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Research Articles

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RESPONSE OF GROWER PIGS TO HIGH COPRA MEAL BASED DIETS SUPPLEMENTED WITH DIFFERENT ENZYME PRODUCTS

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ABSTRACT

The effect of two enzyme products and their combination on the utilization of a high copra meal-based diet by growing pigs was studied. Twenty four, 9-week old crossbred male pigs (24.3 ± 0.20 kg) were assigned to 4 dietary treatments of six pigs each in a completely randomised design. All the diets were formulated to contain 300 g/kg copra meal (CPM). No enzyme product was added to the control diet while the other 3 diets were supplemented with Allzyme® SSF, β-mannanase and their combination (ratio of 1:1), respectively. Feed intake was increased on the Allzyme and mannanase diets (P<0.05) compared to the control and Allzyme + mannanase diets. Allzyme and mannanase supplementation improved final body weight compared to the control (P<0.05). Feed conversion ratio was improved with Allzyme and mannanase supplementation (P<0.05). Feed cost of gain (US$/kg gain) was reduced (P<0.05) on Allzyme supplemented diet. There was no dietary effect on dressing percentage (P>0.05). Pigs fed the control diet recorded higher weights of digesta in the stomach, small and large intestines compared to enzyme treated diets (P<0.05). The lowest weight of digesta in the gut segments was recorded on Allzyme (P<0.05). Allzyme supplementation at 300 g/ton improves the utilization of dietary CPM at 30 g/kg by growing pigs. This supplementation will be beneficial in terms of reduction of pork production cost and income generation in copra meal producing regions.

Keywords: Copra meal, complex structures, enzymes products, pig performance

INTRODUCTION

Feed is the major cost of pig production in the South Pacific because the conventional ingredients are not readily available in the region. Soybean which is the traditional protein ingredient in pig diets is not grown in the region or the cultivation is insignificant to meet demand of the livestock industry. Commercial pig farmers in the region have no other alternative than to import the finished feed or ingredients at exorbitant prices at the moment. These farmers find it difficult to sell pork and break-even in a market where pig products from the scavenging system are in reasonable supply and consumers are rather guided by the cost than quality. This calls for the need to increase research into the usefulness of locally available, cheap feed resources for pig feeding in the region.

Copra meal (CPM), a by-product of coconut oil extraction is readily available in most countries of the region. The composition of CPM is quite variable with the protein content ranging from 190 to 250 g/kg (Mondal *et al.,* 2008; Sundu *et al.,* 2009). The residual oil content of the meal ranges from 35 g/kg (Canapri *et al.,* 2005) to 70 g/kg (Kurian *et al.,* 2007) in solvent and expeller extracted CPM, respectively. Copra meal is high in fibre, mainly non-starch polysaccharides (NSP) (Sundu *et al.,* 2006b), which limits its utilization

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by monogastric animals. The NSP of CPM is mainly in the form of pure mannan, galactomannan, glucomannan, galactoglucomannan, and cellulose (Sundu *et al.,* 2006a). Siebra *et al.* (2008) recommended about 200 g CPM/kg diet for growing pigs.

The beneficial effect of exogenous enzymes on the utilization of NSP by monogastric animals is documented (Khanongnuch *et al.,* 2006). These authors reported an increase in the ME content and an improved nutrient digestibility of CPM-based broiler diets treated with β-mannanase. Allzyme® SSF from Alltech is a complex enzyme with 7 enzyme activities (amylase, cellulase, phytase, phytase, xylanase, betaglucanase, pectinase and protease) which has powerful NSP-degrading activity while β-mannanase is a single enzyme hydrolysing mannan oligosaccharides.

It may be therefore interesting to compare the effects of β-mannanase and Allzyme® SSF on the growth and carcass measurements of grower pigs. This was the object of the present study.

MATERIALS AND METHODS

Experimental Site and Source of Copra Meal

The experiment was conducted at the Piggery Unit of the University of the South Pacific's School of Agriculture and Food Technology, Alafua Campus, Samoa (latitude 13.5°S and longitude 172°W). Copra meal from Pacific Oil, Samoa was used for the experiment. Copra meal, fish meal and soybean meal were analysed at the Central Laboratory, Alafua (Table 1) and used for the formulation of the experimental diets.

Experimental Diet

Four pig grower diets based on 300 g CPM/kg were formulated for the experiment (Table 1). All the diets were formulated to meet or exceed the crude protein, lysine and methionine specifications of NRC (2012). Poultry fat was added to boost the energy level of the diets. The control diet was supplemented with either 300g Allzyme® SSF/tonne, 300g β-Mannanase from/ tonne; or or 300g (150: 150) Allzyme + β-Mannanase /tonne.

Experimental Pigs and Management

Male crossbred growing pigs (24; Large White x Landrace) aged about 16 weeks and weighing 24.3 ± 0.20 kg were used for the 8 week-experiment. The pigs were assigned to 12 standard size concrete floor pig pens with 2 pigs per pen. Each diet was fed ad-libitum to pigs in 3 pens in a completely randomized design. Clean drinking water was also supplied ad-libitum throughout the experimental period.

