* \leq= 0 \quad (2)$$

$$Y = Y^* if \; 0 < Y^* < \infty \quad (3)$$

The model is one of the censored dependent variables because observations at the limits are observed. If the observations at the limits are not observed, the model is known as truncated. In this case, the dependent variable is the amount the farmer is able to pay above ₦3000.00 Nigerian Naira for the conventional maize.

Where: X_i factors that influence pest management decisions (socio-economic, farm-specific, and institutional factors) and include: X_1 = Sex, X_2 = Age of household head (Years); X_3 Membership Cooperative Society (Dummy, 1 if yes, 0 otherwise), X_4 Education level (years of schooling), X_5 Annual income (naira), X_6 Maize farming experience (Years), X_7 Farm Size (hectares), X_8 Access to credit (Dummy, 1 if yes, 0 otherwise), X_9 Extension contact (Dummy, 1 if yes, 0 otherwise), X_{10} Access to land (Dummy, 1 if yes, 0 otherwise), X_{11} Number of dependent in the household, X_{12} Number of Literates in the household, X_{13} Maize farming training (Dummy, 1 if yes, 0 otherwise), and ε_j error terms.

Hypotheses Testing

The null hypotheses (i) and (ii) were tested using t-test statistics embedded in the Two-limit Tobit model at various levels of significance (1%, 5%, and 10%).

$$t_i = \frac{Coefficient(\beta_i)}{Standard\ Error\ (\beta_i)} \quad (4)$$

RESULTS AND DISCUSSION

Socio-economic Characteristics of the Maize Farming Households in the Study Area

Table 1 shows the relevant socio-economic characteristics of the maize farmers in the study area. The result revealed the mean marital status of the maize farming household heads as 77.7%, implying that 77.7% were mainly married with a mean age of approximately 41years. This implies that the maize farmers in the study area are within the economically productive age. According to **Adeola (2010)**, people of this age are more resilient to stress and devote more time to agricultural operations, which can lead to increased output. Farmers' risk aversion, adoption of improved agricultural technologies, and other production-related decisions are all influenced by their age.

The Table further revealed that 90.4% of the maize farmers had formal education. Educational attainment is very important because it could lead to awareness of the possible advantages of modern farming techniques thereby increasing their level of willingness-to-pay for biofortified maize. **Ahmadu (2011)** found a positive correlation between education and the adoption of new innovations.

The mean year of maize farming experience is approximately 10years, implying that a majority of the maize farmers had been in the business for a long time. According to **Nwaobiala (2014)**, with more experience, a farmer can become less fearful of the risks associated with adopting new technology. The mean farm size is 1.73hectares. The maize farmers' average farm size is in agreement with the findings of **Orisakwe & Agumuo (2011)**, who found that most agroforestry farmers in Nigeria own farmlands of no more than two hectares (2ha). 58.9% of the maize farmers are members of one cooperative society or the other. Through collective bargaining, cooperative membership assists farmers in obtaining credit, information, and inputs. According to the literature, intra-community bonds of trust and cooperation may lead to inward-looking behaviour, making individuals less likely to seek out new agricultural innovations **(Van Rijn *et al.* 2012)**.

Table 1 Socio-economic characteristics of the maize farming households in the study area

Socio-economic variable	Measurement	Mean distribution
Sex	Dummy (1, "Male"; 0, otherwise)	0.862
Age	Years	40.67
Marital status	Dummy (1, "Married"; 0 otherwise)	0.777

Maize Farming Experience	Years	9.80
Farm size	Hectares	1.73
Annual Income	Naira (₦)	₦1,530,136.53
Level of Education	Dummy (1, "Formal Education"; 0, otherwise)	0.904
Membership in Cooperative Society	Dummy (1, "Membership"; 0, otherwise)	0.589

Farmers' willingness-to-pay for biofortified maize in the study area

Table 2 below revealed the information obtained from the farmers on their willingness-to-pay for biofortified maize in Gwagwalada Area Council of the Federal Capital Territory. The result shows that 33.0% of the respondents are not willing-to-pay for biofortified maize while a majority (67.0%) were willing-to-pay for biofortified maize in the study area.

Table 2 Farmers' Willingness-to-Pay for Biofortified Maize in the Study Area

Willingness to Pay for Biofortified Maize	Frequency	Percentage (%)
Not WTP for Biofortified Maize	31	33.0
WTP for Biofortified Maize	63	67.0
Total	**94**	**100.0**

Factors that influence the willingness-to-pay for biofortified maize in the study area

Two-limit Tobit model analysis was carried out to determine the factors influencing the maize farmers' willingness-to-pay for biofortified maize in the study area, some factors such as socio-economic characteristics (sex of the farmer, and number of literates in the household), and farm-specific and institutional factors (extension contact, access to land and maize farming training) were regressed against the maize farmers' willingness-to-pay for biofortified maize and the result is presented in table 3 below. The goodness of fit measured by the moderate Pseudo R-square of 0.0507 showed that the choice of explanatory variables included in the two-limit Tobit regression model fairly explained the variation in the maize farmers' willingness-to-pay for biofortified maize. Of the twelve (12) variables included in the model, only 5 variables were statistically significant out of the 12 variables used in the model and thus led to the rejection of the null hypotheses.

The coefficient of sex of the farmers (4681.10) was positive and significantly influenced the maize farmers' willingness-to-pay (WTP) for biofortified maize at a 5% level. This implied that male maize farmers in the area were more likely to show willingness-to-pay (WTP) for biofortified maize than their female counterparts within the study area. In the study by **Michalscheck *et al.,* (2018**), sex was also found to significantly affect the adoption of new agricultural technologies by smallholder farmers in Africa.

Extension contact (-5964.74) is negatively related and statistically significant to willingness-to-pay for biofortified maize at a 5% level of probability, implying that the more extension contacts the maize farmers in the area have, the less willing they become to pay for biofortified maize. This result went against the a priori expectation. But the reason could be that the village extension workers/agents have not really understood the benefits of biofortification of crops. This finding is consistent with the findings of **Emmanuel *et al.,* (2016)** and **FAO, (2014)** that agricultural development is heavily reliant on access to new technologies and information, which extension services can greatly facilitate.

The result further revealed that access to land (6773.12) is positively influenced the maize farmers' willingness to pay for biofortified maize and statistically significant at a 1% level of probability. The implication of this is that the maize farmers' willingness-to-pay for biofortified maize in the study area, increases with their increasing access to agricultural land. This means that maize farmers who own a large area of land are more likely to show willingness-to-pay for biofortified maize than those who are tenants with relatively fewer farm sizes. It is widely assumed that owning land encourages the adoption of new technologies **(Daberkow & McBride, 2003)**. Tenants can be assumed less likely than landowners to adopt new technological innovations, as the benefits may not necessarily flow to them, while land ownership is likely to influence the adoption decision. This is consistent with the result of **Oni (2014) Otitoju & Oni (2017)** on farmers' willingness to plant agroforestry trees.

The number of literates in the farmers' households (-1680.81) is contrary to the a priori expectation related and statistically significant to willingness-to-pay for biofortified maize at a 1% level of probability. This implies that maize farmers with fewer educated persons in their households were more willing to pay for biofortified maize in the study area. This is in contrast to the observation made by **Olumba & Rahji (2014)** that the educational status of farmers positively influences their adoption of improved technologies. The reason could be that those that could read and write were not really involved in the decision-making in the households.

Maize farming training (4279.56) was positive and statistically influenced maize farmers' willingness-to-pay for biofortified maize at a 10% level of significance. This implies that an increase in the maize farming training would increase WTP for biofortified maize by its coefficient, ceteris paribus. Farmers' training is essential in the adoption of agricultural technologies. According to **Tey *et al.,* (2017)**; **Jha *et al.,* (2019)** the adoption of new technology by smallholder farmers in Africa is influenced by a variety of factors. According to **Salami *et al.,* (2017)**, smallholder farmers need to learn how to apply new technologies and processes, as well as how to integrate these new technologies and processes into existing systems, through training.

