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November, 2020

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Correct Citation: Vabi, M.B., Abdulqudus, I.A., Angarawai, I.I., Adogoba, D.S. Kamara, A.Y., Ajeigbe, H.A. and Ojiewo, C. (2020). Adoption and Welfare Impacts of Pearl Millet Technologies in Nigeria. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Patancheru, Telangana-India. Technical Working Document. ISBN 978-93-86527-04-2.

List of Abbreviations and Acronyms

ABU	Ahmadu Bello University
ADP	Agricultural Development Project
ATE	Average Treatment Effect
ATT	Average Treatment on the Treated
CIA	Condition Independent Assumption
AVISA.	Accelerated Varietal Improvement and Seed Delivery of Legumes and Cereals in Africa.
BUK	Bayero University Kano
CDA	Centre for Dry Land Agriculture
DHM	Double Hurdle Model
FAO	Food and Agriculture Organisation of the United Nations
FAOSTAT	FAO's statistical data base
FMARD	Federal Ministry of Agriculture and Rural Development
GM	Gross Margin
HOPE	Harnessing Opportunities for Productivity Enhancement of Sorghum and Millets in Sub-Saharan Africa
IAR	Institute for Agricultural Research
INERA	Institut de l'Environnement et de Recherches Agricoles
IER	Institut d'Economie Rurale
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
LCRI	Lake Chad Research Institute, Maiduguri
LGA	Local Government Area
NASC	National Agricultural Seeds Council
PSM	Propensity Score Matching
ToR	Terms of Reference

ACKNOWLEDGEMENTS

The authors extend their appreciation to Dr Maina Ibn_Mohammed (Pearl Millet Agronomist/Seed Systems Specialist) and Dr. Maryam Dawud (Pearl Millet Breeder), both of the LCRI, Nigeria who provided documents and responded to frequent phone calls from the first author. Mr. Abba Aliyu Kasim of the Federal University of Dutsin-Ma, (Nigeria) helped in developing the map depicting the LGAs from which data was collected. Dr. Hauwa Ladi Yusuf, Head of Department of Food Science and Technology of the Bayero University, Kano (BUK) and Dr. Umar Garba of the Food Science and Technology Department of the BUK, provided useful insights on the nutritional implications of the wide range of foods being consumed by respondents of the survey. Dr. Drabo Inoussa, Pearl Millet breeder of INERA (Burkina Faso), Dr. Gangashetty Prakash, ICRISAT Pearl Millet breeder based in Niamey (Niger) and Dr. Sanogo Moussa Daouda, Pearl Millet breeder of IER (Mali), all provided the documents required to launch the recounting of the full story of Research for Development on Pearl Millet, in and out of Nigeria. Dr. Kapran Issoufou, Dr. Soul-kifouly Middingoyi and Ms. Agathe Diama, all of ICRISAT, all of Mali, read through earlier versions of the report and made very useful comments/inputs which helped in improving the technical quality of the report. Finally, Mr. Andrew Kurga Dooter, English Language Teacher at Prime College, Kano corrected initial versions of this report; he did a tremendous job by ensuring that both word and sentence are well aligned.

The authors also recognise the insights and contributions of the respondents and survey facilitators at all levels - village, LGA and State. By probing and meticulously capturing the required data from respondents during interview sessions, the enumerators contributed to a challenging development mission; we thank all of them for accepting to be part of this exercise. Mr. Lawal Bala, provided timely logistical assistance throughout the execution of the survey.

Funding for all operations of this survey was provided by the Bill and Melinda Gates Foundation (BMGF) within the framework of the implementation of two regional projects i) the *Harnessing Opportunities for Productivity Enhancement (HOPE) of Sorghum* and *Millets in Sub-Saharan Africa and ii) Accelerated Varietal Improvement and Seed Delivery of Legumes and Cereals in Africa (AVISA).*

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Executive Summary

Pearl Millet [*Pennisetum glaucum* (L.) R. Br.] is a small-cereal crop commonly called **Millet.** It has three generic names corresponding to three different types in the Hausa Language in Nigeria: *Gero (early maturing), Maiwa (late maturing and photosensitive), Dauro (transplantable and photo-sensitive).* Several dishes are made from millet and its flour across the Sahel region of West and Central Africa (WCA). The stem is primarily used for construction (houses and fences), the fodder and grain pericarp are important feeds for domestic livestock and poultry. Due to its resilience to drought stress, soil salinity/acidity and high temperatures compared to other cereals Pearl Millet survives well in agro-ecological zones where other cereals will not. Therefore, the crop has a noteworthy role in food and nutrition security of the drier regions of WCA.

This study was carried out in Nigeria with four primary objectives **i)** to determine adoption rates and intensities of adoption of Pearl Millet technologies, **ii)** to identify constraints to the sustained use of Pearl Millet technologies, **iii)** to determine the welfare impacts of adoption of improved Pearl Millet technologies on productivity, gross margin, poverty and food insecurity experiences, and **iv)** to formulate actionable recommendations based on outcomes of the survey.

A four stage sampling techniques was used for the survey. The conscientious use of required procedures resulted in the retention of seven Pearl Millet producing States namely Kano, Katsina, Sokoto, Jigawa, Kebbi, Bauchi and Yobe, twenty-one (21) Local Government Areas (LGAs) and eighty-four (84) villages/communities. Respondents were selected using constituted random numbers giving rise to 1,267 respondents with whom interviews were conducted; only 93 of the respondents were women. The dataset was cleaned and checked after the survey to ensure consistency and completeness. The curated dataset was subjected to the Statistical Package for Social Sciences (SPSS) and/or STATA software for appropriate analyses. Both descriptive statistics appropriate regression models were used; the models included, Double Hurdle Regression, Average Treatment Effect (ATE) and Propensity Score Matching (PSM) Model.

Results of the survey revealed that respondents are mostly adults aged 36 - 60 years (59%), have as occupation crop farming (70% of the respondents), 92% of respondents were married, 72% of them do not belong to farming groups, 44% have received Quranic education, and 33% have household sizes varying between 6-10 persons. Cattle accounted for 42% of annual cash earnings of respondents, 33% of the respondents earn less than ₦30,000.00 while 36% reported annual cash earnings above ₦100,000.00. Majority of the respondents (83%) reported not having access to extension support visits; the ADPs was reported to be the main source of extension support visits (74%) whenever this occurs.

Overall, awareness of Pearl Millet technologies (improved seeds) was estimated at 28%, with 18%, 7% and 3% for SOSAT-C88, SUPER-SOSAT and JIRANI, respectively. Several other Pearl Millet landraces were identified with Yobe State having the highest closely followed by Katsina and Sokoto States. The most popular landraces were *Zango, Gajaro*, *Gero* and *Zabo*. The nicknaming of landraces is often indicative of the onset of processes of acculturation; sobriquets given to the landraces either reflect its *origin, tribal/ethnic group mostly growing the landrace, grain colour, plant height, growth pattern and physical appearance.*

Overall awareness of the improved Pearl Millet technologies being promoted resulted in an adoption rate of 18% with 13% attributed to SOSAT-C88, 4% to SUPER-SOSAT and JIRANI 1%. Eight (08) drivers of adoption, all significant at different levels of probability emerged from the use of the Double Hurdle regression model. These drivers are *farm size, household size, early maturity, high yield, drought tolerance/resistance, access to credit, extension support visits, striga resistance.* The outstanding reason for the adoption of Pearl Millet technologies was early maturity of improved varieties reported by 66% of respondents. The negative features of the varieties being promoted were late maturity (25%), unending growing of *striga* infestation (27%) and pests/diseases (27%). The adoption of crop management practices requiring the procurement of farm inputs particularly fertilizers and pesticides were lower (less than 50%) those requiring bought inputs (between 70% and 86%). In terms of initial sources of improved Pearl Millet seeds grown by respondents, the ADPs, other farmers and owned supplies were mentioned across the States for SOSAT-C88 and SUPER-SOSAT, in all other States except Sokoto and Yobe.

Conscious of prospects of better adoption potentials of the Pearl Millet technologies being promoted by the HOPE and AVISA Projects, the use of the Average Treatment Effect (ATE) revealed a potential adoption rate of 45% with an adoption gap of 27%. The intensity of adoption was 49% for LCIC 9702, 60% for SUPER-SOSAT, 55% for both JIRANI and SOSAT-C88. Despite the extent of incorporation of improved Pearl Millet technologies into farm-fields, an overall dis-adoption rate of 7% was recorded with reasons recounted being recurrent unavailability of improved seeds (33%), feeling of being satisfied with existing landraces (22%), and lack of capital (money) to purchase improved Pearl Millet seeds (22%).

The use of the Propensity Scoring Model (PSM) showed that adoption of improved Pearl Millet technologies had positive and significant impacts on yields, gross margin and welfare of respondents. As an illustration, outcomes of the three PSM matching techniques of the PSM namely *Nearest Neighbour Matching*, *Radius Matching and Kernel Matching*, revealed productivity gains of 26%, a gross margin gain of 55%, an increase in dietary diversity of 21% and contributions to a decrease in poverty status of 8%. Returns on investments in the production of Pearl Millet was 83% for adopters and 43% for non-adopters.

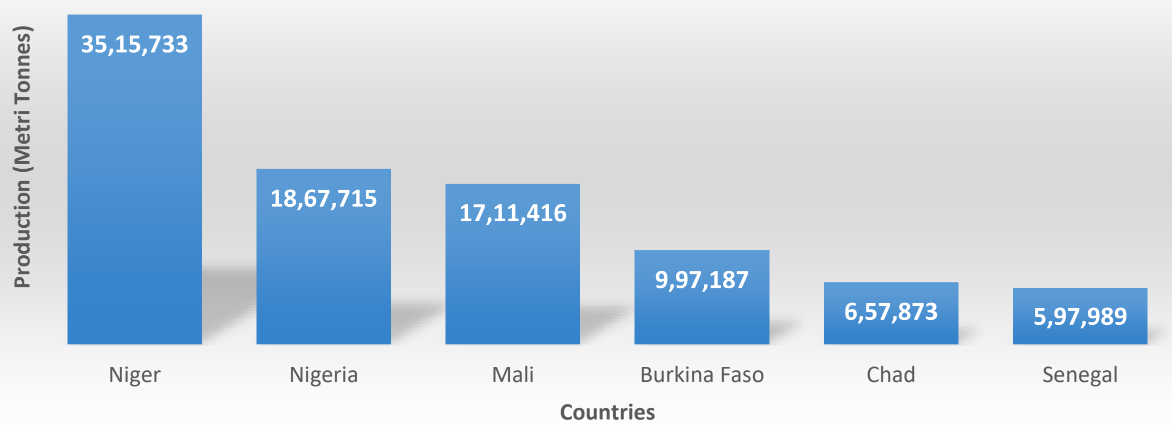
The study recommends a comprehensive strengthening of scaling out efforts of existing Pearl Millet technologies. This comprises a multi-dimensional venture under the auspices of the Lake Chad Research Institute (LCRI), with support from current and future research for development partners focusing on four interrelated components: i*) use of innovative extension approaches in scaling out Pearl Millet technologies ii) promotion of the multiplication and distribution of quality seeds of current varieties iii) intensification of efforts to release varieties with comparative gains, and iv) development and promotion of the processing, marketing and consumption of millet-based products.*

1.0. Introduction

Pearl Millet [*Pennisetum glaucum* (L.) R. Br.] is commonly called **Millet.** It is a multipurpose, robust, tall, fast growing cereal crop with large stems. Other types of millets are: finger millet (*Eleusine coracana*), kodo millet (*Paspalum setaceum*), proso millet (*Penicum miliaceum*), foxtail millet (*Setaria italic*), little millet (*Panicum sumatrense*) and barnyard millet (*Echinochloa utilis*). Together with other cereals - maize (*Zea mays*), sorghum (*Sorghum bicolor*), oats (*Avena sativa*) and barley (*Hordeum vulgare*), they are known as coarse grains (Kaur *et al*. 2012). Over 70% of the Pearl Millet is grown between latitude 7^0 N and 14^0 N in Africa accounting for nearly a third of the world's production. Although millet is grown where annual rainfall ranges between 200-1500 mm, increasingly it grows well in areas with 250 -700 mm annual rainfall. Pearl Millet is a resilient cereal crop because it can grow where many other crops cannot be grown, except pasture. Due to its resilience to drought stress, soil salinity/acidity and high temperatures compared to other cereals, there are opportunities for Millet to make inroads into other agro-ecological zones. These opportunities include growing the crop during the dry months of March to May in the Sahel when temperature can rise up to, and above 40°C. Therefore, as the frequency, severity and duration of climate variability and change intensifies (Kumar *et al.*, 2020), Pearl Millet is likely to become a major feature of farming systems in the Sahel, Sudan and Guinea Savannah agro-ecological zones in countries of West and Central Africa (WCA) in the nearest future.

FAOSTAT (2018) reported that Pearl Millet is grown in five (05) countries of WCA on a total surface area of about 15.4 million hectares with an annual production of 9.3 MT. This same source indicates that the Republic of Niger is the first producer of Pearl Millet in WCA with annual production of about 3,515,733 MT followed by Nigeria with an annual production of about 1,867,715 MT; Mali closely follows with an annual production of about 1,711,416 MT. Other Pearl Millet producing countries in WCA are Burkina Faso, Chad and Senegal **(Figure 1)**. The crop is cultivated on about 1,59 million hectares of agricultural land in Nigeria. Over 60% and 30% of cropland in Borno and Adamawa States, respectively, is devoted for cultivation of millet.

Figure 1: **Production Trends of Pearl Millet in West and Central Africa (2009-2018)**



Source: FAOSTAT (2018)

Pearl Millet plays significant role in food security of the drier regions of WCA. It has three generic names corresponding to three different types in the Hausa Language in Nigeria: *Gero (early maturing), Maiwa (late maturing and photosensitive), Dauro (transplantable and photo-sensitive).* The traditional foods made from millet across the Sahel region of WCA include ***kunu*** (thin porridge), ***masa*** (fried cake), ***fura*** (whole grain pounded made into small round bolls and consumed with milk), ***Ogi*** also known as *akamu or kamu* (thick porridges*)*, ***burukutu*** (a range of alcoholic beverages, sweet/sour opaque beer and non-alcoholic beverages. Its flour is used in preparing ***tuwo*** (a thick binding paste). Though the stem is primarily used for the construction of houses and fences, together with the green fodder and pericarp they are important feeds for domestic livestock and poultry (Ajeigbe *et al.*, 2020).

Regrettably, the potentials of Pearl Millet are constrained by recurrent droughts, unending seasonal emergence of *Striga*, head miner, wild birds, downy mildew and intrinsic poor soil fertility (FAO, 2014; Garba and Mohammed, 2016; Drabo, 2019). Despite considerable investment in research, insufficient attention has been directed to the promotion of released varieties in Nigeria (Coker, 2018). Unlike maize and rice, the exploration of industrial uses of millet grains has also been slower than for other cereal crops. As inadequate attention is paid to the promotion of released varieties of the crop, these aspects have been understudied encouraging NRC (1996) and (Tadele, 2018) to consider it as an orphan crop. Except the work of Ndjeunga *et al.* (2011), Badolo *et al.* (2013) and Tijani *et al.* (2014). for example, available literature is concentrated on the collection and

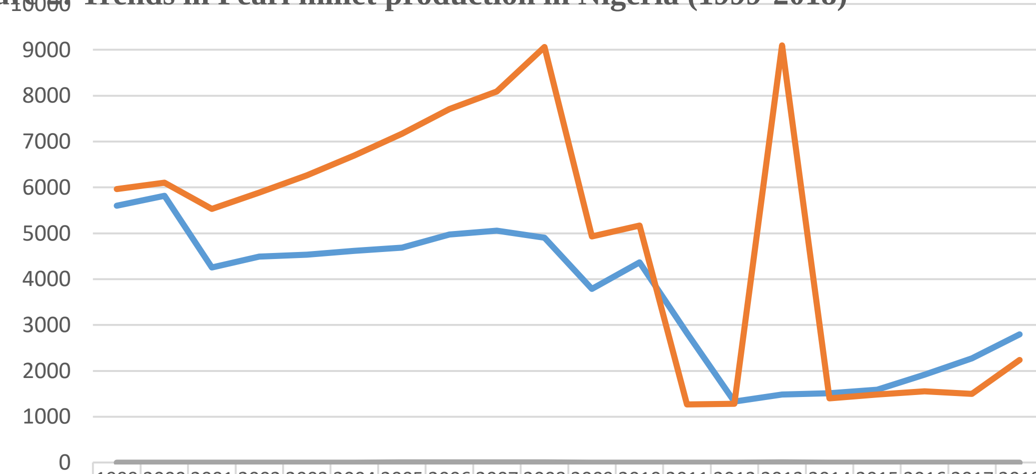
characterization of landraces, genetic advancement of open-pollinated varieties (OPVs) and hybrids (Pusher *et al.*, 2015; Angarawai *et al.*, 2016; Dawud *et al.* 2017; Drabo *et al.*, 2019). In this context, an understanding of drivers of awareness of, and about released varieties, adoption, trait preferences, seed systems and gender mainstreaming become relevant and useful to processes of varietal development.