Data Collection and Chemical Analysis

Growth performance (feed consumption, weight change, feed conversion ratio, and feed cost of production), dressing percentage and digesta weight in different gut segments formed the major response criteria. Weighed quantities of feed were fed daily to pigs in each pen and the left over weighed the next day. Feed consumption was derived by difference between the left over and the quantity fed the previous day. Weight change was monitored by weekly weighing and feed conversion ratio (FCR) calculated as the ratio of feed consumed to weight gained. The cost of the experimental diets (US$/kg) was calculated based on the market price of the ingredients at the time of the experiment and feed cost per kg gain derived as the product of FCR and the cost of the kg feed in each pen.

At the end of the experiment, all pigs were fasted for 12.00 hours (18.00 hours to 06.00 hours), electrically stunned and slaughtered by severing the jugular and carotid vessels and used for carcass measurements. Slaughtered pigs were scalded in hot water at about 650C for 5 min, de-haired using the dull edge of a knife and eviscerated. Carcasses were weighed and expressed as percentage of the slaughter weight. Sections of the gastro-intestinal tract (stomach, small and large intestines) were removed and weighed with the content. The segments were then emptied and weighed and their digesta content calculated by difference between the full and empty weights. Digesta weight in each segment was expressed as percentage of the slaughter weight.

Proximate analysis of the experimental protein sources (copra meal, fish meal and soybean meal) was done at Alafua Campus for proximate composition according to AOAC (2007). Copra

Table 1. Ingredient composition and calculated analysis of the diets

Ingredients (g/kg)	Diets			
	Control	Allzyme SSF	Mannanase	Allzyme SSF + Mannanase
Maize	380	379.7	381.9	380
Wheat bran	126	127	125.8	126.7
Soybean (full fat)	71	70	69	70
Fish meal	50	50	50	50
Copra meal	300	300	300	300
Poultry fat	20	20	20	20
Snail shell	40	40	40	40
*Premix	3	3	3	3
Salt	5	5	5	5
L-Lysine HCL	3	3	3	3
Dl-Methionine	2	2	2	2
**Allzyme® SSF		0.3		
β-Mannanase			0.3	
Allzyme + β Mannanase (1:1)				0.3
Calculated analysis (g/100g DM)				
Crude protein	15.00	14.90	14.90	15.00
Crude fibre	9.85	9.92	9.25	9.98
Lysine	0.90	0.91	0.89	0.88
Methionine	0.60	0.60	0.59	0.57
ME(MJ/Kg)	13.81	13.73	13.77	13.76

*Biomix® provides per kg: vitamin A, 300 000 IU; vitamin D3, 59 500 IU; vitamin E (100%), 0.600 g; vitamin B1 (100%), 0.030 g; vitamin B2 (100%), 0.140 g; vitamin B6 (100%), 0.031 g; vitamin B12 (100%), 0.000605 g; vitamin K3 (100%), 0.040 g; vitamin PP (100%), 0.600 g; calcium pantothenate (100%), 0.300 g; folic acid (100%), 0.021 g; biotin (100%), 0.0006; choline chloride (100%), 2.000 g; iron, 1.500 g, manganese, 0.800 g; copper, 1.937 g; cobalt, 0.010 g; zinc, 1.500 g; iodine, 0.015 g; selenium, 0.004 g; calcium, 1.540 g; Endox, 0.030 g.
**Allzyme SSF (from Alltech) has the following enzyme activities: Amylase, cellulase, and phytase, xylanase, beta-glucanase, pectinase and protease.

meal, fish meal and full-fat soybean contained 249, 687, 368 g/kg crude protein; 113, 2, 52 g/kg crude fibre and 96, 123, 439 g/kg fat, respectively.

Statistical Analysis

Performance data were subjected to analysis of variance using the GLM of the Statistical Package for Social Sciences (SPSS, 2013, version 22). Significant differences were reported at 5% level of probability.

RESULTS

Growth performance data of the pigs (Table 2) showed improved daily weight gain (DWG) and final body weight on the Allzyme supplemented diet ($P<0.05$). DWG did not differ between

mannanase and Allzyme + mannanase as well as between the control and mannanase supplemented diets (P<0.05). Pigs supplemented with Allzyme and mannanase consumed more feed and converted it into weight better (P<0.05). The lowest feed cost/kg live weight (P<0.05) was observed on the Allzyme supplemented diet.

The effects of dietary treatment on dressing percentage and weight of digesta in the gut are shown in Table 3. There was no effect of dietary treatment on dressing percentage of the pigs (P>0.05) but the weight of digesta in the gastro-intestinal segments was affected (P<0.05) by the diet. Digesta weights in the stomach, small and large intestines were significantly reduced (P<0.05) on the Allzyme supplemented diet. The highest digesta weight in all the gastro-intestinal segments was recorded on the control diet (P<0.05).