Table 3 Determinants of Willingness-to-pay for Biofortified Maize in the Study Area

Explanatory Variable	Coefficient	Robust Standard Error	t-value	P>|t|
Sex (Dummy, 1 if male, 0 otherwise)	4681.10	2271.87	2.06**	0.04
Age of the farmer (Years)	-107.77	112.52	-0.96	0.34
Membership Cooperative Society (Dummy, 1 if yes, 0 otherwise)	1073.69	2188.25	0.49	0.61
Education level (years of schooling)	-195.81	213.74	-0.92	0.36
Annual income (naira)	-0.00063	0.00064	-0.98	0.33
Maize farming experience (Years)	-262.97	194.30	-1.35	0.18
Farm Size (hectares)	-890.12	805.47	-1.11	0.27
Access to credit (Dummy, 1 if yes, 0 otherwise)	-252.21	2381.06	-0.11	0.92
Extension contacts (Dummy, 1 if yes, 0 otherwise)	-5964.74	2462.40	-2.42**	0.02
Access to land (Dummy, 1 if yes, 0 otherwise)	6773.12	2412.74	2.81***	0.01
Number of dependent in the household	484.96	595.39	0.81	0.42
Number of Literates in the household	-1680.81	668.69	-2.51***	0.04
Maize farming training (Dummy, 1 if yes, 0 otherwise)	4279.561	2148.96	1.99*	0.05
Constant	12463.66	6560.22	1.90	0.06

Diagnostic statistics: Number of Observation = 94; F (13, 81) = 1.78; Prob > F = 0.0608; Log Pseudo likelihood = -6664.55; Pseudo R-square = 0.0507. Triple asterisk (***), double asterisk and asterisk denote variables significant at 1%, 5% and 10% respectively.
Source: Computed from field data, 2021.

Constraint militating against the willingness of farmers to pay for biofortified maize in the study area

Table 4 showed the constraints militating against the willingness of farmers to pay for biofortified maize in Gwagwalada Area Council. Non-availability of credit facilities was a major constraint with 53.2% of the maize farmers attested to it as a very serious challenge, 28.7% of them attested to it as a serious constraint, 11.7% of them confirmed it as a less serious problem and 6.4% of the sampled farmers believed it not to be a serious problem. Also, 42.6% of the respondents agreed that the non-availability of storage facilities was a very serious constraint, 21.3%ot them believed it was not a serious problem, 19.1% of them believed it was a serious problem, while 17% of them agreed that it's a less serious problem. These constraints posed by credit access and agricultural technology have been linked by **Abdul-Hanan *et al.* (2014)** and **Abdallah (2016)** to credit market imperfections that prevent farmers from obtaining adequate credit.

Again, 47.9% of the maize farmers agreed that inadequate/lack of extension programmes directed to meet the need of farmers was a serious problem, 27.2% of them believed it was a very serious problem, 17% of them believed it was not a serious problem, while 7.4% of them agreed that it was a less serious problem. More so, 31.9% of the maize farmers believed that poor access to and control of land was a serious problem, 28.7% of them agreed that it was a less serious problem, 20.2% of them agreed that it was a very serious problem, while 19.1% of them believed it was not a serious problem. In the same vein, 36.2% of the maize farmers believed that lack of/or inadequate access to supporting institutional facilities was a very serious problem, 33% of them agreed that it was a very serious constraint, 17% believed it was a less serious problem, while 13.8% of them believed it not a serious problem. Also, 39.4% of the maize farmers believed that inadequate facilities to facilitate biofortified maize production was a very serious problem, 35.1% of them believed it was a serious problem, 13.8% of them believed it was a less serious problem, while 11.7% of them believed it was not a serious problem. Investment in structural infrastructures such as roads and the formation of farmer cooperatives has been shown by **Padula et al. (2012)**, and **Andri *et al.,* (2011)** to increase farm incomes.

Again, 33% of the maize farmers believed that the technical know-how of farmers in handling mechanized and technical duties in biofortified maize was a very serious problem, 22.3% of them agreed that it was not a serious problem. So, this confirms the hypothesis of **Alene & Manyong (2007)** that technological know-how has a strong threshold effect on the probability of adoption of modern technology.

Table 4 Frequency and Mean Distribution of Constraints Militating Against the Willingness of Farmers to Pay for Biofortified Maize

Constraints	Very Serious	Serious	Less serious	Not serious	Mean Score
Non-availability of credit facilities	50(53.2)	27(28.7)	11(11.7)	6(6.4)	3.11
Illiteracy of the farmer	25(26.6)	24(25.5)	25(26.6)	20(21.3)	2.10
Non-availability of storage facilities	40(42.6)	18(19.1)	16(17.0)	20(21.3)	2.45
Inadequate/lack of extension programmes directed to meet the need of farmer	26(27.2)	45(47.9)	7(7.4)	16(17.0)	2.62
Non-availability of Labour	21(22.3)	43(45.7)	13(13.8)	17(18.1)	2.40

Insufficient knowledge of credit sources to support paying for biofortified maize	28(29.8)	35(37.2)	16(17.0)	15(16.0)	2.48
Inadequate/lack of government policies to empower paying for biofortification actors	26(27.7)	28(29.8)	19(20.2)	21(22.3)	2.20
Lack of/ or inadequate collateral security required to secure a loan to support paying for biofortification operations	19(20.2)	37(39.4)	18(19.1)	20(21.3)	2.18
Neighbourhood norms, customs, culture and traditional beliefs about maize	15(16.0)	34(36.2)	22(23.4)	23(24.5)	1.96
Poor access to and control of land	19(20.2)	30(31.9)	27(28.7)	18(19.1)	2.05
High cost of resources and services	21(22.3)	32(34.0)	19(20.2)	22(23.4)	2.12
Lack of/or inadequate awareness of and inadequate access to NGOs programmes in biofortification	18(19.1)	34(36.2)	21(22.3)	21(22.3)	2.07
Lack of/or inadequate support systems	28(29.8)	33(35.1)	18(19.1)	15(16.0)	2.43
Lack of/inadequate access to information on biofortified maize	31(33.0)	36(38.3)	11(11.7)	16(17.0)	2.59
Low income of farmers	27(28.7)	32(34.0)	15(16.0)	20(21.3)	2.33
The low technical know-how of farmers in handling mechanized and technical duties in biofortified maize	31(33.0)	31(33.0)	11(11.7)	21(22.3)	2.43
The unwillingness of farmers to take risks in biofortified maize	22(23.4)	32(34.0)	20(21.3)	20(21.3)	2.17
Lack of/or inadequate access to supporting institutional facilities	34(36.2)	31(33.0)	16(17.0)	13(13.8)	2.61
Inadequate facilities to facilitate biofortified maize production	37(39.4)	33(35.1)	13(13.8)	11(11.7)	2.77
Strict government policies in input sector of biofortified maize	28(29.8)	36(38.3)	16(17.0)	14(14.9)	2.51

Source: Computed from field data, 2021.