1.1. Pearl Millet Production in Nigeria

1. 1.1. Pearl millet production trends

As shown in Figure 1, Pearl Millet production in Nigeria witnessed a steady rise between 1999 up to 2008 when it witnessed a sharp decline before stabilising during the 2011 cropping season. Another downward turn occurred between 2011 and 2013 when production further declined. Since 2013, insurgency activities of the Boko Haram Cult which included repeated abductions and cattle rustling completely destabilised agricultural activities in the North East of Nigeria with a heavy toll on Pearl Millet production. Equally, enhanced drought stress, significantly reduced Pearl Millet production beginning from 2007 in the millet producing States of Kebbi and Sokoto. These factors, combined with Boko Haram insurgencies which restricted access to agricultural lands in Borno, Yobe and Adamawa, resulted in sharp declines in production and area cultivated beginning from 2010.

Figure 2: Trends in Pearl millet production in Nigeria (1999-2018)



	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Area Cultivated ('000Ha)	5603	5814	4254	4490	4536	4620	4685	4971	5056	4904	3787	4364	2827	1328	1485	1511	1591	1914	2272	2796
Production ('000MT)	5960	6105	5530	5884	6260	6699	7168	7705	8090	9064	4929	5170	1271	1281	9096	1399	1485	1553	1500	2241
Yield (t/Ha)	1.1	1.1	1.3	1.3	1.4	1.5	1.5	1.5	1.6	1.8	1.3	1.2	0.4	1.0	6.1	0.9	0.9	0.8	0.7	0.8

Area Cultivated ('000Ha)   Production ('000MT)   Yield (t/Ha)

1.1.2. Profiles of Pearl Millet varietal and non-varietal technologies being promoted in Nigeria

Over the past twenty (20) years, collaborative efforts bringing together the Lake Research Institute (LCRI) and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) resulted in the registration and release of twelve (12) improved varieties of Pearl Millet in Nigeria. Four of these varieties namely *SOSAT-C88, SUPER-SOSAT, JIRANI and LCIC9702* are being promoted within the framework of the Harnessing Opportunities for Productivity Enhancement (HOPE 1) since 2009, and the AVISA project since 2018. The promotion of these varieties remains the core business of State-based Agricultural Development Programs (ADPs), Extension Services of State Ministries of Agriculture and agricultural sector partners in Nigeria (**Table 1)**.

Table 1: Improved Pearl Millet Varieties Being Promoted in Nigeria

Improved Variety	Year of released	Yields (Tons/ha)		Best suited agro-ecologies
		Potential	Farmers' fields	
SOSAT-C88 (LCIC MV 1)	2000	2.5 - 3.5	1.5 - 2.0	Sudan
LCIC9702 (LCIC MV 2)	2003	2.0 - 2.5	1.0 -1.5	Sahel and Sudan
SUPER-SOSAT (LCIC MV 3)	2011	4.0 - 4.5	2.0 - 2.5	Northern Guinea and Sudan
JIRANI (LCIC MV 4)	2013	2.5 - 3.0	0.8 - 1.0	Sahel

Upon their release, these improved Pearl Millet varieties are early maturing, high yielding, drought tolerant, have good flour quality and are resistant to diseases notably downy mildew. Also, potential yields vary between 2t/ha and 4t/ha, depending on the variety and religious application of crop management practices. However, yields on farmers' fields have been much lower; varying between 40% and 68% or between 0.8t/ha to 2.5t/ha as shown in Table 1.

1.1.3. Objectives of the survey

Against this background, this study set out to develop an understanding of the extent of awareness of released varieties, their sustained use (adoption) and impacts of improved varieties of adoption of Pearl Millet in selected States of North-western Nigeria. In operational terms, the objectives of the study were to:

1. determine adoption rates and intensities of adoption of Pearl Millet technologies;
2. identify constraints to the sustained use of Pearl Millet technologies;
3. determine the impacts of adoption of improved Pearl Millet technologies on productivity, gross margin, poverty and food insecurity experiences; and
4. based on outcomes of the survey, formulate actionable recommendations.

Pearl Millet farmer foresees better yield from an improved variety in Kano State, Nigeria

Pearl Millet farmer returning from his farm satisfied with a bundle of an improved Pearl Millet variety; Kebbi State, Nigeria

2.0. Methodology

2.1. Sampling and selection of respondents for interviews

A four-stage sampling procedure was used for the survey. The first stage was the purposive selection of seven (07) key Pearl Millet producing States of northern Nigeria **(Figure 3).** These States comprise Kano, Katsina, Sokoto, Jigawa, Kebbi, Bauchi and Yobe. The second stage in the sampling procedure was the selection of three (03) Local Government Areas (LGAs) from each of the States where Pearl Millet technologies have been, and are still being promoted by research for development partners; this resulted in a total of twenty-one (21) LGAs. In the third stage, four (04) villages/communities were selected from each of the LGA to give a total of Eighty-four (84). In the fourth and final stage of the sampling procedure, random numbers were used to select Pearl Millet producers from a sampling frame established for the survey. The sampling frame was developed through a community census in the villages/communities identified for the survey. A total of 1,267 respondents were interviewed during the survey representing 14% of the 9,289 Pearl Millet producers (8,847 men) and 442 (women) identified from the community census. Despite the use of the random number at the fourth stage of the sampling procedure, cautious efforts were made to look for and interview female Pearl Millet farmers in all the villages/communities. During the interviews, respondents not present were replaced by other Pearl Millet farmers suggested by community/village leaders and survey facilitators. The outcome of the thorough application of the four-stage sampling procedures, summarised in **Table 2** is adequately illustrative of Pearl Millet farming Sates in Nigeria

Data was collected in January 2020 with a focused on the 2019 cropping season. Data collected were organised in a structured questionnaire around the following themes, *administrative unit and interview team, composition of, and socio-demographic characteristics of respondent's household, knowledge of improved millet varietal and non-varietal technologies and their utilisation, production systems, cost of farm inputs (including seeds) and market participation, access to credit and extension support services, production and household assets, expenditure on food and non-food items, poverty status and food security/insecurity, social capital and networking.*

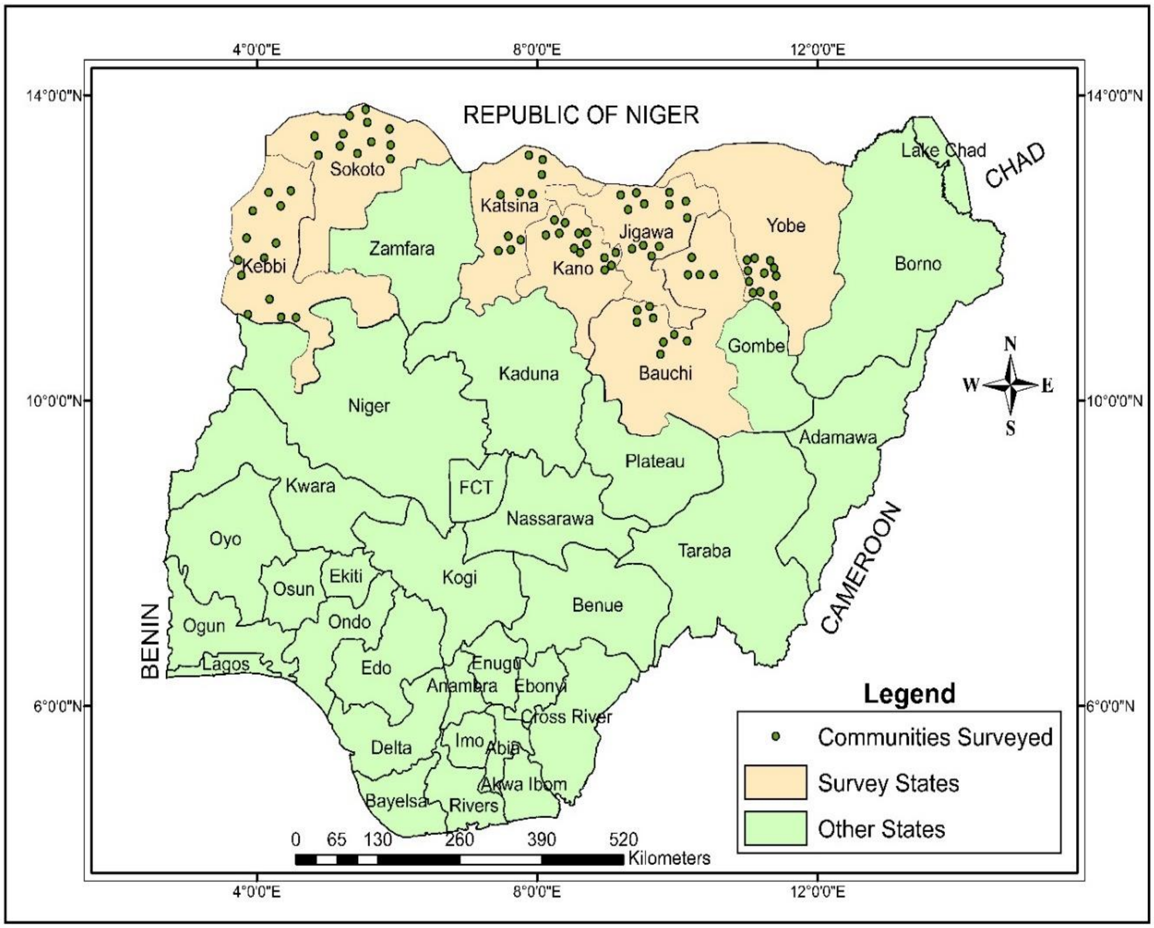


Figure 3: States Selected for Pearl Millet Survey in Nigeria (January, 2020)

Table 2: Distribution of respondents by States

States	**Men**	**Women**	**Totals**
Bauchi	111	9	120
Jigawa	222	1	239
Kano	183	15	198
Katsina	215	17	232
Kebbi	123	10	133
Sokoto	132	10	142
Yobe	188	15	203
Total sample size	**1,174 (93%)**	**93 (7%)**	**1,267**
Sampling frame	**8,847 (95%)**	**442 (5%)**	**9,289**

2.2. Pre-survey training and data collection

A pre-survey training including a pre-test of the questionnaire was organised for the survey teams by ICRISAT. The training and pre-test were aimed at developing a common understating of the data collection instrument, improving the flow of the questions, ensuring appropriate translation of the contents of the questionnaires into the survey language (Hausa) and weeding out irrelevant and recurring questions. After the pre-survey training, an updated version of the questionnaire was uploaded onto the *KOBO Collect* software.

2.3. Organisation of data collection

A total of 30 enumerators were recruited and put into three separate teams of ten (10) each supervised by a Team Leader, himself an enumerator **(Annex 2)**. Each of the teams was assigned a cluster of States as follows **i)** Sokoto and Kebbi States **ii)** Kano, Katsina and Jigawa States, and **iii)** Yobe and Bauchi States (**Annex 3**). Each team/cluster benefited from technical, administrative and logistical back-stopping of a survey coordinator and ICRISAT Socio-economist for WCA based in Kano (Nigeria).

2.4. Data curation and analysis

After both the community census and survey proper, the data was cleaned and checked for consistency, and completeness in the capture of responses from respondents. Obvious errors and outliers were further checked and reviewed. The curated dataset was subjected either to the Statistical Package for Social Sciences (SPSS) or STATA soft wares for appropriate analyses. The Double Hurdle Regression model was used to determine the factors influencing adoption of improved varieties while the Propensity Score Matching (PSM) framework and the Average Treatment Effect on Treated (ATT), was used for the assessment of the welfare impacts of the adoption of Pearl Millet improved technologies.

2.5. Models Used in Assessing Technology Adoption and Welfare Impacts

2.5.1. The Average Treatment Effect (ATE) Model

The counterfactual ATE framework which allows for both nonparametric and parametric methods to derive consistent estimates was used to estimate both subpopulation awareness-unrestricted and awareness–access unrestricted potential adoption rates and associated gaps of Pearl Millet technologies. An underlying assumption of the ATE framework is that the decision of a respondent to adopt a technology is made provisional upon being aware of improved Pearl Millet technologies and having access to them.

Assuming that w=1 stands for respondent's awareness of improved varietal technologies and w=0 for those not aware of them, s=1 for respondents who had access to the improved varietal technologies and s=0 for respondents with no access to the technologies. The potential outcome framework of Rubin (1974), theoretically has four potential adoption outcomes: **i)** an outcome with awareness and access to improved technologies such as seeds say Y_1 (that is, Y_1 is the outcome when w=1 and s=1, **ii)** an outcome when aware but do not have access Y_2 (that is Y_2 is the outcome when w=1 and s= 0, **iii)** outcome with no awareness but access Y_3 (that is Y_3 is the outcome when w=0 and s=1), and **iv)** outcome with no awareness and no access Y_0 (that is Y_0 is the outcome when w=0 and s=0). Hence the observed adoption outcome Y can be expressed for the four potential adoption outcomes as:

$$Y= WSY_1 + W (1-S) Y_2 + (1-W) SY_3 + (1-W) (1-S) Y_0 \quad (1)$$

Since awareness is preconditions for adoption we have $Y_2 = Y_3 = Y_0$ hence equation can be written as (1):

$$Y= WSY_1 \quad (2)$$

A potential outcome is 0 when a respondent is not aware or does not have access, the potential outcome Y_1 is the treatment effect of a given respondent when the respondent is both aware and has access to improved seeds. The ATE of awareness and access is given by the expected value E (Y_1). If awareness is considered as treatment and access to improved seeds as an outcome, every respondent has two potential outcomes with respect to access to improved seeds. When a respondent is aware or not aware, W is a binary that takes the value of 1 for respondent aware of improved Pearl Millet improved varieties and 0 otherwise.

This can be written as observed access to improved seeds outcome S as a function of awareness and the two access to improved seed potential outcomes as:

$$S = WS_1 + (1\text{-}W)\, S_0 \qquad (3)$$

Equation (3) implies that $WS=WS_1$, leading to $y=wsy_1=ws_1y_2$.

Assuming that awareness – unrestricted potential adoption status y_1*

$$y^*= Sy_1 \qquad (4$$

Similarly, the access - unrestricted potential adoption status y** is defined as:

$$y_1^{**}= wy_1 \qquad (5)$$

These two population potential adoption rates are different from the population potential adoption rate when the full population is aware and has access to improved Pearl Millet seeds (with some not necessarily being aware), which is measured by the parameter $E\ (y_1^{**})$ and is the ATE of access to improved Pear Millet seeds on adoption. To distinguish amongst the three population potential adoption rates, the parameter $E\ (y_1)$ will be called awareness-access to seed-unconstrained, whereas the $E(y_1^*)$ and $E(y_1^{**})$ will be called the awareness-unconstrained and access unconstrained population potential adoption rates, respectively. It is clear from equations (3) to (5) above that the observed population adoption rate *E (y)* parameter (which is consistently estimated by the sample adoption rate computed from a random sample) is a measure of the population joint awareness-access and adoption rate (which is the same as the population joint awareness, access to improved seeds and adoption rate as $E(y) = E(wsy_1)$, and not a measure of the population joint awareness and adoption $E\ (wy_1)$ rate, as presented by Diagne and Demont (2007). Hence, in what follows, we will use the notation JEAA (joint awareness-access and adoption) for the observed population parameters *E(y)*. It is also clear from above that $E(y) \leq\ (E\ y^*_1) = E\ (sy_1) \leq\ E\ (y_1)$ and $E\ (y) \leq\ E\ (y_1^{**}) = E\ (wy_1) \leq E(y_1)$ (since *w* and *s* are binary), meaning that the awareness-unconstrained and access-unconstrained population potential adoption rates are both greater than the actual population adoption rate but always lower than the awareness-access to seed-unconstrained population potential adoption rate.