DISCUSSION

The reduced feed intake by pigs on the control and Allzyme + mannanase supplemented diets may be attributed to feed transit time. Lower feed intake in growing pigs fed high fibre diets as a result of gut fill has been reported (da Silva *et al.,* 2012; Kallabis and Kaufmann 2012). Kallabis and Kaufmann (2012) observed reduced feed intake, body weight gain and lower final body weight in growing pigs fed diets containing 7.3% compared to a control group fed 5.18% dietary fibre. It is possible that the concentration of each enzyme in the Allzyme + mannanase was enough to induce sufficient hydrolysis of the diet. The higher lysine and methionine intakes on one hand and a possible increased hydrolytic activity by Allzyme on the other may be reasons for the improved daily gain and heavier final body weight observed on the diet supplemented with this enzyme. The beneficial effect of Allzyme supplementation on pig growth is documented (Alltech, 2009, Akintunde *et al.,* 2011). Mannanase is an NSP degrading enzyme with mannan hydrolysing activity. The poorer daily gain and final body weight on the mannanase diet compared to Allzyme despite similar intakes of lysine and methionine on both diets in the present study suggests that the NSP of CPM may be present in a more complex form than mannan. The complexity of CPM NSP has earlier been reported (Sundu *et al.,* 2006a).

These findings agree with the observations of Kwon and Kim (2015) who found no effect of mannanase supplementation of copra meal or palm kernel meal based diets in pigs. Yoon *et al.* (2009) however, reported improved growth performance of pigs fed diets based on distiller dried grain with soluble (DDGS) supplemented with mannanase. These authors used a higher

Table 2. Growth performance of pigs fed high CPM diets supplemented with different enzyme products

Parameters	Diets				
	Control	Allzyme	Mannanase	Allzyme + Mannanase	SEM
Final weight (kg/pig)	45.5^{c}	58.5^{a}	49.4^{bc}	51.2^{b}	1.186*
Daily feed intake (kg/pig)	1.8^{b}	2.1^{a}	2.2^{a}	1.9^{b}	0.043*
Daily gain (kg/pig)	0.40^{c}	0.62^{a}	0.57^{b}	0.41^{bc}	0.022*
FCR (feed: gain)	4.5^{a}	3.39^{b}	3.9^{b}	4.6^{a}	0.174*
Cost of kg feed (US$)	0.43	0.44	0.45	0.44	n.a
Feed cost/kg gain (US$)	1.95^{a}	1.49^{b}	1.75^{ab}	2.02^{a}	0.095*
Calculated daily intake					
Lysine (g)	16.2^{b}	19.1^{a}	19.6^{a}	16.7^{b}	0.232*
Methionine (g)	10.8^{b}	12.6^{a}	13^{a}	10.8^{b}	0.201*

SEM: standard error of the mean; n.a: not analysed; a, b, c**:** Means within the same row bearing different letter are significantly different; ns: not significant (P>0.05); *: significant (P<0.05).

Table 3. Carcass yield and organs weight of growing pigs fed high copra meal diets supplemented with different enzyme activities

Parameters	Diets				
	Control	Allzyme SSF	Mannanase	Allzyme SSF + Mannanase	SEM
Dressing per cent	65	68	66	66.2	1.451^{NS}
Weight of digesta in different segments (% live weight)					
Stomach	2.4^{a}	1.5^{c}	1.8^{b}	1.9^{b}	0.077*
Small intestine	4.3^{a}	2.4^{c}	3.4^{b}	3.6^{b}	0.068*
Large intestine	5.6^{a}	3.6^{c}	4.3^{b}	3.6^{c}	0.071*

SEM: standard error of the mean, * significant (P<0.05), NS: not significant (P> 0.05).

concentration of the enzyme (500 g vis. 300 g/ton in the present study) and 10 to 15% DDGS against 30% copra meal in this study. Fibre type and level, and enzyme concentration may all affect the effectiveness of fibre hydrolytic enzymes. Despite the similarities in calculated nutrient intake between the groups supplemented with Allzyme and the Allzyme+ mannanase, growth performance was not improved on the latter diet probably because the concentration of individual enzymes in the mixture (150: 150 g/ton) was low enough to cause meaningful hydrolysis. Pigs adapt to high fibre diets by increasing gut weight (Jørgensen *et al.,* 1996). The reduced digesta weight in the gut segments of pigs supplemented with Allzyme in this study may be attributed to an increased hydrolytic activity of Allzyme SSF®.

Conclusion

Allzyme SSF® supplementation at 300 g/ton of feed improves the utilization of up 30% dietary copra meal by growing pigs compared to a control diet without enzyme. Mannanase alone or in combination with Allzyme at this concentration does not improve performance comparable to Allzyme. Allzyme supplementation of copra meal-based diets will reduce cost of pig production; enhance nutrient utilization and income generation in copra meal producing regions. More research in higher levels of copra meal, enzyme concentration, and pig age are recommended.

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ECONOMIC EFFECTS OF COMMERCIALISATION OF CEREAL PRODUCTION IN KWARA STATE, NIGERIA

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ABSTRACT

Enhancing the livelihood of farming households through rational decision making is crucial to economic development. Farmers' decision to commercialize farm output can assist in achieving economic goal of crop production. The aim of this study therefore, is to examine the economic effect of commercialization of cereal production. This study was analyzed by Ordinary Least Square (OLS) technique and Sandler A-test, using the primary data collected from 160 cereal farmers. The study revealed that the commercialization variables such as the nature of cereal crops sold, crop commercialization experience, non-cereal crop income, rice commercialization index, commercialization cost and access to credit significantly explain the per capita income of cereal production. Sandler's A-test revealed the significant dispersion of farming households' income while commercializing cereal crops at different location. Farmers should therefore, harness the commercialization potentials to earn high income from cereal production. Cost saving incentives including transportation subsidy and zero/single digit-interest loan interventions become relevant for cereal farmers to achieve an effective commercialization and hence, increase the returns to cereal production.