CONCLUSION AND RECOMMENDATIONS

The study examined the factors influencing farmers' willingness-to-pay for biofortified maize in Gwagwalada Area Council of Federal Capital Territory, Nigeria. The result shows that majority of the maize farmers in the study area were willing-to-pay for biofortified maize. while sex, farming experience, extension contact, access to land, literacy ratio, and training in maize farming were the factors that influenced the maize farmers' willingness-to-pay for biofortified maize in the study area. For the constraints militating against the willingness of farmers to pay for biofortified maize in the study area; non-availability of credit facilities was a major constraint, non-availability of storage facilities was also a very serious constraint, and inadequate/lack of extension programmes directed to meet the need of farmer was a serious problem, lack of/or inadequate access to supporting institutional facilities and inadequate facilities to facilitate biofortified maize production were also a very serious problem. Therefore, agricultural extension and advisory services/programmes have to develop with a viable component of agricultural biotechnology by the Federal Capital Territory Agricultural Development Programme (FCT-ADP) and the Ministry of Agriculture. Also, stakeholders should ensure to make credit facilities more accessible to maize farmers to enhance the adoption of biofortified crops, especially maize. There is also a need for government and development partners to train farmers more in good agronomic practices with a focus on bio-fortified crops and cropping systems. Regulatory land use acts that will make maize farmers participate more inland ownership systems that are more secure should be put in place for land tenants to benefit so that they can be able to invest and use sustainable maize production strategies to maximize benefits.
This study was limited to the primary data obtained from the respondents in Gwagwalada Area Council in the Federal Capital Territory of Nigeria. There is a need for further research on factors influencing farmers' willingness-to-pay for biofortified maize in other agro-ecological zones of Nigeria and possibly a comparative analysis of factors influencing farmers' willingness-to-pay for biofortified maize across all the agro-ecological zones of Nigeria.

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REGULAR ARTICLE

TECHNICAL EFFICIENCY AND PRODUCTION RISK OF RICE FARMERS IN TOGO

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ABSTRACT
This paper analyzes the risks production effects on the technical efficiency of rice producers in Togo. The stochastic frontier model with flexible risk properties is considered. The cross-sectional data used are from the Fourth National Census of Agriculture (2011-2014) from which a sample of 2123 households was selected. The findings demonstrate that the translog model is the best fit for the mean output function. The study also finds that the risk production is significantly explained by the input variables such as land, seeds, fertilizers and labor. The average technical efficiency is 79.72%. Exogenous variables such as gender, age, experience, household size, number of fields and landownership improve the technical efficiency of rice producers in Togo. The study recommends to the Togolese Government: (i) raise the price of rice to make rice production more attractive, (ii) further subsidize input prices to ensure that they are easily accessible and affordable to producers, and (iii) organize training sessions on the best use of modern capital.

Keywords: *Technical efficiency; Production risk; stochastic frontier; rice; Togo*
JEL: C21 ; D18 ; O13 ; Q12 ; Q18

INTRODUCTION

In almost any production process, particularly in agriculture, risk plays an important role in producers' input allocation and production decisions (**Asche and Tveteras, 1999; Bokusheva and Hockmann, 2006; Kumbhakar, 2002; Nuama, 2006; Villano *et al.*, 2005**). However, farmers' input allocation decisions vary depending on the production risk they incur. They tend to reduce the allocation of an input if it potentially leads to an increase in production risk. In other words, farmers increase allocations of inputs that they deem capable of reducing production risk (**Mamilianti *et al.*, 2019**). The concept of risk in production theory is first explained by the uncertainty linked to product prices and, secondly, by the instability of production. The risk associated with production instability is generally explained by the factors used by the producer in the production process. The quantities of inputs that determine the volume of production are also responsible for the variability of production (**Kumbhakar and Tsionas, 2010; Ngom *et al.*, 2016**). Indeed, some inputs can reduce production risk while others can increase production risk (**Asche and Tveteras, 1999; Just and Pope, 1978**). Thus, a farmer averse to production risks may be reluctant to adopt a new technology that could reduce the risk of production (**Ali, 2019; Just and Pope, 1978; Pope and Kramer, 1979**).

The technical efficiency of farmers is often influenced by exogenous variables that characterize the environment in which the production takes place, such as factors affecting production risk (**Villano and Fleming, 2006**). In Togo as everywhere else, given a number of hazards over which rice farmers have no control (climatic hazard for example), they cannot know with certainty the quantities of rice they will be able to produce. According to the Ministry of Agriculture, Livestock and Fisheries (**MAEP, 2010**), Togolese rice farmers produce below the national average (1 ton / hectare < 2.4 tons / hectare) due to their low productive capacity (inefficiency). In order to achieve much more relevant results, the method of analysis proposed for this study is consistent with model developed by **Kumbhakar (2002)** which allows for production risk and technical inefficiency to be estimated simultaneously in the stochastic frontier analysis. This simultaneous analysis of production risk and technical efficiency has not been fully addressed in Togo. Thus, the results of this study could contribute to the formulation of good policies on rice production in a context of production risks.

The agricultural sector employs 60% of the working population in West Africa although it contributes only 35% to GDP (**Abdulai *et al.*, 2013**). The countries of this region are particularly vulnerable to climate change since people are highly dependent on rain-fed agriculture (**Gemenne *et al.*, 2017**). According to studies conducted by the Food and Agriculture Organization of the United Nations (FAO) on disaster risk strategies and management in West Africa and the Sahel (2011-2013), about 65% of the West African and Sahelian working population belong to the agricultural sector and are subject to climate change and environmental factors. The main abiotic and biotic stresses encountered in their fields are weeds, birds, poor soils, floods, drought, plant diseases and insects. By 2100, the estimated losses on the agricultural sector due to climate change will vary between 2 and 4% of the sub-regional Gross Domestic Product (GDP) (**FAO, 2011**). Agriculture is the engine of Togo's economic and social development. It employs 96% of rural households with nearly 54% of the active population. It contributes about 40% to the Gross Domestic Product (GDP). It is mainly characterized by low use of improved seeds (14.9%) and chemical fertilizers (117 kg/ha compared to normally 150 kg/ha); a weak technical framework for the agricultural working population; low agricultural mechanization (high use of manual agricultural tools such as hoe, cutter); limited access to agricultural credit; etc. (Ministry of Agriculture, Livestock and Fisheries and the Directorate of Agricultural Statistics, Informatics and Documentation (**MAEP and DSID, 2014**)). However, most of the Togolese population is active around rain-fed agriculture, which is very sensitive to climate change and the various aggressions of predators. Indeed, in 2013, due to drought throughout the territory, the GDP of the agricultural sector fell by 4.8% compared to 2012 as shown in Figure 1 below (**MAEP and DSID, 2014).**

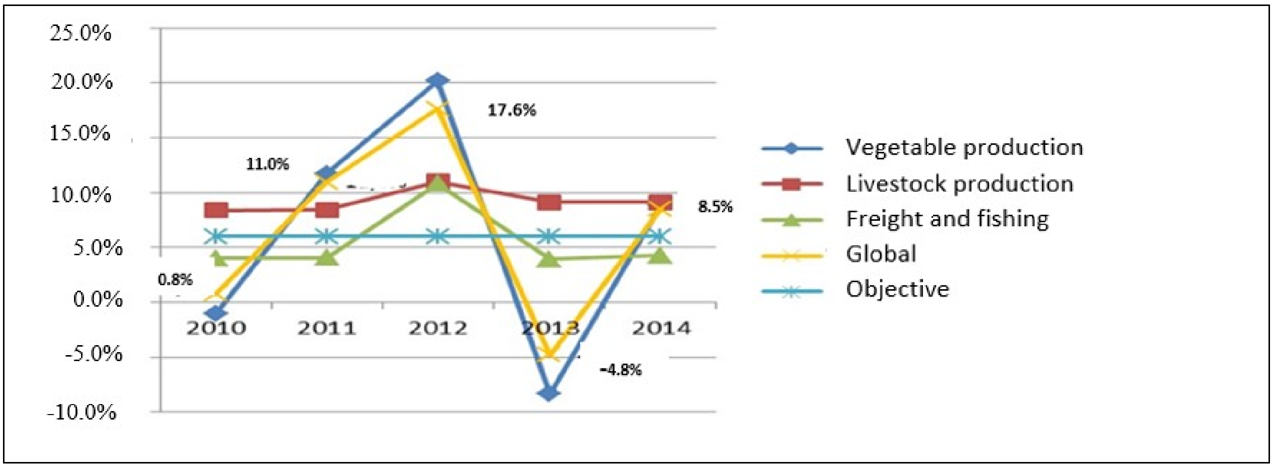

Figure 1: Annual growth rate of the GDP of the agricultural sector
Source: **MAEP and DSID, 2014**

As part of the revival of agricultural production, Togo has prioritized in its objectives, the development of food crops with particular emphasis on rice cultivation, which causes significant foreign exchange outflows. Indeed, ranked third as a consumer product after maize and sorghum, rice produced in Togo covers barely 50% of the country's needs and the deficit is still met by imports estimated at more than four billion CFA francs / year (**MAEP, 2010**). According to studies carried out by the Network of Peasant organizations and producers of West Africa (**ROPPA, 2016**), except the period 1996 to 1998 when national rice production exceeded imports, Togo was dependent on the rest of the world in term of rice demand over the period from 1995 to 2012 (see Fig.2 below).