Three adoption gaps were then defined with one attributed to lack of awareness and access to improved Pearl Millet seeds (equation 6) and the others attributed to lack of awareness (equation 7) and lack of access to improved Pearl Millet seeds (equation 8) as follow:

$$GAP_{ws} = E(y) - E\ (y_1) = JEAA - ATE_{ws} \qquad (6)$$

$$GAP_{w} = E(y) - E\ (y^*_1) = JEAA - ATE_{w} \qquad (7)$$

$$GAP_s = E(y) – E(y^{**}_1) = JEAA – ATE_s \quad (8)$$

where *ATEws* (represents *ATEw*, *ATEs*) is the average treatment effect parameter when awareness and access to improved Pearl Millet seeds (represents awareness, access to improved seeds) are the treatment variables. Given that $ATEw \leq ATEws$ and $ATEs \leq ATEws$ as shown above, the adoption gap attributable to lack of awareness and access to improved Pearl Millet seeds is always smaller in absolute value than both the gap attributable to lack of awareness and the adoption gap attributable to lack of access to improved Pearl Millet seeds. With the ATE estimation framework, the awareness-unrestricted, the access-unrestricted and the awareness-access-unrestricted potential adoption rates can be defined for various subpopulations by the values *x* in support of some random variable *X* as the average treatment effects conditional on *x*, $E(y_1/X = x)$; $E(y^*_1/X = x)$ and $E(y^{**}_1/X = x)$, respectively (the conditional ATE parameters). In particular, the potential adoption rates in the subpopulation with access to improve millet seeds, in the subpopulation aware of improved Pearl Millet seeds and in the subpopulation aware with access to improved Pearl Millet seeds correspond to the average treatment effect on the treated (ATT) parameters represented as follows:

$$ATT_s = E(y_1^{**}/s=1) \quad (9)$$

$$ATT_w = E(y_1^{*}/w=1) \quad (10)$$

$$ATT_{ws} = E(y_1/w=1,s=1) \quad (11)$$

Likewise, the potential adoption rates in the subpopulation without access to improved Pearl Millet seeds that is not aware of improved Pearl Millet seeds and the subpopulation not aware and not having access to improved Pearl Millet seeds are given by the respective ATE on the untreated (ATU) as follow:

$$ATU_s = E(y_1^{**}/s=0) \quad (12)$$

$$ATU_w = E(y_1^{*}/w=0) \quad (13)$$

$$ATU_{ws} = E(y_1/w=0, s=0) \quad (14)$$

Furthermore, awareness will be taken as access to improved seeds and awareness-access to seeds population selection bias (PSB) parameters which measures the extent to which awareness and access to improved Pearl Millet seeds are not randomly distributed in the population, respectively as

$$PSB_w = ATT_w – ATE_w = E(y_1^{*}/w=1) - E(y^*_1) \quad (15)$$

$$PSB_s = ATT_s – ATE_s = E(y_1^{**}/s=1) - E(y_1^{**}) \quad (16)$$

$$PSB_{ws} = ATT_{ws} – ATE_{ws} = E(y_1/w=1, s=1) - E(y_1) \quad (17)$$

The ATE estimation framework is used to provide consistent estimates of $E\ (y^*_1)$ and $E(y_1)$, the awareness-unrestricted and awareness-access unrestricted population potential adoption rates, respectively. Both parameters are identified and estimated in exactly the same way except that, in the case of y_1, we use *ws* (awareness and access to improved millet seeds) variable instead of the *w* (awareness) variable. Although the variable *s* is only observed for the respondents aware (that is, for respondents with $w = 1$), the product *ws* is known for all respondents as shown above. For identification, we assume that the conditional independence assumption (also known as "selection on observables") holds in both cases. More precisely, it is assumed that the distributions of the treatment status variables *w* and *s* are independent of the distribution of the potential outcome y_1 conditional on a vector of covariates *x*. That is, using the standard notation for conditional independence: $w, s \perp y_1/x$ (A1). By the propriety of conditional independence, assumption (A1) also implies that $w \perp y^*_1/x$ Therefore, we can use the same identification results and estimation procedures as in Diagne and Demont (2007) to identify and estimate the awareness-unrestricted and access-unrestricted population potential adoption parameters and their associated adoption gaps and population selection bias.

According to Diagne and Demont (2007), the procedure of the estimation of parametric ATE is based on the following equation which identifies *ATE(x)* and holds under the conditional independence assumption:

$$\text{ATE}(x) = \text{E}\ y^*_1/\text{x} = \text{E}\ (\text{y}/\text{x}, \text{d} = 1) \qquad (18)$$

where $d, y^*_1 = s, y_1$ when access to improved Pearl Millet seeds is the treatment variable, and $d, y^*_1 = w, s_1y_1$ when awareness is the treatment variable. The parametric estimation proceeds by specifying a model for the conditional expectation in the right-hand side of the second of equation (12), which involves the observed variables *y, x, and d*:

$$\text{E}\ (\text{y}|\text{x}, \text{d} = 1) = \text{g}\ (\text{x}, \beta) \qquad (19)$$

where g is a known (possibly non-linear) function of the vector of covariates *x,* and the unknown parameter vector which is to be estimated using standard least squares (LS) or maximum likelihood estimation (MLE) procedures using the observations (y_i, x_i) from the subsample of respondents which

are aware and have access to improved Pearl Millet seeds only, with y as the dependent variable and x as the vector of explanatory variables. With an estimated parameter β , the predicted values $g(x_i, \beta)$ are computed for all the observations i in the sample (including the observations in the non-access subsample). The ATE, ATT, and ATU are estimated by taking the average of the predicted $g(x_i, \beta)$ $i = 1, \cdots, n$ across the full sample (for ATE) and respective subsamples (for ATT and ATU).

$$ATE = \frac{1}{n}\sum_{i=1}^{n} g(x_i, \beta) \quad (20)$$

$$ATT = \frac{1}{n_1}\sum_{i=1}^{n} d_i g(x_i, \beta) \quad (21)$$

$$ATU = \frac{1}{n - n_1}\sum_{i=1}^{n} (1 - d_i) g(x_i, \beta) \quad (22)$$

where n is the sample size and $n_1 = \sum_{i=1}^{n} d_i$ is the sample number of treated. The effects of the determinants of adoption as measured by the K marginal effects of the K-dimensional vector of covariates x at a given point $\bar{x}$ are estimated as:

$$\frac{\partial E(\frac{y_1}{x})}{\partial x_k} = \frac{\partial g(x_0, \beta)}{\partial x_k} = K = 1, \dots \dots .., K \dots \dots \dots \dots \dots \dots \dots \dots \dots .. (23)$$

Where x_k is the K^{th} component of x and all the estimations were done using the statistical package Stata.

2.5.2. Propensity Score Matching (PSM)

The PSM model is used to assess welfare impacts of adopting improved technologies. The model uses propensity scores estimated from a Probit Model to find a suitable counterfactual in the non-adopters that matches the technology adopters. By so doing, it pairs treatment and non-treatment units with similar values on susceptibility (propensity) scores and discards all unmatched values. It is an alternative technique for estimating the effects of being subjected to particular circumstances (treatment) when a random assignment of treatments to the subjects is not feasible. This technique makes comparisons between adopters and non-adopters and draws conclusions based on those who have adopted improved technologies. Since it is impossible to know the outcomes for non-adopters of improved technologies if they adopted, and for adopters after adoption, the PSM is used to determine the average treatment effects on technology adopters (Samuel and Beza, 2019).

The PSM technique matches observations of adopters and non-adopters according to their propensity scores which are the probabilities of adopting improved technologies conditional on the covariates (Rosenbaum and Rubin, 1983).

The PSM is mathematically expressed as follows:

$$ATT = E\{H_1 - H_0|D\} = 1 \quad (18)$$

Where H_1 = value of the outcome for adopters of improved technologies, H_0 = value of the outcome for non-adopters of improved technology.

The problem with equation (18) is that $E\{\mathrm{H}_0|\mathrm{D} = 1\}$ is not observable. However, it is possible to estimate equation (18) by replacing $E\{\mathrm{H}_0|\mathrm{D} = 1\}$ with $E\{\mathrm{H}_0|\mathrm{D} = 0\}$ which is observable. However, adoption of the improved technologies is not randomly assigned to technology end-users but is a result of self-selection process and this replacement may lead to biased estimations of impacts as the adopter group is not statistically comparable to the non-adopters group. Estimation of equation (18) is only possible when E $\{H_0|D = 1\}$ = $E\{H_0|D = 0\}$, and this occurs when adoption is randomly assigned. In the absence of random assignment of adoption, PSM creates a counterfactual by modelling the probability of adoption conditional on observed characteristics, which are unaffected by adoption.

Therefore, controlling for observable characteristics (Z) assumes that technology adoption is random and conditioned on the observables. Hence, the impact estimate is given by:

$$ATT = E\{H_1|D = 1, P(Z)\} - E\{H_0|D = 0, P(Z)\} \quad (19)$$

Where H_1 = value of the outcome for adopters of the improved technologies, H_0 = value of the outcome for non-adopters of the improved technology, D = Adoption (1 for adopters of improved Millet varieties, 0 otherwise) and Z = vector of explanatory variables.

For estimation using a dataset and according to Khander *et al.* (2010), ATT is computed as follows:

$$ATT = \frac{1}{N_d}\left[\sum_{i\epsilon D_1} H_{1i} - \sum_{j\epsilon D_0} \omega(i,j)H_{0j}\right] \quad (20)$$

Where N stands for the number of adopters, $\omega(i, j)$ is a weighing function depending on the specific matching estimator.

In the light of the above, three analytical techniques namely i) *the Nearest Neighbour Matching* (NNM), ii) the *Kernel-based Matching* (KBM), and iii) *the Radius-based Matching (RBM)* are often used to present impact outcomes concurrently. In the NNM, individuals from adopter and non-adopter categories that are closest in terms of propensity scores are matched, the KBM technique is used when the weighted average of outcome variables for all individuals in the non-adopter category is used as counterfactual outcomes, giving importance to observations that provide better matches. RBM involves matching treatments and controls within predefined intervals of the treatment propensity score.

As an analytical model, the PSM

- ✓ allows one to design and analyze non-randomized variables so such as way they mimic the particular characteristics of randomized controlled variables;
- ✓ reduces the dimensionality of matching challenges given that the propensity scores is scalar, though in practice they are actually estimated.

However, it is recognized that the PSM has four major limitations as outlined below:

- ➢ the presence of confounding variables leading to possible biased in the result;
- ➢ only observations that fall in the common support region are used for the estimation;
- ➢ the Average Treatment Effect on the Treated (ATT) estimates may be biased due to violation of the condition independent assumption (CIA).
- ➢ The conditional independence assumption occurs when a given set of covariates or potential outcomes are independent of the treatment assignment.

2.5.3. The Double Hurdle Model (DHM)

The DHM identifies drivers and intensity of adoption using a truncated regression of non-zero observations (Cragg, 1971). The model assumes that technology end-users make consecutive decisions on the adoption and extent of using improved technologies with each inhibition constrained by technology end-user's key characteristics.

Different latent variables are used to classify each decision-making process; the first hurdle is the entry points of the dependent variable (Di) specified as:

$$D_i^* = aZ_i + U_i \qquad (10)$$

$$D_i = 1 \; if \; D_i^* > 1 \qquad (11)$$

$$D_i = 0 \; if \; D_i^* \leq 1 \qquad (12)$$

Where:

D_i = observed dependent variable which can take a value of 1 if a technology end-user adopts at least one improved millet variety and 0, if otherwise.

Z_i = Vectors of explanatory variables (end-user's socio-economic, institutional and technology-specific characteristics), a = vector of parameter estimates and U_i = independent Gauss-Markov error term. The second impediment uses a truncated model to determine the intensity of adoption as the proportion of farm land to be allocated to the improved technologies being adopted. It uses observations only from those technology end-users who indicated positive values on the use of technologies being promoted.

The intensity of adoption also known as intensity hurdle is estimated using a truncated model represented as follows:

$$Y_i^* = \beta X_i + V_i \qquad (13)$$

$$Y_i = \begin{cases} Y_i^* \; if \; Y_i > 0 \; and \; D_i^* > 0 \\ 0, \qquad otherwise \end{cases}$$

Where:

Yi = proportion of land allocated to improved Pearl Millet by farmer I;
Xi = vector of explanatory variables,

β = vector of parameter estimates and;

V_i = error term. The observed value of the proportion of land allocated to improved millet is therefore, given by:

$Y_i = D_i^* \, Y_i^*$ … . (14)

The error terms of the two decision models are distributed as follows:

$$\begin{cases} Ui \\ Vi \end{cases} \sim (0,1), (0, \sigma^2) \; \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots . (15)$$

Where:

U_i and V_i are usually assumed to be independently and normally distributed. Also, it is assumed that for each technology user, the decision on whether to adopt an improved technology and the extent of utilisation (intensity) are made independently. The model can be estimated by the following log-likelihood function:

$$LnL = \sum_0 ln\left[1 - \phi(Z_i\alpha)\Phi\left(\frac{\beta X_i}{\sigma}\right)\right] + \sum_+ ln\left[\phi(Z_i\alpha)\frac{1}{\sigma}\varphi\left(\frac{Y_i - \beta X_i}{\sigma}\right)\right] \qquad (16)$$

Where ϕ and Φ are the standard normal cumulative distribution function and density function, respectively. The function is estimated using the maximum likelihood estimation technique.

The DHM is combination of a truncated regression model and a Probit model. It is reduced to the Tobit model when the first hurdle mechanism is absent in the second hurdle. This can be seen in the log likelihood function when $\phi(Z_i\alpha) = 1$ or $\alpha = \frac{\beta}{\sigma}$ and $X = Z$ and hence, the decision about adoption and level of adoption are made all together. Choosing the appropriate model from both specifications necessitates using a likelihood ratio (LR) test.

In this context and as Green (2000) opined that this will consist of estimating the truncated regression, the Tobit and the Probit models and compute the LR-statistic as follows:

$$LR = -2[lnL_T - (lnL_P + lnL_{TR})] \sim \chi_k^2 \qquad (17)$$

Where L_T, L_P and L_{TR} stand for the likelihoods for the Tobit, the Probit and the truncated regression models respectively; and k is the number of explanatory variables in the equations.

The superiority of the DHM over the Tobit model (or decisions about adoption and extent of adoption are made in two different stages) is considered when the null hypothesis ($\alpha = \frac{\beta}{\sigma}$ vs $\alpha \neq \frac{\beta}{\sigma}$) is rejected i.e $LR > \chi_k^2$. In the DHM, a variable appearing in both equations may have opposite effects as summarised in **Table 3**.

Table 3: A priori expectations for application of Double Hurdle Model

Variables	Measurement	A priori expectations
Dependent variables		
Adoption	Binary: 1 if respondent reports having planted any of the improved millet varieties, 0 otherwise	
Adoption intensity	The proportion of area grown with improved millet varieties (ha)	
Outcome variables		
Yield	Quantity of millet harvested (Kg/ha)	
Gross margin	Profit from Millet production (Naira)	
Independent variables		
Socio-economic factors		
Age	Years	±
Education	Level of Education	+
Household size	Number of persons living and eating from same pot	+
Farm size (ha)	Hectare	+
Institutional factors		
Extension service delivery	Number of extension support visits	+
Membership of farming group	Dummy: 1=Yes, 0= otherwise	+
Access to credit	Dummy: 1 = Yes, 0= Otherwise	+
Technology factors		
High yield	1 = High yield, 0= otherwise	+
Early maturity	1= Yes, 0=Otherwise	+
Medium maturity	1= Yes, 0=Otherwise	+
Plant spacing (intra/inter rows)	1= Yes, 0=Otherwise	+
Timely weeding	1= Yes, 0=Otherwise	+
Thinning	1= Yes, 0=Otherwise	+
Fertilizer application	1= Yes, 0=Otherwise	+
Good food quality	1= Yes, 0=Otherwise	+
Striga resistance	1= Yes, 0=Otherwise	+

3.0. Key Results and Discussions

3.1. Socio-demographic profiles of respondents

Table 4 shows that slightly over half of the respondents; 60% for men and 51% for women who fall into the 36 - 60 bracket. The mean ages were 44 years and 38 years for men and women, respectively. About one third (31%) of the respondents were youths (18 - 35 age bracket); with 43% of them women and 30% men. Overall, respondents of the survey define themselves as farmers (70%), generally engaged in crop farming and livestock production activities. Most of the of the respondents; 93% for men and 84% for women, were married. A majority of the respondents (72%) do not belong to farming groups. At least three reason were advanced for this; ***i)*** *no real benefits of working in groups,* ***ii)*** *registration fees of Ten Thousand (10,000) Naira with CAC- Corporate Affairs Commission, considered to be high, and* ***iii)*** *recurrent use of groups for political reasons.* Forty-four per cent of male respondents reported having Islamic education; 20% and 22% attained secondary and tertiary education, respectively. Women's level of education in Islamic education was higher (60%) than that of men (43%), However, a lower proportion of women (6%) were reported to have attained tertiary education compared to men (24%). It should be noted that both girls and boys undergo Islamic education prior to any form of education across the seven States included in the survey. As a rule, mothers fortify this type of education for their female children right up to their matrimonial homes. In the course of their Islamic training, both boys and girls are taught how to read the Qur'an, how to pray, prophetic traditions (*Hadith)* and how to relate with members of their communities. Women also have a lot more time at all ages to solidify Islamic education in their families. This is a life-long self-assuring practice and core of the socio-cultural legacy that parents pass onto their children as they move onto adulthood.