Keywords: Commercialization, farm income, cereal production, farming households

INTRODUCTION

Farming households are dominating folks in the rural areas of developing countries including Nigeria. According to World Bank, (2010) report, 50.2% of Nigeria's people are mostly residing in the rural areas. Agricultural sector helps to generate income in the rural area as 65-75% of rural populace derived their livelihood mainly from agricultural activities (World Bank, 2002). Agriculture has been the only sector that absorbed over 90% of farming households which are responsible for about 90% of food production on small plot of land (Muhammad-Lawal *et al.,* 2015). Nigeria population keeps growing every day and the quantity of food produced are not enough to meet the growing population demand (Bamiduro and Gbadeyan, 2011). The inadequate food supply is not because of the small plot of farmland's production system found with the households rather, it is due to the fact that agricultural activities are being carried out with rudimentary implement, unimproved input, poor indigenous farming practices and inefficient demand driven commercialization process (Manyong *et al.,* 2005; Ismaila *et al.,* 2010).

Most of farmers in the developing countries are resource poor especially in commercializing their farm outputs. This position of commercialization is assumed to contribute to having low return from crop production. Though, with labor-intensive

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rudimentary farm tools, farming households still strive to quench/alleviate their family hunger and earn low income from food crop produced (Hagos and Geta, 2016). One of the most popular and important crops that satisfy these needs are cereal crops. This is because cereal crops play a vital role in the generation of income and diet of farming households. The grain crops that include maize, rice, wheat, barley, sorghum, millet, oat, rye, triticale, buckwheat, fonio and quinoa, are grown in large quantities and provide more food energy than any other crop across the world. Out of all cereal crops mentioned, the production and consumption of maize, rice and sorghum are very popular in Nigeria. These crops' role to dietary energy supply worth promoting the nutritive health of farmers (Ismaila *et al.,* 2010). Depending on culture and ethnicity food-norms, the consumption pattern through which dietary importance are gained from cereal crops includes: pastes, noodles, cakes, breads, drinks, flakes etc. The by-products after processing of cereal may also serve some importance such as deriving bran, husk, plant parts wax syrup, gum and other residues that could be useful for animal feeds, culturing microbes and industrial activities (Ismaila *et al.,* 2010).

Commercialization is the process contributing to the exchange for goods and services in return of income or wealth accumulation which provide close proximity towards improving living standard (Agwu *et al.,* 2012). Commercialization of cereal by farming household might be done on different methods to boost income. It can be done on location basis depends on the nature of the products, so far, there is an exchange of goods and services between producers and consumers. According to Cambridge dictionary (2014) in Aliresa *et al.* (2015), commercialization means "organizing something to gain or presentation" and "acquiring of product or service to market for earning profit" or "process of turning something in to commercial activity". This definition simply means that commercialization involves applying business methods to achieve profit for a new technology/product/service. An efficient business entrepreneur will be looking for any means to present new products and uphold new productive resources to achieve high profit. Cereal-farming households involve in commercialization not only to get the market surplus sold but also to present demand-driven products and to acquire farm-productive input at locations supporting income and productivity promotion. It was reported that commercialization could only be sustained in the rural market places (Kabiti *et al.,* 2016). Rural market is bulk building centers for chronological marketing of agricultural produce and services. Its periodicity is dimensional in terms of either temporal (day interval) or spatial-temporal market system. Both patterns have the capacity of adding to commercialization efficiency through the effective building up of supply side and demand side (Udosen and Adam, 2009).

However, some cereal farmers would prefer that commercialization based on certain products' nature should be done at home/farm-gate commercialization (wking/peddling/vending). Meanwhile, some farmers are discouraged to exchange their products in the rural market due to adverse situations like transportation break-down, theft, robber attack, poor roads, market-fire disaster, inadequate and unreliable market information to farmers and all result in goods spoilage and loss of life and revenue (Asemote, 2000). The farmers are stranded in the rural market at times, due to dearth insight to determine best commercialization procedures to achieve high profit, products got spoilt from to and fro transportation, product's quality retarded drastically due to late demand and cereal-farmers suffer a huge loss. Identifying the demand needs and where and how consumers want it, farming households' commercialization capable of generating income for sustainable cereal production and intensify the pathway of pulling rural people out of poverty (Rosegrant *et al.,* 2005). The significance of farm income from cereal commercialization is beneficial to farmers in diversifying their diet, purchasing non-farm needs and investing more modern cereal production practices such as in land preparation, soil improvement, weed management, pest control, harvesting. The relevance, which farm income could be used to improve the households' wellbeing is through efficient ways of commercialization. Commercialization of subsistence agriculture takes different forms before it's yielded the expected income. Based on the household's marketing decisions, profit can be maximized from both output and input choices. Farm income from commercialization can occur on the output side with increase in marketed surplus, but it can be occurred on the input side with the increase in purchase inputs or captured through commercialization cost (Hagos and Geta,

2016).