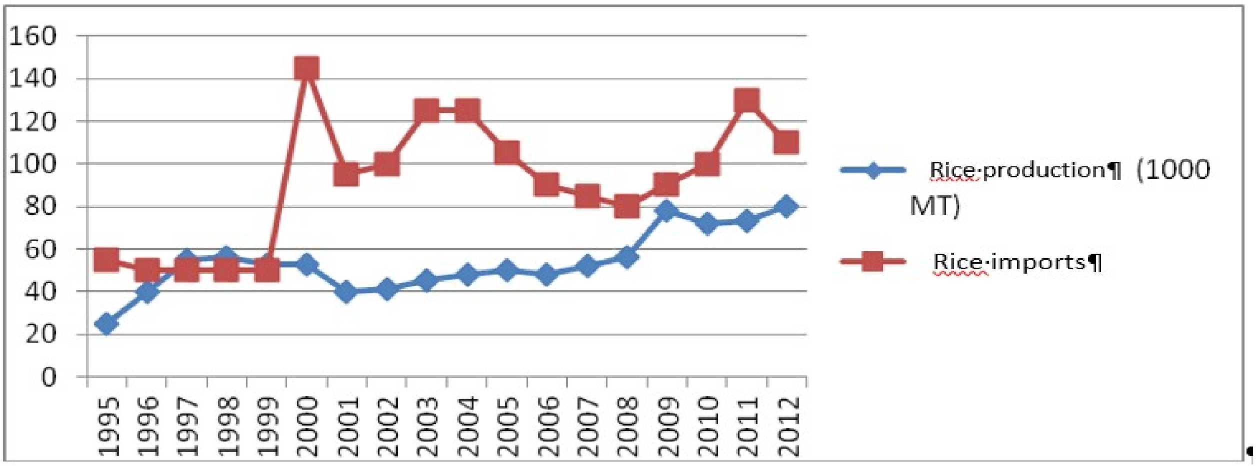

Figure 2: Evolution of rice production and imports in Togo
Source: **ROPPA, 2016. p.15**

In Togo, depending on the locality, rice is produced by both men and women on small individual farms. Indeed, three ecotypes of rice stand out in Togo: rainfed rice practiced mainly on emerging land from water in the Plateaux Region, represents 10% of national production, lowland rice which is by far the most cultivated represents 60% of national production and practiced in all regions of the country, in the shallows; rice produced without water control and irrigated rice practice on developed perimeters represents 30% of national production. In all these ecologies, various improved varieties of rice are grown but the most important are IR841, TGR and NERICA (Togolese Institute of Agronomic Research, the Directorate of Agricultural Statistics, Informatics and Documentation and the Africa Rice Center (**ITRA, DSID and AfricaRice, 2014**)). Rice farms in Togo are subject to a range of agricultural production risks. These include climatic risks of drought, flooding, insufficient rainfall, risks of developing a disease or attacking a crop pest, etc. Beyond these agricultural production risks, one can cite the socio-economic constraints generally related to the factors and means of production (land, seeds, labor, fertilizers, credit, equipment), post-harvest management and the rice products marketing (**ITRA, DSID and AfricaRice, 2014**). In view of all these characteristics of Togolese rice production, this study seeks to answer the following questions: Do production risks not affecting rice farms in Togo? Do Togolese rice farmers make optimal use of the factors of production mainly in a context of production risks? The main objective of this article is to analyze the effects of production risks on the technical efficiency of rice producers in Togo. Specifically, in this context of production risk, it is a question of determining: (i) the effects of production risk factors and (ii) the levels of technical efficiency of rice farmers. This study will help agricultural policy decision-makers to stimulate rice production in Togo and effectively reduce the adverse effects of production risks.

MATERIALS AND METHOD

Theoretical Framework

Majority of the application of frontier methodology in efficiency analysis utilize non-parametric or parametric approaches. The two methods have a range of advantages and disadvantages. which may influence the practical approach in application. The non-parametric frontier technique which has been conventionally assimilated into the Data Envelopment Analysis (DEA) was developed by **Farrell (1957) and Charnes *et al*., (1978)**. The major advantage of the non-parametric frontier analysis is that it does not require the specification of a particular functional form for the technology. The main disadvantage is that it is not possible to estimate parameters for the model and hence impossible to test hypothesis concerning the performance of the model. The parametric frontier analysis which is the Stochastic Frontier Production Function (SFPF) was independently proposed by **Aigner *et al*., (1977)** and **Meeusen** and **Broeck (1977)**. The principal advantage of parametric frontier analysis is that it allows the test of hypothesis concerning the goodness of fit of the model. The major disadvantage is that it requires specification of technology, which may be restrictive in most cases **(Ajibefun, 2008).** Furthermore, the parametric frontier analysis proposes the inputs have similar effect on mean and variance of output. Therefore, if an input influences output positively, it is expected to influence output variance positively and vice versa (**Oppong *et al*., 2016**). But, **Just and Pope (1978)**, production function proposes a separate effect of the inputs on the mean output and the variance of output or output risk. However, this model does not take into account the technical inefficiency of producers in the production process (**Battese et al., 1997; Kumbhakar, 2002; Love and Buccola, 1991; Onumah *et al*., 2010**).
Following **Kumbhakar (2002),** the production process is represented below as Eq. (1):

$$\mathrm{Y_i} = \mathrm{f}(x_i;\ \beta) + \mathrm{g}(x_i;\ \psi)v_i - \mathrm{q}(z_i;\delta)u_i \tag{1}$$

$\mathrm{Y_i}$ refers to the observed output produced by the i-th farm, $\mathrm{f}(x_i;\ \beta)$ is the deterministic output function, $\mathrm{g}(x_i;\ \psi)$ is the output risk function, ψ are the estimated coefficients of production risk function, x_i are the input variables, β are the estimated coefficients of the mean output function, $\mathrm{q}(\mathrm{z_i};\ \delta)$ represents the technical inefficiency model, δ are the estimated effect of the explanatory variables in the technical inefficiency model, v_i represents the random noise in the data, representing production risk and $\mathrm{u_i}$ represents farm specific technical inefficiencies. Technical efficiency of the i-th farm is the ratio of observed output given the values of its inputs and its inefficiency effects to corresponding maximum feasible output if there were no inefficiency effects (**Battese and Coelli, 1988, p.390 in Adinku *et al*., 2013, p.42**).