Table 4: Socio-economic characteristics of respondents

Variables	Men (1,174) n	%	Women (93) n	%	Pooled (1,267) N	Percentage
Age of respondent (years)						
Less than 17	2	0	2	2	4	0
18-35	357	30	40	43	397	31
36-60	700	60	47	51	747	59
Above 60	115	10	4	4	119	10
Maximum	**85**		**90**			
Minimum	**15**		**15**			
Means	**44.22**		**38.74**			
SD	**12.96**		**13.39**			
Main occupation						
Casual Labourers	45	4	7	8	52	4
Farming	827	70	59	63	886	70
Government workers	157	13	3	3	160	13
Self- employed	108	9	17	18	125	10
Students	37	3	7	8	44	3
Marital status						
Divorced	3	0	2	2	5	1
Married	1092	93	78	84	1,170	92
Single	72	6	6	6	78	6
Widow/Widower	7	1	7	8	14	1
Belong to farming group						
Yes	330	28.	21	23	35	28
No	844	72	72	77	916	72
Types and levels of education						
Islamic education **Only**	507	43	56	60	563	44
Primary education	144	12	16	17	160	13
Secondary education	245	21	15	16	260	21
Tertiary education	278	24	6	6	284	22
Household size						
2-5 persons	275	23	27	29	302	24
6-10 persons	457	39	36	39	493	39
Above 10 persons	442	38	30	32	472	37
Maximum	**44**		**26**			
Minimum	**4**		**2**			
Means	**10.57**		**9.95**			
SD	**5.10**		**4.93**			
Farm size (ha)						
Less than 1	123	11	6	6	129	10
1-2 ha	742	63	74	80	816	64
3-5 ha	241	21	10	11	251	20
Above 5 ha	68	6	3	3	71	6
Maximum	**7.5**		**5**			
Minimum	**0.5**		**0.5**			
Means	**2.26**		**1.6**			
SD	**4.45**		**2.26**			

Household sizes for persons between 2-5 for women was higher (29%) than that for men (23%); this was the same (39%) for households having 6-10 persons for male and female respondents; this same trend was observed for all the States pooled together. Overall, 37% broken into 38% male and 32% female respondents reported household sizes above 10 persons. The key reason for household with between 2-5 persons being higher for women than men is that most divorced women take along their children (below 17 years) though divorce is rare in the study sites - only 1% in the case of this survey. Individuals who have divorced are allowed by the prescriptions of Islam to remarry after three months (Suratul Talaq 65:4). The divorce rate reported in this survey reflects a shared practice in the rural areas of the seven States included in the survey; this could be much higher in State capitals.

Farm sizes emerged to be similar for all respondents; 1-2ha, with maximum being 7.5ha and minimum being 0.5ha. Surprisingly, the proportion of female respondents reporting this range was 80% for female and 63% for male respondents. Male respondents dominated ownership of farm size above 2 hectares. As a general rule, women inherit land from their fathers, take care of lands bestowed to their under-aged male children and rarely sell land handed over to them through inheritance. These reasons account for the higher proportion of farm-sizes for women than men in the study States.

3.2. Annual cash earnings of respondents

Table 5 reveals that 36% of respondents reported annual cash earnings above One Hundred Thousand (100,000) Naira. In terms of distribution between male and female respondents, annual cash earnings are higher for female (41%) than male respondents (36%). Similarly, annual cash earnings between ₦51,000 - ₦100,000 for male respondents are lower (19%) than those of female respondents (26%). Higher annual cash earnings for female respondents can be explained by the fact that women engage in several cash income earning activities to raise money to support their young girls as they eventually move into matrimonial. These include rearing of sheep, goats and poultry, processing and sale of groundnut and groundnut-based products. Mean annual cash earnings was Sixty-three Thousand, Seven Hundred and Sixty-seven (63,767) Naira for men, and (62,597) Naira for women; with a difference of One Thousand. These findings point to the fact that Pearl Millet is more of a subsistence than a cash income earning crop. Livestock and poultry constitute safety nets which are gradually transformed into cash as the need arise.

With regards to the sources of annul cash earnings, those from cattle were higher (33%) than from all other sources of annual cash earning. This was followed by annual cash earnings from Pearl Millet

(13%) disaggregated to be 14% and 13%, for men and women, respectively. Other cereals notably rice, was higher for female respondents (23%) than for male respondents (8%). Unlike men, women are habitually engaged in several post-harvest operations and related activities of the rice value chain. In particular, these include parboiling, winnowing, threshing, destoning and road-side eateries.

Table 5: Levels and relative contributions of different sources of cash incomes (Naira)

Variables	**Men**		**Women**		**Pooled**	
	n	**%**	**n**	**%**	**N**	**%**
Less than 30,000	388	33	26	28	414	33
31,000-50,000	140	12	5	5	145	11
51,000-100,000	228	19	24	26	252	20
Above 100,000	418	36	38	41	456	36
Totals	**1,174**	**100**	**93**	**100**	**1,267**	**100**
Maximum	**207,200**		**160,000**			
Minimum	**40,000**		**40,000**			
Means	**63,767**		**62,597**			
SD	**85,386**		**75,379**			
Sources of annual cash incomes						
Pearl Millet	43,995,576	13	4,177,300	14	48,172,876	13
Sorghum	15,5032,95	5	1,547,400	5	17,050,695	5
Other cereals (rice, wheat, maize)	27,318,808	8	7,067,000	23	34,385,808	9
Sheep and goats	27,801,714	8	1,863,808	6	29.665,522	8
Cattle	111,593,016	33	7,544,000	24	119,137,016	33
Poultry (chickens, guinea fowl, etc.)	2,608,848	1	1,601,400	5	4,210,248	1
Groundnut (kernel and by-products)	12,341,430	4	1,020,620	3	13,362,050	4
Other Legumes (soybeans, cowpea)	7,897,808	2	1,303,100	4	9,200,908	3
Vegetables (onions, carrots, etc.)	1,398,750	0	5500	0	1,4042,50	0
Sesame	17,820,103	5	752,500	2	18,572,603	5
Salary from employment	26,844,994	8	1,260,928	4	28,105,922	8
Small-scale trading	31,119,198	9	1,990,940	6	33,110,138	9
Rents (farmland, business premises)	8,023,504	2	663,646	2	8,687,150	2
Totals	**334,267,044**	**100**	**30,798,142**	**100**	**365,065,186**	**100**

Minimum wage rate = ₦30,000 ($79/per month) I USD = ₦380 at the time of the survey

As annual cash earnings from cattle are not only the highest but most reliable source of cash earnings, underlying the importance of interactions between crops and livestock through cash earnings. While cattle bring a lot more money, earnings from sheep, goats and poultry are stable over the season and year.

3.3. Access to agricultural support services (extension and credit)

Table 6 reveals that, extension service support is rare privileges to Pearl Millet farmers; 83% of the respondents reported having no access to extension service support. Sporadic extension service support is provided to both male and female respondents generally by State ADPs, few farming groups to which respondents belong and fellow farmers. Most extension agents are men. most of whom are elderly full-grown making it difficult, if not impossible for women to have access to the rare extension service support often provided by the ADPs.

It is known that extension service support, if well delivered, can be a driving force to technology deployment and adoption. Also, dependable extension service support could neutralise the negative perception of insufficient education and/or sex differences which have potentials of hindering opportunities to raise awareness on agricultural technologies. It is no secret that extension service support to farmers across the study States has been, and will continue to be driven by donor projects. If the use of improved Pearl Millet varieties has to be enhanced, an inclusive extension delivery package needs to be designed and implemented. This package comprises theme-specific farmer trainings, visits to farm-fields, organization of field days and/or seed fairs, facilitation of access to quality seeds, farmer-centred demonstrations and contributions from the print and audio media

It was in this light that Mwangi and Kariuki, (2015) and Mignouna *et al. (*2011), reported direct relationships between technology adoption and access to appropriate extension messages/services. Similarly, access to credit for both farm and other purposes was quite low; 30% for men and 41 % for women **(Table 6).** It should be noted that beginning from the Farm Settlement Scheme in 1967 up to the Anchor Borrower's Program launched in 2015 (Tinuke *et al*., 2018; Coker *et al*., 2018) Pearl Millet has never explicitly been the focus of any government agricultural sector interventions at any level of administration in Nigeria.

Table 6: Access to extension service support and credit

Extension service support	Men		Women		Pooled	
	n	**%**	**n**	**%**	**N**	**%**
Frequency of extension services						
None	970	83	82	88	1,052	83
Monthly	7	1	-	-	7	1
Occasionally	101	9	4	4	105	7
Weekly	4	0	-	-	4	0
Only during the cropping season	92	7	7	8	99	9
N	**1,174**	**100**	**93**	**100**	**1,267**	**100**
Sources of extension service support						
Agricultural Development Program	140	72	19	85	159	74
Farmer cooperatives/groups	15	8	-	-	15	7
ICRISAT	5	3	1	5	6	3
IITA	1	1	-	-	1	0
NGOs	8	4	-	-	8	4
Private seed companies	3	2	-	-	3	1
Newspaper/radio	4	2	1	5	5	3
Other farmers	17	8	1	5	18	8
N	**193**	**100**	**22**	**100**	**215**	**100**
Access to credit (farm operations and others)						
Yes	111	30	12	41	123	31
No	256	70	17	59	273	69
N	**367**	**100**	**29**	**100**	**396**	**100**

3.4. Awareness of, and about Pearl Millet Varieties, Adoption and Dis-adoptions

3.4.1. Pearl Millet landraces across the States included in the Survey

The four improved Pearl Millet varieties are being promoted by the LCRI and other partners in the midst of a wide range of landraces known and being grown by respondents in all the States retained for the survey **(Table 7).**

Table 7: Local millet varieties planted by respondents during the 2019 cropping season

Name attributed to Pearl Millet varieties	States							Totals
	Bauchi	Jigawa	Kano	Katsina	Kebbi	Sokoto	Yobe	
Zango	14 (9)	24 (16)	41 (28)	41 (28)	16 (11)	13 (8)	-	149 (100)
Dan-digali	-	-	-	57 (97)		2 (3)	-	59(100)
Hansi	-	-	-	-	5 (26)	14 (74)	-	19 (100)
Lawur	20 (19)	41 (38)	22 (20)	8 (7)			17 (16)	108 (100)
Bahaushe	-	-	-	-	12 (26)	34 (74)	-	46 (100)
Dogon gero	91 (53)	-	6 (3)	-	32 (19)	43 (25)	-	172(100)
Gajeron gero	10 (15)	4 (6)	12 (18)	-	19 (29)	21 (32)	-	66 (100)
Buzubuzu	-	-	-	-	-	16 (100)	-	16(100)
Dan-Niger	-	-	-	-	5 (56)	4 (44)	-	9 (100)
Dan-salka	-	-	-	9 (18)	40 (82)	-	-	49 (100)
Dan-dagale	-	-	-	87 (49)	-	3(1)	89 (50)	179 (100)
Dan-Karanjo	-	-	39 (98)	-	1 (2)	-	-	40 (100)
Dan-hausa	5 (22)	-	-	1 (4)	14 (61)	3 (13)	-	23 (100)
Dan-wuri	1 (14)	-	5 (72)	-	1 (14)	-	-	7 (100)
Mai-Kujiya	-	-	-	-	7 (100)	-	-	7 (100)
Masangari	-	39 (100)	-	-	-	-	-	39 (100)
Wami	-	13 (93)	-	1 (7)	-	-	-	14 (100)
Gidani		1 (1)	1 (1)	-	4 (2)	3(2)	152 (94)	161 (100)
Dan-Gombe	1 (17)	-	1 (17)	1 (17)	-	3 (49)	-	6 (100)
Dan-janga	-	-	-	1 (14)	1 (14)	4 (58)	1 (14)	7 (100)
Zabo	1 (4)	6 (26)	13 (58)	-	1 (4)	1 (4)	1 (4)	23 (100)
Dauro	1 (5)	-	6 (32)	3 (16)	4 (21)	5 (26)	-	19 (100)
Totals	**155 (12)**	**143 (11)**	**149 (11)**	**211 (17)**	**164 (13)**	**171 (14)**	**262 (22)**	**1,255 (100)**

While varietal identification was a challenging task to the field team, attributing names to articles (including crop varieties/seeds) by ethnic/tribal groups is a common process reflecting a typical example of processes of acculturation. In the case of crops varieties, this naming hardly differentiates between landraces and improved varieties; later support from in tidying up with plant breeders has proven to be helpful during and after socio-economic surveys where they are not intensively involved.

Both landraces and improved varieties described as local by the different tribal/ethnic groups take different names depending on their *origin, tribe, grain color, plant height, growth behavior and physical appearance* **(Table 8).**

Table 8: Patterns of Designation of Pearl Millet Landraces across in the survey States

S/N	Origin of variety	Tribe/ethnic group	Grain colour	Name of Individual	Plant height	Growth behaviour	Physical presentation
1	Wamai	Maiwa	Bakin Gero	Tamangaji	Mai Zango	Gargasa	Gero Maidogon Kai
2	Dan Gombe	Bindir	Farin Gero	Aloka	Zango Gero	Matsangari	Gero Maigashi
3	Wami	Dan Hausa	-	Damangagaji	Zango	Dan Taki	Gero Tsakatsaki
4	Dundari	Lawur	-	Geron Ada	Dogon Gero	Dan Gajaga	Idon Hawainiya
5	Dongo Gero	Bahaushe Gero	-	Karanjau	Gajere Gero	Makeri	Mai Kwalli
6	Dan Arewa	Gero Lawur	-	Yan Karanjao	Mai Dogon Kai	Dan Wuri	Moya
7	Dan Gombe	Gurjiyan Fulani	-	Dan Digali	Gezyara	Yarwuri	Soso
9	Babade	Buzaaye	-	-	-	-	Karamin Hannu
10	Dan Bade	Geron Hausa	-	-	-	-	Mai Kogiya
11	Dan Bidima	Mardau	-	-	-	-	Wuyan Bajimi
12	Dan Borno	-	-	-	-	-	Buzu buzu
13	Dan Buduma	-	-	-	-	-	Wuyan Bijimi
14	Dan Marke	-	-	-	-	-	Gwagwa
15	Danbade	-	-	-	-	-	-
16	Dan Karanjao	-	-	-	-	-	-
17	Geron Hausa	-	-	-	-	-	-
18	Dan Sara	-	-	-	-	-	-
19	Dansara	-	-	-	-	-	-
20	Dan Niger	-	-	-	-	-	-
21	Dan Salka	-	-	-	-	-	-
22	Gera Gera	-	-	-	-	-	-
23	Dan Dagali	-	-	-	-	-	-
24	Yakoro	-	-	-	-	-	-
25	Dambo	-	-	-	-	-	-
26	Salga	-	-	-	-	-	-
27	Dauro	-	-	-	-	-	-
28	Dan Tumfure	-	-	-	-	-	-

3.4.2. Awareness of, and about Pearl Millet Technologies.

Awareness about Pearl Millet technologies in this study refers to the extent to which respondents have *knowledge* of (or have been *exposed*) to Pearl Millet technologies. This is different from the adoption of these technologies which refers to the effective use of the technologies being promoted by individual respondents. As shown in **Table 9**, knowledge of, and information about improved Pearl Millet varietal technologies is 28% (360 out of 1,267 respondents). Badolo *et al.* (2013) reported a much higher awareness rate of 43% for SOSAT-C88 and 24% for Ex-Borno. Seventy-four per cent of respondents mentioned the ADPs as main source of information on Pearl Millet followed by other farmers (friends, neighbours, etc.). Awareness is concentrated within respondents aged 36–60 years where 19% of them reported being aware of improved Pearl Millet varieties **(Table 9).** Awareness of SOSAT-C88, SUPER-SOSAT and JIRANI was more rampant; 17%, 7% and 2%, respectively.