In terms of commercialization, farming household's income comes from different aspects of activities taken place in the rural community. The large portion of farming household's income comes from agriculture used and helps to sustain farmers' livelihood. The intricacy of commercialization is for agricultural products to be moved from farm centers to the individuals who desire to buy them for their immediate consumption and in turn raise cash earnings of small scale farmers (Bamiduro and Gbadeyan, 2011). Since, commercialization is driven by what consumer wants, hence, farmers are still finding it difficult to understand the determinants of farm income from commercialization viewpoints. Several studies across the world examined the determinants of commercialization either on location basis or otherwise (Barrett 2007; Gabre-Madhin et al. 2007; Davidova et al. 2009; Berhanu, Moti 2010; Agwu et al, 2013; Abu 2015; Gebreslassie et. al., 2015; Kabiti et al., 2016). Meanwhile, some other studies carried out on the determinants of income, income-inequality and income diversification (Babatunde, 2008; Ibekwe, 2010; Ibekwe et. al., 2010; Waniyame, 2010; Idown et al., 2011; Adebayo, Akogwu andYisa, 2012;). However, to our knowledge, we are not aware of study that have focused on economic outcome of commercialization of cereal production in Nigeria. Considering the significance of farm income as an economic goal and commercialization to the farmers' livelihood, it is therefore, imperative to carryout empirical research that gives clear understanding on the economic effect of commercialization of cereal production and we hypothesis that farm income from commercializing crops at home/farm-gate and market place are equal. In the light of this, the study intended to meet the following objectives such as to:

1. Describe the socio-economic characteristics of cereal producers

2. Determine the effect of location of commercialization on per capita income of cereal producers.

This study would provide relevant information that add to knowledge and enable cereal farmers understand the commercialization of cereal production variables contributed to high farm income. It shall also serve as a guide to enhance policy formulation by Government, stakeholders, and human livelihood planners in supportive to meeting the agenda of sustainable development goals (SDG).

METHODOLOGY

Study Area

The study was conducted in Kwara State, Nigeria. The agronomical practices in the state strive under two main seasons: wet and dry season with average temperature ranges between 27^{o} and 35^{o} C and a mean annual rainfall of 1,000-1,500mm. The natural vegetation cover in the state consists of rainforest in the south and guinea savannah to the north. The landscape comprises of hills, valleys and plains. The state has river Niger as a major river that transverses the state while the other rivers include: Asa, Osin, and Owu fall which serves as tourists attraction. With the existence of these natural endowments, the state is characterized with favorable weather conditions, good soil types, suitable topography and humidity that make possible the cultivation and development of several economic crops, especially cereal and others like cassava, vegetables, yam, cowpea, etc. (Kwara Agricultural Development Project KADP, 2011).

Data Collection and Sampling Techniques

The study depends on primary data which were collected from sampled farming households. According to KADP, Agricultural Production Survey Results (2011), the popularly planted cereal crops in the study area are maize, rice and sorghum. Data are collected on this available grain -framework from cereal farmers using structured questionnaire. Other secondary sources of information for the study were gathered from KADP annual survey results, online-journals, statistical reports. The cross section survey considers a three-stage random sampling techniques for selecting sample from registered target population of the study. The first stage is a random selection of one block each from the four Agricultural Development Project's Zones- Zone A, B, C and zones D in the study area. The second stage is a random selection of two (2) rural-cells from each selected block/district. The third stage, involves a random selection of twenty (20) cereal producers from each selected rural-cell/

Table 1. Data on the socioeconomic profile of the sampled farmers

Features	Frequency	Percentage (%)	Cumm frequency
Gender			
Male	134	84	134
Female	26	16	160
Age			
<30	3	2	3
30-60	119	73	122
>60	38	24	160
Marital Status			
Single	3	2	3
Married	131	82	134
Widow	9	6	143
Divorced	17	11	160
Households size			
<15	99	62	99
15-30	53	33	152
>30	8	5	160
Educational Status			
No formal	90	56	90
Formal	70	44	160
Comm_ Experience (yr)			
<5	19	12	19
5-30	51	32	70
>30	90	56	160
Cereal commc' nature			
Raw commodity	19	12	19
Value added	23	14	42
Both form	118	74	160
Commc distribution			
Farm gate/Home	13	8	13
Rural market place	20	13	33
Both location	127	79	160
Cooperative Membership			
Yes	93	58	93
No	67	42	160

community. Information gathered from 160 respondents (cereal producers) for the purpose of analysis or testing of hypothesis.

Analytical Techniques

The main tools employed to analyze the data collected for the study are: Descriptive Statistics (frequency distribution, percentages and mean), Pearson Product Moment Correlation (PPMC) and Ordinary Least Square (OLS). The PPMC was used to express the relationship that exist between crop commercialization variables and socioeconomic profiles of the respondents. The OLS was used to analyze the economic effect of commercialization of cereal production.