The technical efficiency of the i-th farm is given by Eq. (2):

$$\mathrm{TE_i} = \frac{\mathrm{E}(\mathrm{Y_i}\ /x_i\ ,u_i)}{\mathrm{E}(\mathrm{Y_i}\ /u_i = 0)} = \frac{\mathrm{f}\ (x_i\ ;\alpha) - \mathrm{g_i}(x_i\ ;\beta)u_i}{\mathrm{f}\ (x_i\ ;\alpha)} = 1 - \frac{\mathrm{g_i}(x_i\ ;\beta)u_i}{\mathrm{f}\ (x_i\ ;\alpha)} \tag{2}$$

The technical inefficiency (TI) is given by Eq. (3):

$$\mathrm{TI_i} = \frac{\mathrm{g_i}(x_i\ ;\beta)u_i}{\mathrm{f}\ (x_i\ ;\alpha)} \tag{3}$$

The technical efficiency becomes (Eq. 4):

$$\mathrm{TE_i}\ = 1 - \ \mathrm{TI_i} \tag{4}$$

The variance of output or production risk is given by Eq. (5):

$$\mathrm{Var}(\mathrm{Y_i}/\mathrm{x_i}, \mathrm{u_i}) = \ \mathrm{g}^2(\mathrm{x_i};\ \psi) \tag{5}$$

The marginal effect of the input variables on the production risk is given by Eq. (6):

$$\frac{\partial V(Y)}{\partial x_j} = \frac{\partial g^2(x,\psi)}{\partial x_j} = 2g(x,\psi)g_j(x,\psi) \tag{6}$$

Thus.

$\frac{\partial g^2(x,\psi)}{\partial x_j} < 0 \Rightarrow$ Risk decreasing of the j'th input.

$\frac{\partial g^2(x,\psi)}{\partial x_j} = 0 \Rightarrow$ Risk neutral of the j'th input and

$\frac{\partial g^2(x,\psi)}{\partial x_j} > 0 \Rightarrow$ Risk increasing of the j'th input.

Based on the assumptions of the random errors a log likelihood function for the observed farm output is parameterized in terms of $\sigma^2 = \sigma_u^2 + \sigma_v^2$, $\lambda = \frac{\sigma_u^2}{\sigma_v^2}$ (**Aigner *et al.*, (1977)**. However, this parameterization has a limitation since the variance, ${\sigma_u}^2$ refers to the variance of the untruncated random variable instead of the truncated half normal model (**Adinku *et al.*, 2013, p.28**). A different parametrization proposed by **Battese and Corra (1977, p.171)** helps solve the above problem. This new specification is given by Eq. (7):

$$\gamma = \frac{\sigma_u^2}{\sigma^2} = \frac{\sigma_u^2}{\sigma_u^2 + \sigma_v^2} \tag{7}$$

Where σ^2 and γ are the variance parameters. The maximization of the appropriate log likelihood function gives the estimates of the model. For $0 < \gamma < 1$, the output variability is characterized by technical inefficiency and stochastic errors, γ measure the level of the inefficiency in the variance parameter (σ^2).

Empirical Model Specification

The empirical application of this study is consistent with model developed by **Kumbhakar (2002)** which allows for production risk and technical inefficiency to be estimated simultaneously in the stochastic frontier analysis. However, there are generally two functional forms of the stochastic frontier model that are often used; the Cobb-Douglas and the translog functional forms (**Adinku *et al.*, 2013, p.44**). In this study, the translog model of the production function is used and specified as Eq. (8):

$$\ln Y_i = \beta_0 + \sum_{i=1}^{5} \beta_j \ln x_{ij} + \frac{1}{2}\sum_{i=1}^{5}\sum_{k=1}^{5} \beta_{jk} \ln x_{ij} \ln x_{ki} + \varepsilon_i \tag{8}$$

β_j denotes the unknown true values of the technology parameters. If, $\beta_{jk} = 0$ then the translog stochastic frontier model reduces to the Cobb-Douglas model. The composed error term is given as Eq. (9):

$$\varepsilon_i = g(x_i;\ \psi) - q(x_i;\ z_i) \tag{9}$$

$g(x_i;\ \psi)$ is the risk component and $q(x_i;\ z_i)$ is the technical inefficiency component.

Elasticity

The elasticities of output with respect to the different inputs are functions of the level of inputs involved and generally expressed as Eq. (10):

$$\frac{\partial \mathrm{LnE}(Y_i)}{\partial \ln x_{ji}} = \{\beta_j + \beta_{jj} \mathrm{Ln} x_{ji} + \sum_{k\neq 1} \beta_{jk} \ln x_{ki}\} \tag{10}$$

However, when the output and input variables have been normalized by the respective sample means. the first-order coefficient can be interpreted as elasticities of output with respect to the different input (**Onumah *et al.*, 2010**). For this study, the output and input variables have been normalized using the standardized mean method, the first-order coefficients of the input variables can therefore be interpreted as elasticities of output. The sum total of the output elasticities is the estimated scale elasticity (Ɛ), which is defines as the percentage change in output as a result of 1 percent change in all input factors. Scale elasticities greater than one indicates an increasing return to scale. An estimate less than one indicates a decreasing return to scale, whiles an estimate equal to one indicates a constant return to scale (**Khreisat, 2011**). The input variables used in this study are land, seed, fertilizer, labor and modern capital (Table 1).

Table 1 Variable Description of the Input Variables in the Rice Production Process

Variable	Variable Description	Measurement
Y_i	Output	Kilograms (kg).
x_{1i}	Land	Hectare (ha).
x_{2i}	Seed	Kilograms (kg).
x_{3i}	Fertilizer	Kilograms (kg).
x_{4i}	Labor	Number of people per day on the rice farm
x_{5i}	Modern capital	Dummy, 1 assigned to farmers who used a tractor, hitched or motorized harrow, plough and 0 otherwise.

Production risk

The linear production risk function is specified as Eq. (11):

$$g(x_i\,;\psi)v_i = \psi_0 + \sum_{m=1}^{5}\psi_m\, x_{mi} \tag{11}$$

Where x_i's represent the input variables, ψ are the estimated risk model parameters and the v_i's are the pure noise effects, x_{1i} denotes land measured in hectare, x_{2i} denotes seed measured in kilograms, x_{3i} denotes fertilizer measured in kilograms, x_{4i} denotes labor measured in number of people per day on the rice farm, x_{5i} denotes modern capital measured as a dummy, 1 assigned to farmers who used a tractor, hitched or motorized harrow, plough and 0 otherwise, $\psi_{m's}$ are the marginal production risks of the individual inputs and if it is positive it means that the respective input is a risk increasing input. If it is negative it means that respective input reduces output variance.

Technical Inefficiency

The linear technical inefficiency model is given as Eq. (12):

$$q(z_i\,;\delta_i) = \delta_0 + \sum_{j=1}^{15}\delta_n\, z_{ni} \tag{12}$$

where z_i's are the exogenous explanatory variables and the δ_i's are the estimated coefficients of the technical inefficiency model. The exogenous variables used in this study are gender, age, educational level, experience. household size, number of fields, main activity of the farmer, member of a farmer based organization, extension visit, credit access, landownership and regional effects (Table 2).

Table 2 Description of Exogenous Variables

Variable	Variable Description	Measurement
z_1	Gender	1= Male, 0 = Female
z_2	Age	Years
z_3	Educational Level	None = 0 Literate (A person who has just learned to write and speak French) = 1 Primary level = 2 Middle School = 3 High school = 4 University level = 5 Vocational level = 6
z_4	Experience	Number of years that the farmer has been engaged in rice farming.
z_5	Household size	Number of people (men, women and children) who are living with the farmer during the cropping year.
z_6	Number of fields	Total number of plots that can be delimited on the holding.
z_7	Main activity of the farmer	1= Agriculture, 0 = otherwise
z_8	Member of a farmer based organization	1= Yes, 0 =No
z_9	Extension visit	1= farmers who had interactions with the extension agent during the production year to

		solicit for advice, 0 = No
z_{10}	Credit Access	1 = farmer had access to credit, 0 = No
z_{11}	Landownership	1= farmer owns his farm, 0 = farmer operating on a rented land.
z_{12}	Plateaux Region	1 = Yes, 0 = otherwise
z_{13}	Central Region	1 = Yes, 0 = otherwise
z_{14}	Kara Region	1 = Yes, 0 = otherwise
z_{15}	Savanes Region	1 = Yes, 0 = otherwise

Statement of Hypothesis

The following hypothesis were considered for investigation.

H_0: $\beta_{jk} = 0$, the coefficients of the second-order variable in the Translog model are zero. This implies that the Cobb-Douglas function is the best fit for the model.