Table 9: Awareness of, and about Pear Millet Technologies

Awareness	**SOSAT-C88**		**SUPER-SOSAT**		**JIRANI**		**LCIC9702**		**Pooled**	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**N**	**%**
Sex										
Men	223	17	84	7	33	2	10	1	350	27
Women	6	1	3	0	1	0	-	-	10	1
N	**229**	**17**	**87**	**7**	**34**	**3**	**10**	**1**	**360**	**28**
Age groups (years)										
18-35	65	5	19	1	5	-	-	-	89	6
36-60	142	11	60	5	27	2	8	1	237	19
Above 60	22	2	8	1	2	0	2	0	34	3
N	**229**	**18**	**87**	**7**	**34**	**2**	**10**	**1**	**360**	**28**

In terms of distribution of awareness of, and about the varietal technologies in each by State, **Table 10** shows that awareness was concentrated in Kano State, with the worst case occurring in Bauchi Jigawa, Yobe and Kebbi States. The relative higher awareness rate in Kano could be explained not only by higher interventions of many research for development partners (demonstrations, field days, interactions with seed companies, etc.) but also by higher levels of interactions between research staff and a range of agricultural sector partners with interest in Pearl Millet. Many seed companies are located in State capitals especially Kano city.

Table 10: Awareness of, and about Pear Millet Technologies by States

Millet Varieties	State							Pooled
	Bauchi	Jigawa	Kano	Katsina	Yobe	Sokoto	Kebbi	
SOSAT-C88	19 (1)	13(1)	101(8)	30(2)	9 (1)	33 (3)	14 (2)	229 (18)
SUPER-SOSAT	7 (1)	9 (1)	49 (4)	2 (0)	5 (0)	10 (1)	5 (0)	87 (7)
JIRANI	1 (0)	2 (0)	12 (2)	4 (0)	5 (0)	8 (1)	2 (0)	34 (3)
LCIC9702	2 (0)	1 (0)	4 (0)	1 (0)	-	2 (0)	-	10 (0)
N	**29 (2)**	**25 (2)**	**166 (14)**	**10 (2)**	**19 (1)**	**53 (5)**	**21 (2)**	**360 (28)**

N.B.: Figures in parentheses are percentages

3.4.3. Sources of initial improved seeds of Pearl Millet

Respondents reported that Agricultural Development Project/Programs (ADPs) was the source of initial improved seeds of SOSAT-C88 and SUPER-SOSAT in Jigawa (38%) and Katsina (50%). A wide range of sources from both the formal and informal seed sources were also reported to have contributed to making available initial sources of both SOSAT-C88 and SUPER-SOSAT. Based on the absolute values, these included relatives of the respondent, other farmers, and agro dealers; this was similar for the SUPER-SOSAT **(Table 11 and 12)**.

Table 11: Sources of initial improved seeds of SOSAT-C88 according to States

Initial source of improved seeds in the States	States							Pooled	
	Bauchi	Jigawa	Kano	Katsina	Kebbi	Sokoto	Yobe	N	%
Formal sources									
ADP	14(16)	34 (38)	21 (23)	7(8)	3(3)	2(2)	9(10)	90	100
Research institutes (IAR, LCRI)	-	2 (67)	1 (33)	-	-	-	-	3	100
Seed companies	5(100)	-	-	-	-	-	-	5	100
ICRISAT, Nigeria	-	-	2(100)	-	-	-	-	2	100
NGOs	-	1(13)	3(37)	-	3(37)	1(13)	-	8	100
Agro-dealers	5 (50)	-	2(20)	-	1(10)	2(20)	-	10	100
Informal sources									
Community leaders	-	-	2 (67)	-	1(33)	-	-	3	100
Other farmers	3 (22)	5 (36)	2(14)		2(14)	2(14)	-	14	
Relatives	-	14 (54)	6(23)	5(19)	-	-	1(14)	26	100
CBOs	2(33)	3(50)	1(17)	-	-	-	-	6	100
Owned sources	-	2 (17)	-	10(83)	-	-	-	12	100

State ADP are considered to be part of the Nigerian formal seed system. On-farm trials for the release of these varieties are reported to have been conducted in these States with the participation of the ADPs of Katsina, Kano, Kebbi and Jigawa. Also, some of the respondents in these States hosted demonstrations of both phases of the HOPE Project and benefited from the distribution of mini-packs destined for the dissemination of improved seeds of both sorghum and Peart Millet. A number of the respondents also benefited from the Integrated Striga and Soil Fertility Management (ISSFM) technology. They also participated in field days and seed fairs organised by the project. As routine partners of IAR, ICRISAT and LCRI on most projects, it is not surprising that the ADPs are cited as leading source of initial seeds of improved Pearl Millet varieties of the crops being promoted by development partners in Nigeria.

Table 12: Sources of initial improved seeds of SUPER-SOSAT according to States

Initial source of improved seeds in the States	**Survey States**							**Pooled**	
	Bauchi	**Jigawa**	**Kano**	**Katsina**	**Kebbi**	**Sokoto**	**Yobe**	**N**	**%**
Formal sources									
ADP	5(25)	2(10)	2(10)	10(50)	1(5)	-	-	20	100
Research institutes (IAR, LCRI)	-	-	-	-	-	-	-	-	-
Seed companies	1(50)	1(50)	-	-	-	-	-	2	100
ICRISAT	-	1(33)	-	-	-	-	2(67)	3	100
NGOs	-	5(71)	-	2(29)	-	-	-	7	100
Agro-dealers	-	3(25)	2 (17)	6(50)	1(8)	-	-	12	100
Informal sources									
Community leaders	-	-	-	-	-	-	-	-	-
Other farmers	-	6(75)	-	2(25)	-	-	-	8	100
Relatives	-	9(70)	2(15)	2(15)	-	-	-	13	100
CBOs	2	-	-	-	-	-	-	2	100
Owned	-	2 (17)	-	10(83)	-	-	-	12	100

The insignificant role of private seed companies, LCRI and IAR underscores the little or no responsiveness being devoted to the crop by the formal seed system. This may be a reflection of non-functional linkages between the LCRI which has the mandate for the development and promotion of Pearl Millet in Nigeria. Formal links between the LCRI and seed sector actors in Nigeria is patchy and only triggered through donor-funded projects; examples being the HOPE and AVISA projects. This compels Pearl Millet farmers to be tempted to clean and recuperate seeds from season to season.

SOSAT-C88, for example, released in 2000 has remained the known and eventually preferred Pearl Millet variety over twenty-one years (2000-2020); this is similar to SUPER-SOSAT which was released in 2011. In the States included in this survey, the contribution of the ADP in production, distribution and marketing is not sufficiently impactful. However, the giving out of Pearl Millet improved varieties by relatives, other farmers, agro-dealers and NGOs in the States points to the fact that the use of improved varieties could be revived.

Overall, results of awareness, adoption, dis-adoption reveal a wide range of factors crucial in varietal development and promotion. Awareness of, and information about improved Pearl Millet varietal technologies, and subsequent adoption remains low after nearly two decades of concerted efforts to stimulate the four improved Pearl Millet varieties by a cohort of research and development partners. Despite end-users' perceptions of high yield, sustaining the use of improved Pearl Millet varieties is constrained by challenges of difficult access to appropriate classes of seeds, recurrent appearance of striga infestation and late maturity, as well as the conviction of being satisfied with prevailing landraces varieties. As reiterated by Adesina and Baidu-Forson (1995), technology promotion efforts alone are unlikely to enhance adoption of improved crop varieties unless desired traits of end-users are visibly evident; these traits do not yet seem to be sufficiently convincing to respondents engaged in Pearl Millet farming in the States targeted for this survey.

3.4.4. Status of adoption of Pearl Millet technologies.

Varietal technologies consist of **improved crop varieties** which convey inherent ingredients such as higher potential grain yields, ability to respond to other inputs such as fertilizers, better tolerance to stresses (drought, diseases and pests), shorter maturity, better tastes, higher nutrient contents, better quality and/or quantity of fodder. Non-varietal technologies comprise management practices required for improved crop varieties to fully reveal their inherent genetic potentials. These practices include: using the most suitable soils, respecting technical guidelines on weeding operations, pesticide and techniques of application, adherence to fertilizer doses and techniques of application, etc. Due to resounding reasons, most studies on technology adoption usually focused on varietal technologies especially those of Kaliba *et al*. (2018), Obayelu and Ajayi (2018), Oyinbo *et al.* (2019) and Manda *et al.* (2020). and conservation agriculture (Arslan *et al.*, 2013; Chinseu *et al.*, 2019). Drawing inspiration from early studies of Griliches (1957), cross-sectional studies on the adoption of varietal

technologies have consistently attributed farmers' decisions to the alleged benefits of improved technologies (higher yields, tastier food and better market values).

Despite this distinction, a very thin line exists between Pearl Millet varietal and non-varietal technologies, the four core non-varietal technologies that contribute to yield increases namely, *thinning, spacing, fertilizer application and timely weeding* are considered to be integral parts of the common practice of Pearl Millet cultivation over several years in the study States. Therefore, in the context of this survey, a Pearl Millet technology is said to have been adopted when any of the four **improved varieties** being promoted (SOSAT-C88, SUPER-SOSAT, JIRANI and LCIC9702) was planted during the 2019 cropping season. In addition, the application of any of the recommended crop management practices was considered to be an added advantage to the respondent.

As summarised in **Table 13**, adoption of Pearl Millet technologies was very low - only 18%. The trend is similar for men and women as well as each of the varietal technologies being promoted; 11% for men and 2% for women for SOSAT-C88. Badolo *et al.* (2013) disaggregated by adoption by variety and reported 37% for SOSAT-C88. **Table 14** shows that the adoption of Pearl Millet technologies was concentrated within the 36-60 year age group which recorded an adoption rate of 11% and respondents above 60 years being the worst with a global adoption rate of only 2%. Again, SOSAT-C88 was the varietal technology most adopted for all age-groups.

Table 13: Adoption of Pearl Millet technologies by sex of respondents

Varieties	**Men**		**Women**		**Pooled**	
	n	**%**	**n**	**%**	**N**	**%**
SOSAT-C88	141	11	19	2	160	13
SUPER-SOSAT	51	4	4	-	55	4
JIRANI	12	1	-	-	12	1
LCIC9702	3	-	-	-	3	-
Overall rate	**207**	**16**	**23**	**2**	**230**	**18**

Table 14: Adoption rate of Pearl Millet technologies by age groups of respondents

Age groups	SOSAT-C88		SUPER-SOSAT		JIRANI		LCIC9702		Pooled	
	n	%	n	%	n	%	n	%	N	%
18-35	51	4	9	1	3	-	-	-	63	5
36-60	98	8	35	3	9	1	2	-	144	11
above 60	11	1	11	1	-	-	1	-	23	2
Adoption Rate	**160**	**13**	**55**	**4**	**12**	**1**	**3**	**-**	**230**	**18**

Adoption rates were found to be generally low in all the States enlisted in the survey **(Table 14)** with 13% overall rate for SOSAT-C88-388 which is also a popular varietal technology in all the seven States of the survey. With respect to the adoption of Peal Millet crop management or agronomic practices, **Table 15** reveals that respondents are quite familiar with these practices, arising from several years of experience in planting and nurturing of the crop. This is the case with thinning, timely removal of diseased plants and striga after emergence, etc.

Table 15: Adoption of Pearl Millet Technologies by survey States

Adoption	Survey State							Pooled
	Bauchi	**Jigawa**	**Kano**	**Katsina**	**Kebbi**	**Sokoto**	**Yobe**	
SOSAT-C88	28 (2)	54 (4)	30 (2)	22 (2)	9 (1)	7 (1)	10 (1)	160(13)
SUPER-SOSAT	7 (1)	23 (2)	6 (0)	15 (1)	2 (0)	-	2 (0)	55 (4)
JIRANI	-	2 (0)	10 (1)	-	-	-	-	12 (1)
LCIC9702	-	-	-	2 (0)	-	1 (0)	-	3 (0)
Adoption rates	**35 (3)**	**79 (6)**	**46 (3)**	**39 (3)**	**11 (1)**	**8 (1)**	**12 (1)**	230 (18)

The combined skills and knowledge of these crop management practices with appropriate extension support should lead to better yields. Compared to other varietal technologies, lower insufficient use of organic matter was observed while chemical fertilizer is rarely applied. Tijani *et al*. (2014) also reported that 33.8% and 11.1% of Pearl Millet farmers use lower than recommended rates of fertilizers and herbicides, respectively, in Borno State due to their untimely availability. Like improved Pearl Millet varietal technologies, (improved seeds), fertilizers are generally not available when required, and even when available, there are often concerns over adulteration. Similarly, spacing of 75cm x 30cm is an age-old farming practice where crops are usually planted in rows spaced at 75cm in Northern Nigeria; both tractor or animal drawn ridgers in most of the States are fixed at widths of 75cm between rows (Ajeigbe *et al.*, 2016). Weeding is equally a common practice amongst sorghum and millet farmers across the States included in the study.

Table 16: Adoption of Pearl Millet crop management practices by respondents

Recommended agronomic practices	N	%
• Apply 4 bags of 50 kg NPK per hectare at planting	388	31
• Plant at 30 cm x 75 cm with 6-8 seeds hole	521	41
• Before planting, dress seeds with apron plus: 5kg per sachet/ha	224	18
• Carry out third weeding to minimize Striga, if required	574	45
• Thin to 2 plants per hill after germination or during first weeding	585	46
• Apply Farm Yard Manure (FYM): 2 tons/ha during harrowing	781	62
• Carry out first weeding at 3-5 weeks after planting	1,094	86
• Carry out second weeding at 6-8 weeks after planting	948	75
• Allow harvested millet stands to dry on farm fields	1,093	86
• Only thresh panicles when completely dry at least 12-15 weeks	938	74
• Systematically remove diseased plants including Striga	653	52
• Apply small doses of NPK 15-15-15 (3 grams/hole) after thinning	494	39
• Apply and cover 3 grams hole of Urea fertilizer between stands	451	36
• Plant/sow when rains are fully established	966	76
• Apply pre-emergence herbicide after harrowing and/or planting	296	23
• Use traction animals or tractor for harrowing and or ploughing	1,007	80

3.4.5. Intensity of adoption of improved Pearl Millet technologies

A corresponding feature of technology adoption is the *intensity of adoption* which is the **proportion** of cultivated land area on which any of the improved varieties of Pearl Millet was planted during the 2019 cropping season. Expressed as a proportion or percentage, it is the **extent** to which varietal technology adopters have used or are using improved technologies. Both adoption rates and intensity of adoption provide a snapshot of how technologies have been incorporated into crop farming systems. As shown in **Table 17**, adopters of SUPER-SOSAT planted this variety on approximately 60% of their land, while those who adopted SOSAT-C88 planted it on about 54% of their cultivated land.

Table 17: Intensity of adoption of Pearl Millet Varietal Technologies

Improved Pearl Millet variety	Farm size (ha)	Total cultivated area (ha)	Adoption intensity (%)
9702 (LCIC MV 2)	1.19	2.26	49
JIRANI (LCIC MV 4)	1.33	2.21	55
SOSAT-C88 (LCIC MV 1)	1.42	2.41	54
SUPPOER-SOSAT (LCIC MV 3)	1.18	2.3	60

3.4.6. Comprehensive adoption scenarios for Pearl Millet technologies

Concerned about low the awareness and adoption rates of 28% and 18%, respectively, the Average Treatment Effect (ATE) was used to estimate population adoption rates and adoption gap considering that commonly used adoption estimators suffer biases specifically non-exposure and selection biases as diligently summarised by (Diagne and Demont, 2007). In effect, the first source of selection bias emanates from respondent's self-selection implying that exposure to technologies can be attributed to the respondent's choice. The second source of selection bias is the fact that some respondents particularly lead farmers (innovators), and village/communities could already have been exposed to technologies through research operations (on-farm trials, demonstration, field days, etc.). In this case, the adoption rate among this group of respondents is likely to over represent the true population adoption rate.