The explicit form of the OLS model expressed as:

$Y_i=f(X_{ij})+\mu_i$..... (1)

i = 1 to 160 (n)
j = 1 to 10 predictor variables

Where

Yi= per capita farm income as a proxy of economic effect (₦)
X1 = Nature of crop surplus (0= raw, 1= value added);
X2 = Commercialization experience (year);
X3 = Cereal commercialization cost (₦);
X4 = Maize commercialization index;
X5 = Rice commercialization index;
X6 = Sorghum commercialization index;
X7 = Gender (male=0, female=1);
X8 = Cooperative membership (no=0, yes=1);
X9 = Access to credit (no= 0, yes = 1);
X10= Non-cereal income (₦);
and ui= error term

This OLS technique followed the production functions fitted according to Muhammad-Lawal et al., (2013) as:

Linear Function:

$Y=a_0+b_1X_1+b_2X_2+...b_{10}X_{10}$..... .....*(2)*

Semi-log Function:

$Y=a_0+b_1logX_1+b_2logX_2+....+B_{10}logX_{10}$.....(3)

Cobb-Douglas Function:

$logY=a_0+b_1logX_1+b_2logX_2+....b10logX_{10}$....(4)

Exponential Function:

logY=a0+b1X1+b2X2+....b10X10.....(5)

Where, Y = dependent variable; a0 = Intercept; bj = Regression coefficients of the independent variables, Xj at j = 1, 2...10.

It shows how the dependent variable varies with the input level of the independent variables. The criteria used in selecting best fit out of the four functional equations included: (i)highest R2-value, (ii) highest number of significant variables, (iii) highest F-value and (iv) conformity to the apriori expectations of the regression coefficients. (Olayide and Heady, 1982; Muhammad-Lawal *et al.,* 2013). The model was estimated using maximum likelihood method and the Analysis of Variance ANOVA to confirm the existence of relationship in the OLS estimates.

Among the variables are commercialization indices for the common cereal produced by farmers in the study. The indices followed the commercialization index formulae given by Hagos and Geta (2016):

Sandler's A-test examines whether there is significance difference between income of cereal commercialization at home/farm-gate and market

$$Commercialization\ index = \frac{Value\ of\ Agricultural\ Sales}{Agricultural\ Production\ Value} \ldots\ldots\ldots\ldots (6)$$

place. Sandler's A-test exhibit the same function as t-test analysis but it association with large samples gives it an extra advantage (Kothari, 2014). This study was followed by a null hypothesis that:

H0: $Yi=Yi$ i.e., Farm income of cereal commercialization at home/farm-gate and market place are alike.

The hypothesis testing done using A-statistics with Significance level of α= 5%. The A-statistics formulated as:

Sandler's A-test formulae, where; Di = the two variables' differences (the aggregate farm income at different commercialization location i.e. home/

$$A = \frac{\sum_{i=0}^{n} D^2}{\left(\sum_{i=0}^{n} D\right)^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

farm-gate and marketplace) and n − 1 is the number of degrees of freedom for samples, Ac< At implies rejecting null hypothesis (Kothari, 2014).

RESULTS AND DISCUSSION

Socio-economic Characteristics

Table 1 shows the gender of respondents in the study area, dominated by male with 84% percent. This result was in consonance with findings of Adenegan *et al.* (2012) quoted that: "a typical Nigerian farming system especially in the western region where men are predominantly farmers". In relation to this observation, is the study of Cunningham et al., (2008) who also argue that not only on farming but also off-farming activities, men are likely to receive more income due to their acumen in bargaining and in negotiating and embarking on contracts.

embarking on contracts. The common age peculiar to these farmers, ranges between 30 and 60 years with 73% distribution. This is most productive segment of age range. About 82% of the respondents were married. This is the pre-cursor of increase in households' size. In relation to the respondents' family status, 62% of the respondents had below 15 members with household which contribute to the households' income in terms of alternative source of labour. According to Alene *et al.* (2008) and Omiti *et al.* (2009) postulated that the household size affects labor supply for production and submitted that more food is consumed than is produced, thus this have effect on income. This implies that household members tend to consume more than what is sold. In terms of schooling, 56% of the respondents were not educated. Meanwhile, the preference for education is desirable to minimize costs of search and screening information and transaction cost in both factor and product market (Matungul et al., 2001). The knowledge of commercialization and managing expenses requires to participate in the market as it's depends on the level of formal education. In the table 1, 54% of the respondents have commercial experience of more than thirty years which implies that there must be correlation between farmers' age and commercial experience. This is because farming households used to practice farming activities alongside with commercializing the surplus right from young. The nature of cereal crop surplus is another area of concern, 74% of the respondents get their commodity sold in either raw-form or adding value to it. Depending on the state of capital, the respondents look for easier means to dispose their goods that fetched them a quick and easy access to high income. The fact that security has contributed to why farming households have their farm very close to their homestead. This reduces the transportation cost of farm goods from farm to their home. However, in this study, 79% of the farmers prefer to sell their goods in both home/ farm-gate and marketplace. Also, from the study, the respondents that are member of cooperative were 93 (58%) out of 160 sampled rural households. This implies that majority of the households were benefiting from the cooperative's common goals which assist them adopting the best strategy to commercialization of farm produce.