H_0: $\Psi_1 = \Psi_2 ... = \Psi_5 = 0$, the null hypothesis that output variability is not explained by production risk in input factors.

H_0: $\lambda = 0$, the null hypothesis specifies that inefficiency effects are absent from the model at every level. The variance of the inefficiency term is zero; the exogenous factors should be incorporated into the mean output function and estimated using Ordinary Least Square. However, if $\lambda > 0$, it means that the technical inefficiency effects are present in the model and hence the stochastic frontier model must be employed.

H_0: $\delta_1 = \delta_2 = ... = \delta_{15} = 0$, the null hypothesis that exogenous variables do not account for technical inefficiency.

H_0: $\delta_{12} = \delta_{13} = \delta_{14}\ \delta_{15} = 0$, the null hypothesis that there are no regional effects on technical efficiency of production.

$H_0 : \bar{X}_A = \bar{X}_B$, the null hypothesis that mean technical efficiency for Region A is the same as that of Region B.

Where:
If $\bar{X}_A$ is the mean technical efficiency of rice producers in Savanes Region, $\bar{X}_B$ is the mean technical efficiency of rice producers in Kara or Centrale or Plateaux or Maritime Region.
If $\bar{X}_A$ is the mean technical efficiency of rice producers in Kara Region, $\bar{X}_B$ is the mean technical efficiency of rice producers in Centrale or Plateaux or Maritime Region.
If $\bar{X}_A$ is the mean technical efficiency of rice producers in Centrale Region, $\bar{X}_B$ is the mean technical efficiency of rice producers in Plateaux or Maritime Region.
If $\bar{X}_A$ is the mean technical efficiency of rice producers in Plateaux Region, $\bar{X}_B$ is the mean technical efficiency of rice producers in Maritime Region.

The entire hypothesis with the exception of the sixth one (i.e. the difference in mean technical efficiency) was investigated using the generalized likelihood-ratio statistic (LR) which is given by Eq. (13):

$$LR = -2\{\ln[L(H_0)] - \ln[L(H_1)]\} \tag{13}$$

Where: $L(H_0)$ and $L(H_1)$ are values of likelihood function under the null (H_0) and alternative (H_1) hypothesis, respectively. LR has approximately a Chi-square distribution if the given null hypothesis is true with a degree of freedom equal to the number of parameters assumed to be zero in (H_0). The third hypothesis however assumes a mixed Chi-square distribution hence Table 1 of **Kodde and Palm (1986, p.1246)** is used. The difference in mean technical efficiency is investigated using a t-test.

Data sources

This study used cross-sectional data from the Fourth National Census of Agriculture of Togo (4th RNA. 2011 – 2014). These survey data were carried out by the Agricultural Statistics Directorate (DSID) and Agricultural Ministry (MAEP) of Togo following the modular approach advocated by FAO. At the end, rice producers were identified throughout the whole country and in each region. After eliminating missing information this reduces the sample data size to 2123 rice producers distributed as follows: Maritime region (105), Plateaux region (423), Central region (275), Kara region (463) and Savanes Region (857).

RESULTS AND DISCUSION

Summary Statistics of the Output and the Input

The average production of rice producers in the study area is 969.70 kg. This is lower than the national average which is 2.4 tons/ha (**MAEP, 2010**). The average lands rice cultivated are less than one hectare (0.53 ha). The rice producers in the study area use an average of 13.71 kg of seed, among which we most often have IR841, TGR and NERICA. They also use different combinations of fertilizers such as NPK 15.15.15, organic fertilizers and Urea for rice production. The average amount of fertilizer used is 103.48 kg. In terms of labor, an average of 3 people per day work on each producer's farm (Table 3).

Table 3 Summary statistics of the output and input variables

Variables	Mean	Standard Deviation	Minimum	Maximum
Output (kg)	969.70	3661.20	25	104247
Land (ha)	0.53	1.84	0.01	51.89
Seed (kg)	13.71	19.75	3	500
Fertilizer (kg)	103.48	543.56	10	13620
Labor (Man-days)	3.12	2.17	1	28

Source: Authors based on the Fourth National Census of Agriculture data, Togo.

Statistical description of socioeconomic and demographic quantitative variables

The heads of households in the study area are on average 45 years old and have an average of almost 9 years of experience in the field of rice production. The average household size is 7 people. The total number of fields on all farms is on average 6 (Table 4).

Table 4 Descriptive statistics of demographic and socioeconomic characteristics of farmers

Variables	Mean	Standard Deviation	Minimum	Maximum
Age (Years)	44.56	14.53	18	85
Experience (Year)	9.22	8.55	1	61
Household size (Number of people in the farmer household)	7.24	4.22	1	45
Number of fields (total number of plots)	5.86	4.01	1	20

Source: Authors based on the Fourth National Census of Agriculture data, Togo.

Statistical description of qualitative production and socioeconomic and demographic variables

According to table 5 below, only 16% of the farmers used the modern capital (tractor, hitched or motorized harrow, plough). This low proportion can be explained by the lack of financial means or by excessively high costs of modern capital. Rice farms are largely marked by a strong male predominance (90%) against only 10% for women. This can be justified by the fact that most of the land used by women is largely ceded by their husbands. Men would have more access to land than women. The distribution of producers in the study area according to level of education is as follows: 47.9% of producers have no level of education; 3.63% are literate; 25.34% reached the Primary level; 17.62% reached the Middle school; 3.96% reached the High school; 0.8% have reached the University school and 0.75% have followed vocational training in agriculture. Agriculture is the predominant activity of nearly 70% of farmers. A small proportion (7%) of farmers are members of an agricultural association or group. Thus, the low proportions of 4 and 3% respectively of participation of farmers with extension agents and access to agricultural credits can be explained by low participation of farmers in agricultural organizations. The producers who own the cultivated lands are on average 36%. Finally, only 5% of farmers in the study areas are from the Maritime Region, 20% from the Plateaux Region, 13% from the Central Region, 22% from the Kara Region and 40% from the Savanes Region.

Table 5 Descriptive statistics of qualitative production and socioeconomic and demographic variables

Variables	Frequency (%)
Modern capital (1 = if use tractor, hitched or motorized harrow, plough)	16
Gender (1= Male)	90
Educational Level:	
None = 0	47.9
Literate (A person who has just learned to write and speak French) = 1	3.63

Primary level = 2	25.34
Middle school = 3	17.62
High school = 4	3.96
University level = 5	0.8
Vocational level = 6	0.75
Main activity (1= Agriculture)	70
Member of a farmer based organization (1= Yes)	7
Extension visit (1= Yes)	4
Credit Access (Access to credit = 1)	3
Landownership (Own land = 1)	36

Source: Authors based on the Fourth National Census of Agriculture data. Togo.

Testing of hypothesis

Results of the various hypothesis tested are presented in Table 6, Hypotheses 1, 2, 3, 4 and 5 are rejected at 0.01 level of significance. This implies respectively that, (i) the translog model is an adequate representation of the data than the Cobb-Douglas model. (ii) The variability of rice production is explained by production risk in input variables. (iii) The variation in the observed output from the frontier output is due to technical inefficiency and random noise. From Table 7 it is observed that the estimated lambda is 2.627 and it is significantly greater than zero. This implies that variation in output explained by technical inefficiency is relatively larger than the deviations in output from pure noise component of the composed error term. This makes the stochastic model a better model than the deterministic frontier. Gamma ($\gamma = 0.8735$) which is also a measure of the level of the inefficiency in the variance parameter is significant at 1 percent indicating that 87 percent of the total variations in rice output are due to technical inefficiencies in the study area. (iv) The technical inefficiencies are explained by exogenous variables. (v) There are regional effects on technical efficiency of production.