Against this background, approaches used in the estimation of adoption rates often result in inconsistent adoption estimates even if established from a randomly selected sample. The non-exposure bias results from the fact that potential end-users of technologies who have not had the opportunities to be exposed to new technologies cannot adopt them resulting in *population* adoption rates frequently underestimated. **Table 18** shows that a potential adoption rate of 45.3%, decomposed into four components i) an adoption rate of 13.8% under a scenario where potential beneficiaries are exposed to Pearl Millet technologies, ii) an adoption rate of 22.7% amongst respondents not exposed to Pearl Millet technologies, iii) actual adoption rate estimated from the survey 18%, and iv) adoption gaps of 27.3%. Awareness and access to improved seeds are two major determinants of the Pearl Millet technology adoption in the States targeted for the study. The absence of sustained awareness and access to improved seeds considerably play down the potential adoption rate. The corresponding estimate of the adoption gap of 27.3% resulting from non-availability[1] of seeds can be which is the unsatisfied demand for improved seeds. This suggests that there is scope for scaling out the production, distribution and marketing of improved Pearl Millet varieties.

[1] Assuming the main challenge is the availability of quality seeds and not affordability

Table 18: Pearl Millet adoption scenarios

Variables	N	%	Parameters without constrained awareness			Parameters with unconstrained awareness with access to improved seeds		
			Coeff.	Robust Std err	z-value	Coeff.	Robust Std err	z-value
Population adoption rate	574	45.3	1,168.64**	42.50	23.32	1,206.78**	42.50	57.50
Adoption rate among respondents exposed and having access to improved seeds	175	13.8	1,133.14**	17.09	30.56	1,125.82**	19.66	66.43
Adoption rate among non-exposed respondent without access to improved seeds	288	22.7	1,121.97**	18.85	12.81	1,134.49**	16.95	23.97
Observed adoption rate	230	18.0	1,133.14**	17.09	66.3	1,125.82**	19.66	57.26
Adoption gap	344	27.3	35.5	33.25		80.96	25.55	

Note ** is significant at 5%

Also, the use of the ATE framework enable us to determine yield difference due to unconstrained awareness of improved Pearl Millet varieties. Under this circumstance, the potential yield is 1,168kg/ha though yield actually recorded is 1,133.14 kg/ha resulting in a yield differences of 35.5kg/ha which is positive and statistically significant at 5%. In a similar vein, with awareness and access to improved seeds unconstrained, the potential yield is 1,206.78kg/ha though yield actually recorded is 1,125.82kg/ha resulting in a yield difference of 80.96kg/ha which is also positive and statistically significant at 5%. These results corroborate those of Ogutu *et al.* (2020) who reported a lower adoption rate of 54% against a potential adoption rate of 62% for NERICA rice in northern Nigeria.

3.4.7. Reasons for adoption of the Pearl Millet technologies being promoted

Respondents who planted improved Pearl Millet varieties during the 2019 cropping season were further probed to provide the major reason(s) for their decisions to adopt. Results summarised in **Table 19** revealed reasons for the adoption of Pearl Millet technologies vary from early maturity

(66%) to it high yielding potentials (11%). Unfortunately, adoption was not directly or indirectly linked to the actual or potential market value of the Pearl Millet varieties being promoted. Tijani *et al.* (2014) reported similar adoption trends of Pearl Millet technologies in Borno State; respondents reported 33% for early maturity, 21% for high yield, 19% for disease resistance, 18% for drought resistance and 6% for good food quality.

Table 19: Reasons for adoption of Pearl Millet varieties being promoted

Reason for adoption	Frequency	Percentage
• Drought resistance	8	4
• Early maturing	136	66
• Good food quality	6	3
• High yielding	22	11
• Medium maturing	20	10
• *Striga* resistant	4	2
• Resistance to pests/diseases	5	2
• Others	4	2
Total	**205**	**100**

The crushing reason given by respondents for adopting improved Pearl Millet varieties were further substantiated by their positive features as summarised in **Table 20.** Again, these positive features underline early maturity (38%), medium maturity (18%) and high yielding materials (16%).

Table 20: Positive features of improved Pearl Millet varieties according to respondents

Features	Men		Women		Pooled	
	n	**%**	**n**	**%**	**N**	**%**
Early maturity	457	39	29	31	486	38
Medium maturity	226	19	7	8	233	18
High yielding	197	17	8	9	205	16
Striga resistance	22	2	3	3	25	2
Pest/disease resistance	68	6	3	3	71	6
Good food quality	178	15	4	4	182	14
Drought resistance	26	2	39	42	65	5
N	**1174**	**100**	**93**	**100**	**1267**	**100**

3.4.8. Dis-adoption from the sustained use of improved Pearl Millet varietal technologies

Dis-adoption, also referred to as 'discontinuance or withdrawal' was defined by Rogers (2003) as a technology end-user's decision to reject a technology after having used or adopted it. Technically, dis-adoption can either be a *replacement and complete suspension*. As recapitulated by Chinseu1 *et al.* (2019), replacement dis-adoption occurs when technology end-users substitute technologies with others while suspension dis-adoption occurs when technology end-users are dissatisfied with conditions of accessing and using technologies. In both cases, dis-adoption is largely linked to dissatisfaction with the **alleged attributes** of technologies. These could include complexity of the technology, suitability with felt needs, fitness with beliefs, personal experiences and difficult enabling contexts. **Table 21** reveals an overall dis-adoption rate of 7% of the Pearl Millet technologies adopted by respondents; these vary from 6% for SOSAT-C88 and SUPER-SOSAT reported from the survey; and LCIC9702 29%.

Table 21: Dis-adoption rates and reasons for dis-adoption of improved Millet technologies

Variables	**SOSAT-C88**		**SUPER-SOSAT**		**JIRANI**		**LCIC9702**		**Pooled**	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**N**	**%**
Adopters	160	13	55	4	12	1	3	-	230	18
Dis-adoption	11	6	4	6	1	7	2	29	18	7
Reasons for dis-adoption										
Insufficient capital	3	27	-	-	-	-	1	100	4	22
Unavailability of seeds	3	27	2	50	1	50	-	-	6	33
Susceptibility to diseases	1	9	-	-	-	-	-	-	1	6
Satisfied with present varieties (mostly local)	1	9	2	50	1	50	-	-	4	22
Required special skills	3	28	-	-	-	-	-	-	3	17
Totals	**11**	**100**	**4**	**100**	**2**	**100**	**1**	**100**	**18**	**100**

Also, the reasons for dis-adoption as provided in **Table 21** above which varied from *difficult access to improved seeds* (33%), being *satisfied with existing seeds* (22% - most of which are local varieties) and *need for special skills if improved Pearl Millet technologies were adopted* (17%). As a result,

dis-adoption of improved Pearl Millet technologies could be linked to both replacement (return to the planting of other varieties, most of them being local varieties as presented below) and dissatisfaction with the performance of the varieties being promoted by the LCRI and development partners of Nigeria

3.4.9. Constraints to adoption of Pearl Millet improved technologies.

The adoption of Pearl Millet varieties was reported being constrained by a series of factors as shown in **Table 22.**

Table 22: Negative features of improved Pearl Millet varieties being promoted and constraints to technology adoption

Variables	Men		Women		Pooled	
	n	**%**	**n**	**%**	**N**	**%**
Negative features						
Late maturity	429	37	35	38	464	37
Striga infestation	333	28	34	37	367	29
Poor food quality	167	14	14	15	181	14
Pests/disease pressure	245	21	10	11	255	20
N	**1174**	**100**	**93**	**100**	**1267**	**100**
Production constraints						
Lack of information	258	26	32	41	290	27
High cost of inputs	307	31	18	23	325	30
Unavailability of seeds	419	43	28	36	455	43
N	**984**	**100**	**78**	**100**	**1070**	**100**

The adoption, dis-adoption and reasons for dis-adoption align with a diversity of socio-institutional contexts already undertaken by several authors particularly those of Mwangi and Kariuki (2015), Dhraief (2018), Muhammad (2015), Mbavai *et al.* (2015), Adzawla *et al*. (2016), Melesse (2015), Ndjeuka *et al.* (2013), Ndjeuga *et al.* (2011), Ndjeuga *et al. (*2012) and Vabi *et al.* (2018). Furthermore, Roger (2003), posited that end-users of technologies pass through five key stages namely 1) awareness/knowledge, 2) persuasion, 3) decision, 4) implementation, and 5) confirmation. The 28% level of awareness of Pearl Millet varieties revealed by this survey suggest that the bulk of respondents are either still at the awareness/knowledge stage or that the varieties being promoted do not really meet end-user requirements. The low levels of awareness have been translated into low adoption rates compared to those reported by Ndjeunga (2011) who reported an adoption rate of 47%.

3.4.10. Opportunities for women in the Pearl Millet value chain

Enhancing a sex or gender perspective is particularly important in a context of a search for relevance of research outputs and accountability. In the light of this a thoughtful methodology was implemented for the Pearl Millet survey in Nigeria. Beginning with a community census, out of a total of 9,289 Pearl Millet potential respondents, a total of 442 (5%) women were identified and 8,847 of them were men, despite cautious efforts to search and interview women. In the final sample of 1,267 respondents, only 93 (7%) of them were women. The sample size of women in the survey can partially be explained by the very diffident participation of women in Pearl Millet production **(Box 1)** manifested in the villages/communities where data/information was collected.

Box 1: Science-based knowledge is gender neutral amongst Muslims.

…My lord! increase me in Knowledge (Q20; verse 114)
Having knowledge should not be a reason for being arrogant in fact, having more knowledge about ourselves and the world makes us fell humble before the greatness of creation of Allah (Subuhannahu wa ta'ala).

"And likewise of men and Ad-Dawabb [moving (living) creatures, beasts], and cattle, are of various colours. It is only those who have knowledge among His slaves that fear Allah. Verily, Allah is All-Mighty, Oft-Forgiving. (Q35, verse 28)

The prophet (peace be upon him) said seeking knowledge is an obligation on every Muslim'' (Bayhaqiyya and Ahmad).

The above saying of the prophet as related above does not restrict anyone from obtaining knowledge of the world be it male or female instead it encourages both parties to seek for beneficial knowledge for this world and hereafter.

The specific outcomes of women's participation in the survey are summarised below:

- **Variety specific awareness rate for Pearl Millet technologies was 17% for men (SOSAT-C88), 1% for women** (SOSAT-C88) and 1% for LCIC9702 - men and 0% - women for LCIC9702.

- **77% of women do not belong to farming groups,** like both men and women jointly explained, this is linked to past experiences of using farming groups as political tools, the perception of the cost of registration with relevant Nigerian authorities being expensive, and not having seen concrete support coming from belonging to farming groups.

- **Women's level of education in Islamic education was higher (60%) than that of men (43%).** Both girls and boys undergo Islamic education prior to any form of education. As a rule, mothers fortify this type of education for their female children up to their matrimonial homes. Both boys and girls are taught how to read the Qur'an, how to pray, prophetic traditions (*Hadith)* and how to relate with members of their communities. Women also have a lot more time at all ages to solidify this type of education in their families. This is a life-long self-assuring practice and core of the socio-cultural legacy that parents pass onto their children as they move onto adulthood.

- **Household sizes for persons between 2-5 for women was higher (29%) than that for men (23%);** this was the same (39%) for households having 6-10 persons for male and female respondents. Most divorced women take along their children.

- **Annual cash earnings are higher for female (41%) than male respondents (36%).** Similarly, annual cash earnings between ₦51,000 - ₦100,000 for male respondents are lower (19%) than those of female respondents (26%). This could be explained by the fact that women engage in several cash income earning activities to raise money to support their young girls as they eventually move into matrimonial. These include rearing of sheep, goats and poultry, processing and sale of groundnut and groundnut-based products. Unlike men, women are habitually engaged in several post-harvest operations and related activities of the rice value chain. These include parboiling, winnowing, threshing, destoning and road-side eateries.

- T**he adoption rate of Pearl Millet technologies was 18%; 11% for men and 1% for women** for SOSAT-C88 being the best and LCIC9702 was the worst. The adoption of Pearl Millet technologies was concentrated within the 36-60 year age group which recorded an adoption rate of 11% and respondents above 60 years being the worst with an overall adoption rate of only 2%.

- **The wide range of food from Pearl Millet is a pointer to enhancing women's role.** Only 14% (175 out of 1,267) respondents reported selling Pearl Millet. This is good news from a food and nutrition security perspective considering that Pearl Millet has a higher crude protein content than other cereals regularly consumed in the States included in the survey. It also contains high amounts of dietary fibre, Vitamin B6, folic and oxalic acids and fatty acids and vitamin E especially in the bran. It also contains minerals: iron, magnesium, phosphorous, potassium, zinc, calcium and copper. Also, the popular list of options for family meals in the States included in the survey are huge opportunities for healthies Pearl Millet-based foods notably ***kunu***, ***masa fura***, ***Ogi***, ***burukutu***, ***tuwo.*** This implies that millet-based recipes will be very valuable to women.

Women contributing to participatory varietal selection exercise in Jigawa State, Nigeria

Evidence provided by this survey on women's engagement in the production segment of the Pearl Millet value chain signals the need to explore/exploit opportunities for women in other segments of the Pearl Millet value chain. Outcomes of the survey haves confirmed that women have high Islamic literacy levels, they have high cash income earning potential, they are engaged in a range of post-harvest operations etc. Operating a in socio-cultural context which potentially limits their access to improved Pearl Millet technologies, extension service support, etc. there is need to design and

implement programs that stimulate and/or enhance available opportunities for women to contribute to all segments of the Pearl Millet value chain in Nigeria.

3.4.11. Determinants of the adoption of improved Pearl Millet technologies

The Double Hurdle Model (DHM) was used to estimate the determinants and intensity of adoption of improved Pearl Millet technologies **(Table 23)**. In the first step, the Probit model was used to filter out the determinants of adoption and in the second step, the truncated normal regression model was used to estimate the determinants of intensity of adoption.

The estimated LR Chi-square was 252.91 and Log-likelihood of -436.62 explains the goodness of fit of the DHM model indicating a joint significance of both the drivers and intensity of adoption. The results further reveal variation in the estimated Probit and truncated model indicating that the factors influencing Pearl Millet farmers' decisions to adopt improved varieties are not exactly same with factors that influence adoption intensity justifying the use of DHM model.

Table 23 shows the eight (08) factors which influence the adoption of improved Pearl Millet technologies; these are *farm size, household size, early maturity, high yield, drought tolerance/resistance, access to credit, extension support visits, striga resistance.*

In terms of the socio-demographic characteristics of respondents:

- the estimated coefficient of household size is negative and significant at 5% implying that large household sizes will tend to spend less on hired labour for Pearl Millet production.
- the estimated coefficient of farm size was positive and significant at 1% implying that owners of large farm sizes are more likely to influence adoption of improved Pearl Millet technologies.

In terms of institutional factors,

- the estimated coefficient of access to credit and extension support visits are both positive and significant at 5% and 1%, respectively, implying that Pearl Millet farmers who have access to credit facilities and extension support visits are more likely to be influenced to adopt improved Pearl Millet technologies.

Table 23: Determinants and intensity of adoption of technologies (Double Hurdle Model)

Variables	Probit Model		Truncated Model	
	Co-efficient	**P-values**	**Co-efficent**	**P-values**
Intercept	0.36(0.07)	0.00***	1.86(0.27)	0.00***
(a) Respondents' characteristics				
Sex	0.03 (0.03)	0.32	0.26(0.16)	0.10*
Age	0.0004(0.0008)	0.96	0.002 (0.003)	0.47
Level of education	0.003 (0.005)	0.60	0.018 (0.02)	0.44
Household size	-0.006 (0.002)	0.03**	0.010 (0.008)	0.21
Farm size	0.11 (0.009)	0.00***	0.07 (0.03)	0.04**
(b) Institutional characteristics				
Access to credit	0.106 (0.044)	0.02**	0.16 (0.15)	0.21
Extension support visits	0.03 (0.024)	0.01***	0.08 (0.09)	0.39
(c) Technology characteristics				
Early maturity	0.03 (0.028)	0.01***	0.75 (0.10)	0.00***
High yield	0.02 (0.03)	0.01***	0.42 (0.11)	0.00***
Drought resistance/tolerance	0.02 (0.02)	0.04**	0.36 (0.11)	0.02**
Resistance to pests/diseases	0.05 (0.03)	0.05**	0.42 (0.16)	0.00***
Striga Resistance	-0.005 (0.03)	0.85	0.41 (0.11)	0.00***
Good food quality	0.0007 (0.02)	0.97	-0.06 (0.94)	0.98
N	**1,267**			
Sigma			**0.007**	
LR Chi-square	**252.91**			
Prob > Chi-square	**0.000**			
Pseudo R-square	**0.22**			
Log-likelihood	**-436.62**			

*****, **, * significant at 1%, 5% and 10%**

With respect to technology characteristics:

- the estimated coefficient of early maturity is positive and significant at 10% implying that improved Pearl Millet varieties with shorter cycles will increase prospects of their adoption. This result aligns with those of Oyakilome (2019) who reported that earliness of improved maize varieties in Nigeria was an important driver for adoption;
- resistance to pests/diseases is significant and positive at 5% implying that drought tolerant/resistant Pearl Millet varieties are more likely to influence adoption decisions. This corroborates with the findings of Oyakilome (2019) which revealed that drought resistant materials tend to influence the adoption of improved maize varieties in Nigeria.