Analysis of Socio-economic Profiles and Commercialization of Cereal by Farmers

The result in Table 2 reveals that there was stronger positive relationship between crop commercialization experience on age and household size with correlation coefficients (r) of 0.8205 and 0.5547, respectively. The coefficients of 0.3738 and 0.0289 on education and cooperative membership show negative relationship with households' experience on crops commercialization. Except for gender with coefficient of -0.0384, a weak positive relationship has been indicated by nature of crop surplus for commercialization on socioeconomic features like age, marital status, household's size, education. The distribution pattern of commercial crops express a weak negative relationship with the correlation coefficients of 0.0883 and 0.1011 on marital status and education. Leaving the gender, age and household's size having weak positive association with the distribution pattern of the commercial crops. We can infer from this analysis that there are stronger correlation between crop commercialization experience and age and household size. In order to prevent the arises of biased estimates due to multicollinearity in our regression model, only crop commercialization experience and other uncorrelated variables were retained for regression analysis.

Economic Effect of Commercialization of Cereal Production

Operationalizing the model specification in equation (1), Table 3 shows the estimates of determinants of farm income with respect to commercialization of cereal production which expresses in four functional forms vis: linear, semi log, Cobb Douglas and exponential function. The Cobb Douglas function was chosen as the lead equation because it has the highest number of significant coefficients, R^2-value, F-value and conform to a *priori* expectations of the regression model. The model shows that about 80% of per capita income variability was explained by various relevant-explanatory variables and this prove how good the fitness of the model. However, before fitting the model, the explanatory variables were subjected to preliminary test for existence of relationship which confirm by the robust value (65%) of F-test. The result of OLS technique, show that the regression coefficient of nature of cereal crop surplus is positively significant showing burly

Table 2. Result of tabular analysis of crop commercialization vectors and socioeconomic profile of cereal farmers

Cross Tabulation	Gender	Age	Marital status	HH size	Education	Crop comm Experience	Nature of comm	Distr of comm pattern	Cooperative membership
Gender	1								
Age	0.1259	1							
Marital status	-0.175	-0.0075	1						
HH size	0.2499	0.6869	-0.028	1					
Education	0.0993	-0.4631	0.1875	-0.4843	1				
Crop comm Experience	0.0569	0.8205	0.0327	0.5547	-0.3738	1			
Nature of comm crop	-0.0384	0.0639	0.0433	0.0164	0.0575	0.1279	1		
Distr of comm pattern	0.0126	0.0419	-0.0883	0.0466	-0.1011	0.0626	0.1666	1	
Cooperative membership	0.0549	-0.0429	-0.0505	-0.0066	0.0582	-0.0289	0.1172	-0.1341	1

association between farm income and commercialization vectors. The data on log farm income and log determinants relating to cereal commercialization have been used to fit the log linear farm income function (1). Following the expression in equation (4), the regression result of model 1 (per capita income) in table 2 shows that the coefficients of nature of commercialized cereal, commercialization experience, maize commercialization index, rice commercialization index and non-cereal income, which is constant elasticity of farm income, is significantly positive at various 10%, 5% and 1% levels. Some of the value is just above the unity, as in the case of linear farm income function, showing that a one percent increase in nature of cereal crop surplus and maize commercialization index lead to 1.7049 and 1.8925 percent increase in the farm income of cereal producers respectively. The implies that, the proportionate change in farm income is higher than the proportionate change for nature of cereal crop surplus and maize commercialization index showing the elastic nature of the farm income of cereal producers. Other positive significant values are below unity, which imply that one percent increase in commercialization experience, rice commercialization index and non-cereal income lead to 0.2299, 0.9748, 0.3393 percent increase in the farm income. This indicates that the proportional change in commercialization experience, rice commercialization index and non-cereal income translating to small change in per capita income, showing the inelastic nature of the deriving revenue. These result affirmed the conclusion of Gebreslassie *et al.* (2015) that, participation in crop commercialization has a positive and significant impact on smallholder livelihoods through improved income and asset holdings. Likewise, this statement was also in consistence with the inference reported from Barrett (2007); Gabre-Madhin *et al.* (2007); Davidova *et al.* (2009); Berhanu, Moti (2010); Agwu *et al.* (2013); Abu (2015); Kabiti *et al.* (2016). However, the result further shows that the regression coefficients of commercialization cost and access to credit have sign of coefficients that are negatively significant at 1% and 10% levels respectively. This is showing the opposite relationship between farm income and commercialization cost as well as against access to credit. The rate of change of per capita income to commercialization cost and access to credit are inelastic (0.8762 & 0.5629). These findings are supported by Wanyama *et al.* (2010) that reported that lack of capital, become detrimental factor for farmers to integrate from subsistence agriculture to commercial farming. Hence, suggested that credit scheme policy would play significant role in