Table 6 Results of hypothesis test

Null Hypothesis	Test Statistic (λ)	Critical value (λ^2)	Decision
H_0: $\beta_{jk} = 0$	280.51***	30.58	Reject H_0
H_0: $\psi_1 = \psi_2 ... = \psi_5 = 0$	181.73***	15.09	Reject H_0
H_0: $\lambda = 0$	802.31***	5.412	Reject H_0
H_0: $\delta_1 = \delta_2 = ... = \delta_{15} = 0$	2301.02***	30.58	Reject H_0
H_0: $\delta_{12} = \delta_{13} = \delta_{14}\ \delta_{15} = 0$	2138.53***	13.23	Reject H_0

Source: Authors computations. ***, indicate 1%, level of significance. The critical value of the third hypothesis was obtained from Table 1 of **Kodde and Palm (1986).**

Elasticity of production and returns to scale

The output elasticities based on estimates of the mean output function (Table 7) are presented in Table 8.

Table 7 Maximum likelihood estimates of the Translog Mean Output Function

Variables	Parameters	Estimates	Standard Errors
Constant	β_0	0.155***	0.003
Ln(Land)	β_1	1.002***	0.002
Ln(Seed)	β_2	0.011***	0.003
Ln(Fertilizer)	β_3	-0.005**	0.002
Ln(Labor)	β_4	0.003	0.004
Modern capital	β_5	-0.003**	0.001
0.5 x $[Ln(Land)]^2$	β_6	0.006***	0.002
0.5 x $[Ln(Seed)]^2$	β_7	-0.013***	0.004
0.5 x $[Ln(Fertilizer)]^2$	β_8	0.004**	0.002
0.5 x $[Ln(Labor)]^2$	β_9	0.014***	0.005
0.5 x $(Modern\ capital)^2$	β_{10}	-0.001*	0.000
Ln(Land) x Ln(Seed)	β_{11}	0.000	0.002
Ln(Land) x Ln(Fertil)	β_{12}	-0.002	0.001

Ln(Land) x Ln(Labor)	β_{13}	0.002	0.002
Ln(Land) x CapMod	β_{14}	-0.001	0.001
Ln(Seed) x Ln(Fertil)	β_{15}	0.007***	0.002
Ln(Seed) x Ln(Labor)	β_{16}	-0.004	0.003
Ln(Seed) x CapMod	β_{17}	-0.001	0.001
Ln(Fertil) x Ln(Labor)	β_{18}	-0.001	0.003
Ln(Fertil) x CapMod	β_{19}	-0.000	0.001
Ln(Labor) x CapMod	β_{20}	-0.002*	0.001
Variance parameters			
Sigma_u		0.108	0.003
Sigma_v		0.041	0.002
Lambda (λ=)σ_u/σ_v		2.627	0.004
Sigma-square ($\sigma^2 = \sigma^2{}_u + \sigma^2{}_v$)		0.013	0.001
Gamma ($\gamma = \sigma^2{}_u/\sigma^2$)		0.874	

Source: Authors computations. ***, **, *, indicate 1%, 5%, and 10% level of significance respectively

However, the discussion of the parameters of the mean output function are based on output elasticities (Table 8).

Table 8 Elasticity of Production and Returns to Scale

Variables	Elasticity
Land	1.002***
Seed	0.011***
Fertilizer	-0.005**
Labor	0.003
Returns to Scale (RTS)	1.01

Source: Authors computations. ***, **, indicate 1% and 5% level of significance respectively

An increase of 1% in land leads to 1.002% increase in production. Compared to other elasticities, we can say that the increase in rice production in Togo depends largely on the land. This result is also reflected in studies conducted by **Villano and Fleming (2006)** and **Tran (2019)**. As for the work of **Tiedemann and Latacz-Lohmann (2013)** and **Oppong *et al.*, (2016),** the land is positively related to average production. A 1% increase in the quantities of seeds used leads to an increase in production of 0.011%. As in the papers of **Adinku *et al.*, (2013). Kara *et al.*, (2019)** and **Oppong *et al.*, (2016)**, we can say that the optimal amounts of seeds used by Togolese rice farmers are not yet reached. The small positive effect is explained by the high use (85.1%) of traditional seeds (MAEP and DSID, 2013). The negative effects of production variables such as the quantities of fertilizers (-0.005%) used and the use of modern capital (-0.3%) are unexpected in the context of this study. Indeed, we admit with **Kaboré (2007)** that the quantities of fertilizers used tend to increase yields by improving soil fertility. Also, it is noted in **Fontan (2008)** that a misuse or control of modern capital due to a lack of training would lead to a reduction in production.

The return to scale is increasing because the sum of the partial elasticities of production is equal to 1.01 > 1. Indeed, the constant return to scale test rejects the null hypothesis thus reflecting the lack of uniqueness of the sum of the partial elasticities (LRcalculated = 159.87 > LRlu = 6.63). This implies that a simultaneous increase of 1% of all inputs used in the production process leads to an increase in production of 1.01%.

Estimates of marginal output risk

The estimates for the marginal input risk are presented in Table 9.

Table 9 Maximum Likelihood Estimates of the Linear Production Risk Function

Variables	Parameters	Estimates	Standard Errors	P > [z]
Constant	Ψ_0	-6.490***	0.096	0.000
Land	Ψ_1	-0.109*	0.057	0.056
Seed	Ψ_2	-0.622***	0.096	0.000
Fertilizer	Ψ_3	0.457***	0.085	0.000
Labor	Ψ_4	-0.737***	0.227	0.001

Modern capital	Ψ_5	-0.056	0.035	0.115

Source: Authors computations. ***, * indicate 1% and 10% level of significance respectively

A 1% increase in the land leads to a reduction in production risks of 0.11%. Togolese rice farmers would become more involved in their production activities as they increase their land. On the other hand, for **Battese *et al*., (1997) and Guttormsen and Roll (2013)**, any increase in the land would lead to a reduction in working time per square meter. This leads to a reduction in productive capacity and thus to a decrease in production. For **Oppong *et al*., (2016),** the larger the land, the more it is exposed to effects of adverse weather conditions at harvest or planting times.

An increase of 1% in the amount of seed used leads to a reduction in production risks of 0.62%. The seeds used by Togolese rice farmers would be resistant to climatic hazards, plant diseases and would also be adapted to their production environment. This result is consistent with that of the study conducted by **Guttormsen and Roll (2013)**. For the latter, the use of improved seeds adapted to the production environment leads to less variation in the quantity and quality of the crop produced. On the other hand, for **Picazo-Tadeo and Wall (2011)** the quantities of seeds used by Spanish rice farmers increase the risk of production. A 1% increase in the amount of labor leads to a reduction in production risks of 0.74%. This implies that Togo rice farmers would have a good quality of used labor. Beyond this, a good quality of the labor would lead to an increase in the producer's ability to cope with the negative effects of rainfall instability (ease of setting up irrigation systems, better monitoring and maintenance of the crop for example). This result is similar to the analysis conducted by **Kara *et al*., (2019).** In **Adinku *et al*., (2013),** a use of labor beyond the optimal level per hectare may lead to a decrease in production and thus an increase in the variability of production.

A 1% increase in the amounts of fertilizer used leads to an increase in production variability of 0.46%. The quantities of fertilizers used by Togolese rice farmers would be of poor quality. It may be of good quality but with levels of use too low or too high compared to the optimal level. This result is consistent with the study of **Bokusheva and Hockmann (2006).** However, the results of **Adinku et al., (2013)** and **Kara *et al*., (2019)** shows a reduction in production risks of 0.824% and 0.3468% respectively given an increase of 1% in the amount of fertilizers.

Technical Efficiency Estimates

The estimates of the parameters for the determinants of inefficiency are presented in Table 10.