Regarding outcomes of the truncated regression model, the estimated coefficient of sex is positive and significant at 10% implying that men are more likely to incorporate improved Pearl Millet varieties into their crop lands. The estimated coefficient of farm size was positive and significant at 1%. This is as expected considering that increasing the intensity of adoption means increasing the land area allocated to improved Pearl Millet varietal technologies; hence large farm holdings constitute incentives for increasing the intensity of adoption of improved millet varieties. The estimated coefficient of high yield material, early maturity, resistance to pests/diseases and striga resistance are all positive and highly significant at 1% suggesting that these traits influence farmers' decisions to increase land areas allocated to improved Pearl Millet technologies into their farmlands. In the case of drought tolerance/resistance, its estimated coefficient is significant and positive at 5%; implying that this trait has the likelihood of increasing the extent to which improved Pearl Millet materials could be adopted.

3.4.12. Productivity and welfare outcomes according to adoption status

Table 24 shows that farm size are quite similar for both adopters and non-adopters. While mean yields for adopters was 1,436 tons/ha that for non-adopters was 1,074 tons/ha resulting in a difference of 362 kg/ha which is statistically significant at 1% level.

Concerning food insecurity experienced by the two adopter categories, Pearl Millet technology adopters had a higher dietary diversity than non-adopters, the difference being statistically significant at 1% level. Non-adopters experienced a larger food insecurity experience and had more respondents with experiences of severe and moderate food insecurity.

Similarly, the poverty headcount of 0.69 is same for adopters and non-adopters, the difference between the two groups not being statistically significant at 10% level. This implies that approximately 69% of respondents are considered to be poor in both groups. A poverty gap of 0.59 for both adopters and non-adopters implies that the depth of poverty is similar within in both groups. The poverty severity index which measures the number of people who are extremely poor is 0.42 implying that 42% of respondents are below the poverty line are extremely poor.

Table 24: Mean comparison of productivity and welfare outcomes by adopter categories

Variables	Sample (N=1,267)	Adopters (n=230)	Non-Adopters (n=1037)	T-stat
Productivity				
Yield (kg)	1,216	1,937	1,077	859 (8.45) ***
Farm size (ha)	1	2	1	0 (2.26) **
Yield (kg/Ha)	1,132	1,436	1,074	362 (8.83) ***
Food security				
Household dietary diversity	5	7	5	2 (11.00) ***
Food insecurity experience	2	1	2	-1 (7.60) ***
Severe food insecurity	0	0	0	-0 (4.9) ***
Moderate food insecurity	0	0	0	-0 (4.55) ***
Mild food insecurity	0	0	0	0 (1.9) *
Poverty Profile				
Mean income per capita (₦)	44,411			
2/3Mean (Poverty Line - ₦)	29,607			
Head Count Index (α_0)	0.69	0.69	0.68	0 (0.25)
Poverty Gap Index (α_1)	0.59	0.57	0.59	-0 (0.65)
Poverty Severity Index (α_2)	0.42	0.40	0.42	-0 (0.54)

*p<0.1, ** p<0.05, *** p<0.01

3.4.13. Impacts of Adoption of Pearl Millet Technologies on Productivity

After a satisfactory balancing for the PSM **(Table 25),** its matching techniques namely i) nearest neighbour matching (NNM), ii) radius matching (RM) and iii) kernel matching (KM), the welfare variables were then estimated productivity, gross margin, household dietary diversity and poverty.

Table 25: Satisfactory balancing for propensity score matching

Blocks	Treated	Control
0	179	851
0.2	46	191
N	**225**	**1,042**

Table 26 confirms a positive and significant treatment effect at 1% probability level of the adoption of improved millet technologies on productivity using the three PSM matching techniques. The results of the three matching methods show an increase in millet productivity ranging between 261kg/ha to 284kg/ha, with productivity gains of 26%.

Table 26: Welfare impacts of Pearl Millet technology adoption

Matching Algorithm	**Means**		**Std-error**	**ATT**	**Gains (%)**
	Treated	**Control**			
Impact of improved varieties on productivity (Kg/ha)					
Nearest Neighbour matching	1,366	1,082	60.1800	261.61(4.35) ***	26
Radius Matching	1,366	1,082	50.2000	284 .00 (5.65) ***	26
Kernel Matching	1,366	1,082	0.0005	284.00 (5.76) ***	26
Impact of improved varieties on gross margin per hectare					
Nearest Neighbour matching	34,992	22,515	3,008.88	13,616 (4.53) ***	55
Radius Matching	34,992	22,515	2,528.53	12,478 (4.93) ***	55
Kernel Matching	34,992	22,515	0.000015	12,460 (5.34) ***	55
Impact of improved varieties on household dietary diversity score					
Nearest Neighbour matching	6.08	5.04	0.245	2.03 (8.37) ***	21
Radius Matching	6.08	5.04	0.149	1.77 (11.94) ***	21
Kernel Matching	6.08	5.04	0.163	1.77(14.07) ***	21
Impact of improved varieties on poverty					
Nearest Neighbour matching	0.39	0.36	0.049	0.047 (9.53) ***	8
Radius Matching	0.39	0.36	0.036	0.03 (8.30) ***	8
Kernel Matching	0.39	0.36	0.8097	0.028(8.58) ***	8

*** p<0.01

Similarly, adoption of improved Pearl Millet technologies led to an increase in gross margin per hectare varying from 12,478 to13,616 Naira; with gross margins gains of 55%. Likewise, the adoption of improved millet is associated with a significant increase of dietary diversity score by 2.03 points, representing about 21% increase and an decrease in poverty status by 0.004, with gains of 8%.

These results suggest that the adoption of improved Pearl Millet technologies has significant impacts on productivity, gross margin and food security in the States included in the survey. The results agree with those of Oyinbo *et al. (*2019) and Manda *et al. (*2020) who concluded that the adoption of improved maize and cowpea varieties in Nigeria had significant effects on productivity and cash incomes.

3.4.14. Financial gains from the adoption of Pearl Millet Technologies

Table 27 summarises the inputs: seeds, fertilizer, labour, pesticides and herbicide required for the production of one (1) hectare of Pearl Millet seeds/grains; all valued at the prevailing market price during the 2019 cropping season. Labour was measured using man-day/ha for each farm operation; this accounted for 45% (₦23,950) for adopters and 23% (₦10,400) for non-adopters. Main operations were land preparation, planting, weeding, threshing, harvesting and packaging. This was followed by expenditure on inputs 54% (29,400) for adopters and 77% (₦41,990) for non- adopters. The cost of fertilizer was 41% (₦22,500) and 69% (₦37,500) for adopters and non-adopters, respectively. These results agree with the findings of Sani *et al.* (2013) and Vabi *et al.* (2018b) who reported higher expenses per hectare for labour than other inputs in the production of certified seeds of groundnut in most of the States retained for this study. Vabi *et al.* (2018b) further argued that a tactful combination of hired and family labour and/or male/female labour, could help smallholder farmers move into cost effective input combinations.

While adopters reported total variable cost (TVC) of ₦53,350, non-adopters incurre TVC of ₦52,390 to cultivate a hectare of Pearl Millet farm leading to a gross margin of ₦44,150 and ₦22, 610. The operating ratio for adopters was 54% and 53% for adopters and non-adopters, respectively. Return on Investment (RoI) for adopters of Pearl Millet production across the study States was ₦0.83 (or 83%) for adopters and 0.43% (43%) for non-adopters. However, producing Pearl Millet on a commercial basis could be constrained by low market potentials for a crop primarily produced for subsistence. The gross margins are also low (₦44,150 and ₦22,610 for adopters and non-adopters, respectively. Similarly, awareness is low across the States included in the survey for all the varieties being promoted; it is known that commercial seed companies rarely invest in promotional activities.

Table 27: Financial Returns of Pearl Millet Production/ha/season for adopters

Description of variables	Quantity	Unit Cost (₦)	Total Cost (₦)	%
a) Adopters of Pearl Millet Technologies				
Cost of Seed (kg)	30	120	3,600	7
Cost of Fertilizer (kg)	150	150	22,500	41
Cost of Pesticides (litres)	1	1,000	1,000	2
Cost of Herbicides(litres)	2	1,150	2,300	4
Sub-total			**29,400**	**54**
Labour (man-days)				
· Land preparation(₦/Ha)	2		6,000	11
· Planting(₦/Ha)	5	250	1,250	1
· Weeding(₦/Ha)	6	700	4,200	10
· Harvesting(₦/Ha)	10	400	4,000	7
· Threshing(₦/Ha)	10	400	4,000	7
· Packaging			4,500	8
Sub-total			**23,950**	**45**
Total variable Costs			53,350	100
Total revenue	13bags(100kg)	₦7500/bag	97,500	
Gross margin			44,150	
Operating ratio			0.54	
Return on Investment (RoI)			0.83	
b) Non-adopters of Pearl Millet Technologies				
Cost of Seed (kg)	27	120	3,240	6
Cost of Fertilizer (kg)	250	150	37,500	69
Cost of Pesticides (litres)	0.5	1,000	500	1
Cost of Herbicides(litres)	0.5	1,500	750	1
Sub-total			**41,990**	**77**
Labour (man-days)				
· Land preparation(₦/Ha)	6	400	2,400	5
· Planting(₦/Ha)	5	300	1,500	2
· Weeding(₦/Ha)	3	500	1,500	7
· Harvesting(₦/Ha)	5	500	2,500	5
· Threshing(₦/Ha)	5	300	1,500	3
· Packaging			1,000	2
Sub-total			**10,400**	**23**
				100
Total variable Costs			52,390	
Total revenue	10bags(100kg)	₦7500/Bag	75,000	
Gross margin			22,610	
Operating ratio			0.53	
Return on Investment (RoI)			**0.43**	

3.4.15. Nutrition implications of locally consumed food items by respondents

Lack of balanced diets, manifested through under and/or over-nutrition, is a major concern in developing countries (FAO, 2019). The range of food items allegedly being consumed by respondents were identified and summarised in **Table 28** into three broad categories *a) respondents falling between 0-30% who reported least consumed food items b) respondents grouped between 31-70% who reported moderately consumed food items and c) respondents between 71-100% who reported the most consumed food items.* The nutrition implications of consuming each category of these food items could be useful in food and nutrient security in the States include in this survey targeting Pearl Millet.

Table 28: Categories of food reported being consumed by respondents

Respondent Groupings	Categories	Group of food reported being consumed	Nutrition Implications
0-30%	Least consumed food items	butter, goat meat, fish, milk, chicken, eggs, maize flour, orange, banana, pineapple, avocado, pawpaw, guava, yam flour, yam, garri, cocoyam, Irish potato, sweet potato, eggplant, okra, vegetables, mango and water	- Group contains all the nutrient foods such as vitamins, protein, fats, carbohydrates, minerals and Fibre; - Group contains requirements for balanced diets; - Group is also most suitable for growing children, adolescents, pregnant/lactating mothers; - Group most likely to contain healthy individuals depending on the combination of nutrients taken.
31-70%	Moderately consumed foods items	beef, sorghum flour, plantains, cowpea, pepper, millet flour mango and water	- Group is rich in energy giving foods (carbohydrates) and moderate in proteins and vitamins; - Group is poor in oil, except from beef); - Group is most suitable for adults who require considerable energy for crop farming activities.
71-100%	Most consumed foods items	Rice, maize mangos, palm oil, groundnut oil, water, tomatoes, millet flour, groundnut and onions	- Group is rich in carbohydrates, oils and moderate in vitamins; - Group is poor in protein, with groundnuts being the only source; - Group lacks essential nutrients which could manifest in undesirable health conditions including malnourished children and even adults.

4.0. Summary, Conclusion and Recommendations

4.1. Summary and conclusion

Pearl Millet [*Pennisetum glaucum* (L.) R. Br.] is a small cereal grain crop commonly called **Millet.** It has three generic names corresponding to three different types in the Hausa Language in Nigeria: *Gero (early maturing), Maiwa (late maturing and photosensitive), Dauro (transplantable and photo-sensitive).* The crop is most resilient to drought stress, soil salinity/acidity and high temperatures compared to other cereals. Several dishes are made from millet across the Sahel region of WCA. Though the stem is primarily used for construction (houses and fences) while the fodder and pericarp are important feeds for domestic livestock and poultry.

The potentials of Pearl Millet are constrained by a series of factors: recurrent droughts, unending s*triga*, head miner, wild birds, downy mildew and intrinsic poor soil fertility. There has also been little institutional support to develop and promote Pearl Millet in Nigeria. Research for development actions on Pearl Millet in across WCA have been a lot more oriented towards the collection and characterization of landraces, challenges limiting production, generation advancement of open-pollinated varieties (OPVs) and hybrids. In this context, an understanding of drivers of awareness of, and about released varieties, adoption, trait preferences, seed systems and gender mainstreaming become relevant and useful to processes of varietal development. The four stage sampling procedures to determine adoption rates and intensities of adoption of Pearl Millet technologies, i) identify limitations the sustained use of Pearl Millet technologies ii) determine the impacts of the adoption of improved Pearl Millet technologies on productivity, gross margin, poverty and food security experiences, iii) based on outcomes of the survey, formulate actionable recommendations.

In order to achieve the objectives, set out for the survey, a four staged sampling procedure was used. The conscientious use of these procedures resulted in the retention of seven (07) predominant Pearl Millet producing States, thirty-one (31) LGA and eighty-four (84) communities/villages. Interviews were then organised with respondents in the communities/villages to collect data using a structured questionnaire from a total of 1,267 respondents, 93 of them being women. Data was collected by thirty (30) enumerators working in three separate teams under the supervision of a survey coordinator and cloud server administrator.

The dataset was cleaned and checked after the survey to ensure consistency and completeness. The curated datasets were subjected either to the Statistical Package for Social Sciences (SPSS) or STATA soft wares for appropriate analyses. The Average Treatment Effect (ATE), Propensity Score Matching (PSM), and Double Hurdle Regression models were used, wherever suitable.

Results of the survey revealed that respondents are adults aged between 36 - 60 years (59%), have crop farming (70%) as main occupation, are married (92%), do not belong to farming groups (72%), have Quranic education (44%) and have household sizes varying between 6 -10 persons (39%). Cattle account for 33% of annual earnings of respondents, 33% of respondents earn less than ₦30,000.00 while 36% reported annual cash earnings above ₦100,000.00. A majority of respondents (83%) reported not having access to extension support with 74% reporting extension support visits by the ADPs whenever they occur.

Several landraces of Pearl Millet were identified with Yobe State topping the list followed by Katsina and Sokoto States. The most widespread landraces were *Zango, Gajaro Gero* and *Zabo*. The naming of local varieties indicating the onset of acculturation processes bringing to the open at six major elements - *name of the source, tribe of source, colour of material, height of material when fully grown, growth pattern, and even appearance* Awareness of improved Pearl Millet varieties was estimated at 28% with that of SOSAT-C88 being 18% and SUPER-SOSAT being 7% and 3% for JIRANI. Awareness of. and knowledge about improved Pearl Millet varieties resulted in an overall adoption rate of 18% with 13% attributed to SOSAT-C88 and 4% to SUPER-SOSAT and the rest to JIRANI. Two outstanding reasons emerged for adoption: early maturity (66%), medium maturity (10%) and high yielding materials (11%). The negative features of the varieties being promoted were reported to be late maturity (25%), unending susceptibility to striga infestation (27%) and to other pests/diseases (27%). The adoption of crop management practices requiring the purchase of farm inputs particularly fertilizers and pesticides were lower (less than 50%) those requiring bought inputs (between 70% and 86%). In terms of initial sources of improved Pearl Millet seeds grown by respondents, the ADPs, other farmers and owned supplies were mentioned across the States for SOSAT-C88 and SUPER-SOSAT, in all other States except Sokoto and Yobe. The intensity of adoption ranged from 49% for LCIC9702, 60% for SUPER-SOSAT, 55% for JIRANI and 54% for SOSAT-C88. These figures notwithstanding, dis-adoption (withdrawal) rate of 7% was reported with

reasons recounted being unavailability of seeds (33%), satisfaction with present planting materials; most of which are local materials, and lack of capital or money to purchase improved seeds.