Table 10 Maximum Likelihood Estimates of the Technical Inefficiency Model

Variables	Parameters	Estimates	Standard Errors	P > [z]
Constant	δ_0	-1.615***	0.172	0.000
Gender	δ_1	-0.318***	0.103	0.002
Age	δ_2	-0.006***	0.002	0.009
Education	δ_3	0.112***	0.024	0.000
Experience	δ_4	-0.008**	0.003	0.025
Household Size	δ_5	-0.016**	0.008	0.028
Number of fields	δ_6	-0.013*	0.008	0.083
Main occupation	δ_7	0.194***	0.070	0.005
Member of a farmer based organization	δ_8	0.017	0.173	0.924
Extension visits	δ_9	0.041	0.214	0.850
Credit Access	δ_{10}	-0.356	0.240	0.138
Landownership	δ_{11}	-0.626***	0.065	0.000
Plateaux Region	δ_{12}	2.134***	0.173	0.000
Central Region	δ_{13}	-37.485	1203.503	0.975
Kara Region	δ_{14}	0.996***	0.175	0.000
Savannah Region	δ_{15}	-1 459***	0.182	0.000

Source: Authors computations. ***, **, *, indicate 1%, 5% and 10% level of significance respectively

The expected result of the coefficient of the gender variable, which reflects the fact that the male producer would be technically more efficient than the female producer, is verified. This coefficient is -0.318 and significant at 1%. This result is consistent with **Kibaara's (2005)** conclusion that male rice farmers would be physically better able to engage in agricultural activity, they would have more access to agricultural credit and would attend more agricultural extension seminars and thus, would probably reduce their technical inefficiency. The expected effect of the age variable which states according to **Adinku *et al*., (2013)** that older producers would be technically less efficient than younger is confirmed with negative effect equal to -0.006 and is significant at 1% on the technical inefficiency. Conversely, **Coelli and Battese (1996)**, stated that, age could have a positive or negative effect on technical inefficiency. Older producers may be more traditional and conservative and therefore less willing to adopt best agricultural practices.

The positive (0.112) and significant effect of the educational level variable on technical inefficiency is unexpected in this study. Indeed, in accordance with **Battese and Coelli (1995),** the level of education is supposed to increase farmers' capacities on the use of existing modern technologies and thus improve their levels of efficiency. However, for **Owour and Shem (2009),** educational attainment is negatively correlated with the technical efficiency of farmers. One explanation is that technical skills in agricultural activities especially in developing countries are influenced more by practical training in modern farming methods than by mere formal schooling. For the effect of the agricultural work experience variable, it is negative (-0.008) and significant at 5% on the technical inefficiency. Indeed, for **Ogundari and Akinbogun (2010),** experience based on the acquisition of the best agricultural techniques over time through practice, negatively affects technical inefficiency. However, the paper of **Adinku et al., (2013)** revealed that many years of rice production only indicate adherence to old production methods that may be technically less efficient.

Household size has a negative effect (-0.016) and significant at 5% on the technical inefficiency. This finding supports the hypothesis that a large family size means more labor to meet the needs of agricultural activities **(Dhungana *et al*., 2004; Kaboré, 2007).** The number of fields defining the fragmentation of a farm. negatively (-0.013) and significantly affects the technical inefficiency. This relationship is explained by the fact that a geographical dispersion of fields can make it possible to diversify the risk. Indeed, in **Fontan (2008),** a producer holding distinct fields, better results may be observed on a particular field located on different reliefs.

Rice farmers whose main activity is agriculture would be technically more efficient because they would have more experience. Therefore, they would have more potential on the efficient use of agricultural inputs (**Adinku *et al*., 2013**). This result is not the case in this study. The effect of the main activity variable was positive (0.194) and significant at 1% on the technical inefficiency. Togolese rice farmers with agriculture as main activity, whose would diversify their energies on a diverse set of agricultural speculations, may be technically less efficient because of a suboptimal use of their available resources. The results also show that rice farmers operating on their own land are less efficient than those operating on leased land. The effect of this variable is negative (-0.626) and significant at 1%. This finding is consistent with the hypothesis that long years of leasing would motivate farmers to work harder to meet their contractual obligations (**Helfand and Levine, 2004; Coelli *et al*., 2005**). Also, a negative relationship would be linked to the constraints of the agency, reflecting the problems of surveillance and therefore, a decrease in the performance of companies (**Giannakas *et al*., 2003; Reddy, 2002).**

Technical Efficiency Estimates

The technical efficiency scores of Togolese rice farmers are between 37.14% and 99.51% and are on average 79.72% (Fig. 3). This means that without using additional resources, rice farmers can increase their production by 20.28% on average. They can also reduce their production costs by 20.28% to be technically efficient. The mean equality tests show that there exists a significant difference between the mean technical efficiencies of the different regions of Togo.

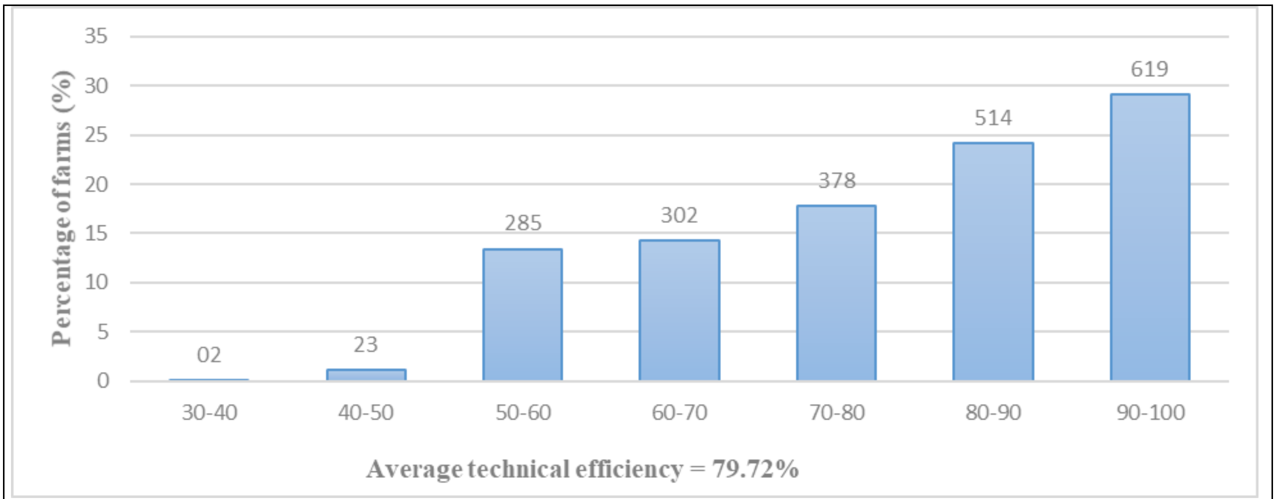

Figure 3: Graphical representation of technical efficiency scores

Source: Authors design based on the Fourth National Census of Agriculture data, Togo.

CONCLUSIONS AND RECOMMENDATIONS

The present study reveals through its results that production risk and technical inefficiency prevent Togolese rice farmers from realizing their frontier output. The production risk is significantly explained by production variables such as the land, the quantities of seeds and fertilizers used and the labor. The technical inefficiency is significantly explained by a set of exogenous variables such as gender, age, educational level, experience, household size, number of fields and the main occupation of the rice farmer. The results also reveal a significant difference in mean technical efficiencies of the different Regions. In light of the findings, it is recommended that the Togolese government: (i) raise the price of rice to make rice production more attractive, (ii) further subsidize input prices to ensure that they are easily accessible and affordable to producers and (iii) organize training sessions on the best use of modern capital. Thus, the results of this analysis are of particular interest to the Togolese economy in general and to the rice sector in particular, which is facing very strong demand. However, panel data would provide better estimates of observed phenomena than cross-sectional data (**Kumbhakar, 1993; Wan and Battese, 1992**). In perspective, incorporating the risk preference function into the flexible production risk model would allow for the study of producers' behaviors towards input allocation decisions **(Kumbhakar and Tveteras, 2003).**

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