Conscious of possibilities of a better adoption potentials of the Pearl Millet varieties being promoted, the Average Treatment Effect (ATE) was used to estimate potential adoption and adoption gap. Outcomes of the estimation resulted in a population adoption rate of 45.3% and an adoption gap of 27.3%. These results imply that intensifying access to information on improved Pearl Millet and improving access to improved seeds of the varieties being promoted could improve adoption rate. It is evident that the current adoption rate of 18% is bound to increase as Pearl Millet farmers beyond the respondents of this survey learn more about the real features of the improved Pearl Millet varieties being promoted.

Impact were assessed at three levels; *i) productivity of adopters of improved Pearl Millet technologies ii) gross margin of adopters of improved Pearl Millet technologies, and iii) welfare of adopters of improved Pearl Millet technologies.* The use of the (PSM) impact model showed that adoption of improved Pearl Millet technologies had positive and significant impacts on productivity, gross margin and welfare of respondents. Outcomes of the three matching techniques of the PSM namely *Nearest Neighbour Matching, Radius Matching and Kernel Matching* for example, showed an average increase in yield varying between 261kg/ha to 284kg/ha, with a productivity gain of 26%. Similarly, adoption of improved Pearl Millet technologies led to an increase in gross margin per hectare varying between ₦12,478 and ₦13,616; with a gross margin gain of 55%. Likewise, the adoption of improved Pearl Millet technologies is associated with an increase in dietary diversity score of 2.03 points, representing 21% increase and a decrease in a poverty improvement of 8%. Also, returns on investment (RoI) of producing Pearl Millet across the States included in the survey was 76%.

4.2. Recommendations

The major recommendation from this study is a comprehensive intensification of the **scaling out of existing Pearl Millet technologies.** The evidence emerging from this survey points to the fact that Pearl Millet has not received the attention it deserves at States and Federal Government levels. This revelation has significant practical implications on the engagement of stakeholders to scale out available Pearl Millet technologies. This entails a single package four component multi-dimensional scaling initiative comprising the following components:

i) **Use of innovative extension approaches in scaling out Pearl Millet technologies:** extension service delivery is central in raising awareness and providing adequate support to end-users of agricultural technologies. Respondents of this survey reported having limited extension support visits (83%) with most of this being promoted by the ADPs. Recognising the limits of the T&V extension approaches, all the States where the IFAD-CASP and TRIMMING projects are being implemented have embraced the Farmer Field and Business School (FFBS) approach in spreading out science-based knowledge and practices. The FFBS approach uses participatory techniques to help technology users develop analytical skills, thinking and creativity in making farm-level decisions within the framework of value chain (Kenmore, 1997). The approach does not require all farmers to attend training sessions, rather only a few end-users from villages/communities are trained in farming techniques across a commodity value chain. The selected end-users are also drilled on facilitation skills and knowledge to become support agents to other farmers and are expected to duplicate such skills and knowledge with other farmers in their networks.

ii) **Promotion of the multiplication, distribution and marketing of quality seeds of the Pearl Millet varieties:** considering that difficulties in accessing seeds was a major reason for dis-adoption (33%), it is vital that a lot more efforts be done to facilitate access of quality seeds to potential users. In this connection, the community-based seed production (CBSP) approach seems to be the most feasible. The CBSP approach is directed at empowering registered farmer groups to produce seeds from traceable source(s) and make them available to a larger number of farmers within and around their communities. As stressed by Vabi *et al.* (2018), this approach is both community

and market-oriented and is a core element of the Nigerian 2014 Seed Policy. Also, there will be a need to intensify collaboration with the Lake Chad Research Institute (LCRI)) and engage private seed companies to ensure that delivery mechanisms are improved to enable farmers access seeds at affordable prices.

iii) **Promotion of the processing, marketing and consumption of millet-based products:** Pearl Millet is perceived as a subsistence crop in the seven States included in this survey; only 14% (175 out of 1,267) respondents reported selling Pearl Millet. It also contains high amounts of dietary fibre, vitamin B6, folic and oxalic acids and fatty acids and vitamin E especially in the bran. It also contains minerals including iron, magnesium, phosphorous, potassium, zinc, calcium and copper. The whole grain contains is rich phytochemicals which have been reported to lower cholesterol levels as well reduce risk of diabetics, constipation and colon cancer (Johari and Kawatra, 2016; USDA, 2019). In the States included in the survey, millet-based recipes are very valuable and popular. This is good news for the promotion of the consumption of the and engagement of women. The crop is reported to have a higher crude protein content than other cereals (sorghum, maize, rice and wheat) consumed in the seven States included in the survey.

iv) **Strengthening national efforts towards the release of high-yielding Pearl Millet varieties**: Except SUPER-SOSAT, on-farm yields are at least 50% less than yields obtained on-station. It is not an over-statement that key institutional partners of the LCRI do not yet know released Pearl Millet varieties in Nigeria. The survey reveals that awareness of, and about the varieties being promoted are low; SOSAT-C88 (18%), SUPER-SOSAT (7%), JIRANI (3%) and LCIC9702 (0%). Adoption rates are embarrassing SOSAT-C88 (13%), SUPER-SOSAT (4%), JIRANI (1%) and LCIC9702 (0%). The intensity of adoption varied between 49% for LCIC9702 and 60% for SUPER-SOSAT and 54% for both SOSAT-C88 and JIRANI. Dis-adoption rates were higher for JIRANI. Overall, dis-adoption was essentially due to the unavailability of improved seeds, the perception of being satisfied with landraces (some of which could be or are outcomes of successive cross-pollinations with the improved varieties. It is against this background that this study recommends the intensification of efforts towards the development of varieties which are high-yielding.

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Annex 1: Background information on the States included into Pearl Millet Adoption Survey

Cluster 1: Sokoto and Kebbi States

Both Sokoto and Kebbi States lie to the far extreme northwest of Nigeria (Figure 1); with both States sharing land borders with the Republic of Niger hence providing vast opportunities for cross-border formal and informal exchanges. While Sokoto States has twenty-three (23) Local Government Areas (LGAs), Kebbi States has twenty-one (21) LGAs.

Using projections of the 2006 National Population Census, the population of Sokoto States is estimated at 3,702,676 while that of Kebbi States is estimated at 4,917,327 (States-based Population Census Reports, 2006). With an annual national population growth rate of 3.3%, these figures have been changing though they also differ according to the source. Though there are several ethnic/tribal groups in the two States, the population comprises the Hausa, Fulani, and other ethnic/tribal groups. Christianity is also practiced in both States. Apart from Hausa and Fulani, other Nigerian ethnic/tribal groups are also found in the two States. The main medium of communication are Hausa and Fulfulde.

Over eighty percent (80%) of the population of both States is engaged in agriculture. The main crops produced are millet, sorghum (guinea corn), maize, rice, potatoes, cassava, groundnuts, and beans; these crops are grown for both subsistence and cash income generation. All categories of livestock – cattle, sheep, goats, chickens, camels, donkeys, etc. are found within households. Farm-families along the Rivers Sokoto, Niger, and Rima as well as dams and lakes also do fishing and cultivate vegetables in the dry season where irrigation is feasible. Each States has an Agricultural and Rural Development Authority, ordinarily known as ADP organized into Extension Zones (Dodo, 1996).

Both States fall within the Sudan and Savanah agro-ecological zone which has been presented by Vabi *et al.* (2018) for groundnut production in Nigeria. The dry season starts from October, and lasts up to April and may extend to May or June in some parts of the States. The wet season generally begins in April-May and may extend to September-October. The mean annual rainfall ranges between 500mm and 1,300mm. The annual average temperature in the States is 28.3 °C, with Sokoto being one of the hottest cities in the world, though maximum daytime temperatures are under 40 °C most of the year. The warmest months are from February to April, where daytime temperatures can exceed 45°C. In Kebbi States, the mean annual temperature can be as high as 26°C. However, between December and February, mean annual temperatures can go down to about 21°C and up to 40°C from April to June. The highest recorded temperature in Sokoto has been 47.2°C, which is also the highest recorded temperature in Nigeria.

Both states were included in the implementation of the USAID funded project because they fall within the Feed the Future Zone of Influence (FtFZI). A total of 11 Local Government Areas (LGAs) were selected from both States for project implementation with six selected from Kebbi (out of a total of 27 LGAs) and five from Sokoto (out of a total of 23 LGAs). The criteria for selecting LGAs were *Feed the Future Zone of Influence, important groundnut production area, the potential for high impacts, accessibility and security, presence of other implementing partners, size of the region and potentials of high women involvement.*

Cluster 2: Kano, Katsina and Jigawa States

Kano, Jigawa, and Katsina lie in the North-western part of Nigeria, Kano is referred to as the capital of the northwest states, which was created on 27^{th} May 1967, Jigawa was carved out of Kano states on 27^{th} August 1991 and Katsina was created from Kaduna on 23^{rd} September 1987. However, Kano lies between latitudes 10^{0} 33' to 12^{0} 37' N and longitude 7^{0} 34' to 9^{0} 25' E, while Katsina and Jigawa are located between latitude 11^{0} 08' North and 13^{0} 22' North and longitude 6^{0} 52' East and 9^{0} 20' East and also latitudes 11.00^{0}N to 13.00^{0}N and longitudes 8.00^{0}E to 10.15^{0}E of the Greenwich meridian. The major rivers in the Kano and Jigawa states include Hadeja Jama'are river, Kafin Hausa river and Iggie River while Katsina has river Gada and Karadua.

According to the population census of 2006, Kano has a population estimate of 9,383,683. With an annual growth rate of 3.3%, the projected population by the year 2018 could be 13,099,622. Both Katsina and Jigawa have a population estimated to be 5,792,578 and 2,829,929 respectively. The dominant tribes/ethnic groups in the northwest states include Fulani's and Hausa, whose major languages Hausa. The major religions in the states are Islam and Christianity.

Also, Kano states has forty -four (44) local government areas while Katsina and Jigawa have Thirty-four (34) and Twenty-seven (27) local government areas, respectively.

The major occupation of the people in the north-western part of Nigeria is farming, in which the states are blessed with vast fertile land for agricultural activities. In Kano states, the annual rainfall varies from 600 – 1200 mm in the Guinea Savannah to 300 – 600 in the Sudan Savannah. The length of the growing periods ranges from 90 – 150 days in the Sudan Savannah and 150 - 200 days in the Guinea Savannah zone. Katsina has an annual rainfall of 1000mm and an annual maximum and minimum temperature of 32^{0}C and 19^{0}C, with oppressive wet season mostly cloudy. Furthermore, the Jigawa states has an average annual rainfall of about 700mm, which is higher in the southern part of the states. (JARDA, 2005) and mean daily temperature is estimated at 27^{0}C with minimum and maximum put at 19^{0}C and 35^{0}C respectively.

Crops commonly grown in the northwest zone of the country include groundnut, cowpea, sorghum, millet, maize, cassava, and sweet potatoes which flourish under rain-fed agriculture in the zone. But the development of irrigation farming schemes in the Kano and Jigawa states increases the production of maize, rice, onions, pepper, and tomatoes. Categories of livestock found in farming households include cattle, goat, donkey and poultry which contribute to the livelihood of the farmers. Both Katsina and Jigawa share boundaries with the Niger Republic and also with the presence of the International livestock market in Jigawa States, there is an opportunity for economic activities in the states.

Cluster 3: Bauchi and Yobe States Cluster

Yobe states was created on 27th August 1991 from the former Borno states, while Bauchi states was also created on 3rd February 1976 from the then North-Eastern states. They are located in the north-eastern part of Nigeria. Both states share boundaries with Yobe east of Bauchi. While Bauchi states has twenty (20) local government areas, Yobe has seventeen (17) local government areas.

The National Population Census (NPC) of 2016 estimated total population of Bauchi at 3,727,347 and that of Yobe at 4,248,436 (NPC,2016). There are different ethnic/Tribal groups in both states, the majority of which are the Fulani and Kanuri. Other groups in the states include Bolewa and Warji. Both Islam and Christianity are practised in the two States, Islam predominates. The most popular means of communication in both States are Hausa and Fulfude.

The main agro ecological zones are the Northern Guinea and Sudan savannah, Agriculture is the mainstay of the populations of both states. The major crops in both States are maize, sorghum, Pearl Millet and groundnut. As a whole low input and rain fed agriculture is the order of the day with outputs destined for household consumption. This also applies to livestock where cattle, small ruminants and poultry are found in most farm-households.

Bauchi states has some major rivers particularly Hadeja, Jama'are, Gongola and Dindima while Yobe States has Misau River; these rivers make off-season farming activities possible. The cropping season in the States starts from April and ends in November. Annual rainfall ranges between 1300mm in the south and 700mm in the north, with a relative humidity of 12% in February and 68% in August. Mean annual temperatures are as low as 27^0C and 29^0C, respectively in Bauchi States.

Annex 2: Field Teams of the Pearl Millet Adoption Survey in Nigeria

Kano-Katsina-Jigawa Team

S/N	Name	Highest Qualification	GSM
1	Muhammad Hussaini	MSc. Agricultural Economics	07033969793
2	Adediran Abdulrasheed	BSc. Microbiology	07031020607
3	Francis Kato Rekwot	BSc. Economics	08065383232
4	Aminu Rabiu	MSc. Geography	07038232602
5	Abdulhamidu Aliyu Ahmad	ND Animal Health & Production	08033050743
6	Tajudeen Ibrahim Bashir	BEd. Islamic Studies	07063111313
7	Ibrahim Isah Da'u	HND Business Administration and Management	08036854658
8	Kamaludeen Abubakar Baba	MSc. Remote Sensing and Geographic Information Systems	07031020607
9	Samiratu Musa	BSc. Mass Communication	08163581557
10	Christopher Musa Ndahi	BSc. Public Administration	08063979155

Kebbi-Sokoto Team

S/N	Name	Highest Qualification	GSM
1	Wilson O. Godwin	BSc. Statistics and Research	07030262251
2	Aliyu Mustapha	BSc. Botany	08063979155
3	David Erhabor	HND Business Administration and Management	07036112248
4	Ibrahim Bala	BSc. Agric Economics &Ext.	08168183008
5	Fadimatu Tafida	MSc. Agro Economics	07035153797
6	Badaru Umar Hamish	NCE Physics/Chemistry	07063206120
7	Joel Mohammed Bwala	BSc. Agric Economics & Extension	08034151061
8	Christopher Rekwot	BSc. International Studies	07068810812
9	Auwal Lawal	BEd. Physics	08061631070
10	Yakubu Aminu	BSc. Geography	08064346060

Bauchi-Yobe Team

S/N	Name	Highest Qualification	GSM
1	Muhammad Badmus	BTech. Computer Science and Education	07033969793
2	Adamu Ali	BSc. Agric Economics & Ext.	07030351535
3	Fidelis Batram Rekwot	BEng. Electrical Engineering	08068646649
4	Josiah Kogi	BAgric. Agric Economics & Rural Sociology	08165611902
5	Abubakar Dahiru	BSc. Agriculture	08032172086
6	Joan Etuhu	BSc. Agric Economics (in view)	08060314963
7	Halima Abbas	BSc. Agric Economics & Rural Development	08131871289
8	Sanusi Dankawu	MSc. Agronomy	08068986227
9	Bashir Boyi	BSc. Agricultural Extension	08060325519
10	Abubakar Muhammad Hassan	BSc. Economics	07031668855

About ICRISAT

ICRISAT - International Crops Research Institute for the Semi-Arid Tropics, is a non-profit, non-political organization that conducts agricultural research for development in the drylands of Asia and sub-Saharan Africa. Covering 6.5 million square kilometres of land in 55 countries, the dryland tropics has over 2 billion people, and 644 million of them are amongst the poorest of the poor. ICRISAT and its partners help empower these poor people to overcome poverty, hunger and degraded environments through better agricultural practices.

ICRISAT is headquartered in Hyderabad, Telangana State of India and has two Regional Offices in Nairobi (Kenya) and Bamako (Mali), with Country Offices in Niger, Nigeria, Zimbabwe, Malawi, Ethiopia and Mozambique. The Nigerian office of ICRISAT is located within the Kano Station of the Institute for Agricultural Research (IAR) of the Ahmadu Bello University (ABU) - Zaria.

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A prosperous, food secure and resilient dryland tropics

The Mission of ICRISAT is