Table 3. Result of economic effect of commercialization of cereal crops

Variable	Linear	Semi log	Double log	Exponential
Constant	0.1160 (11.92)	1.4851 (15.86)	1.9579 (4.51)	0.1544 (43.90)
X_1	0.1491*** (4.11)	0.3035*** (8.00)	1.7049*** (9.02)	0.4505*** (3.44)
X_2	0.4110 (1.46)	0.5869*** (4.34)	0.2299* (1.67)	0.1899* (1.87)
X_3	-0.4646 (1.07)	-0.0273 (0.56)	-0.8762* (1.69)	-0.0000165 (1.06)
X_4	0.8110*** (2.69)	1.0338*** (7.73)	1.8925*** (5.28)	0.5096*** (4.68)
X_5	0.2670 (0.21)	0.3724 (1.49)	0.9748** (1.96)	0.0102*** (2.33)
X_6	0.3798 (0.40)	0.0916 (0.14)	1.8225 (0.10)	0.0895 (0.26)
X_7	0.2321 (0.53)	0.3446 (1.22)	0.2342 (1.54)	0.3452 (1.63)
X_8	0.2212 (0.64)	0.0306 (0.08)	1.8685 (0.19)	0.0531 (0.42)
X_9	-0.1341*** (5.92)	-0.2302*** (3.52)	-0.5629*** (3.48)	-0.0531*** (6.49)
X_{10}	0.1848** (1.98)	1.1309 (0.52)	0.3393* (1.65)	0.6134 (0.26)
R2	0.7623	0.734	0.7961	0.7096
F-value	53.44	45.98	65.08	40.72

Estimation coefficients with t-value in parentheses. ***, **, * were significant at 1%, 5%, and 10% level respectively.

the households' income diversification (Babatune, 2008; Ibekwe, 2010; Ibekwe *et. al.,* 2010; Waniyame, 2010; Idown *et al*., 2011; Adebayo, Akogwu and Yisa, 2012). Therefore, such policy would also be sufficing for commercialization of cereal production to promote per capita income.

Effect of Location on Commercialization

Since H0 was one-sided, we applied one-tailed test of Sandler's A-test. According to equation (7), the result in Table (4) showed that at 5% level of significant, the table value of A-statistic was given as 0.369. The computed value of 0.0431 was therefore lower than the table value and as such A-statistic is significant and accordingly H0 was rejected. In other words, there is significant dispersion in the per capita income generated from home/farm-gate and marketplace which signifies the relevancy of the location of commercialization of cereal output to increase farm income. (This inference will be the same for paired t test that applies only in case of small samples). Thus, the per capita income from marketplace commercialization is high compare to home/farm-gate commercialization. So the higher level of marketplace crop commercialization, the more the households gain more income. This result confirmed the assertion of Rahman and Westley (2001) that "crop production and its respective commercialization accounts for over sixty percent of peasant household's income".

Conclusion and Recommendations

The commercialization variable such as the nature of cereal crop surplus sold, commercialization experience, maize and rice surplus for commercialization and non-cereal crop income have significant impact to increase farm income of cereal producers. The cereal commercialization cost and access to credit were

Table 4. Influence of location on cereal income generation

Sample size: 160 Included observation: 120 (A_t =0.369)					
Outcome Variable	Home/farm-gate (N=140)	Marketplace (N=147)	$\sum D_i^2$	$(\sum D_i)^2$	A-value
Per capita income	615	2380	210	4872	0.0431

the only variables that significantly and negatively explain farm income of cereal producers. It is also inferred from the study that, there is significant different in the per capita income got from cereal commercialization at home/farm-gate and marketplace. So, location of commercialization has effect on farm income as it was revealed by Sandler's A-test result. The study is therefore suggested that: Farmers should be encouraged to explore and harness the potentials in commercialization of cereal production to improve profit. Cost saving incentives in terms of transportation subsidy and zero/single digit-interest loan should be available for cereal farmers to facilitate effective commercialization and hence, increase farm income.

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Niugini Agrisaiens

OCCURRENCE OF *Meloidogyne incognita* IN SWEETPOTATO GARDENS IN THE LOWLAND PROVINCES OF PAPUA NEW GUINEA

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ABSTRACT

Meloidogyne incognita is an important pathogenic nematode worldwide and has been reported to cause significant yield losses on sweetpotato. A survey was conducted in eight provinces of Papua New Guinea (PNG) lowlands, where sweetpotato is grown to assess the presence of this pathogen. DNA from nematode samples, were PCR-amplified using species-specific DNA primers and produced expected DNA bands of 1.2 kbps. Sweetpotato root systems were assessed for presence of galls and egg masses and showed a rating index range of 0 to 5. Assessment of soil samples showed a population range of 0 to 720 per 250 cm3 soil. Sole and mixed cropping systems did not appear to influence the disease ratings and population counts, as low and high scores were recorded for both systems. Meloidogyne incognita was recorded from sweetpotato gardens in 20 out of 22 local level government (LLGs) areas surveyed in eight provinces. Incidence of M. incognita from five random samples using DNA-based PCR detection, ranged from 0 to 100% with 8 and 3 out of 22 LLGs recording over 50% and 100% incidence, respectively. This survey revealed that there is widespread distribution with high incidence of M. incognita in sweetpotato gardens in the lowlands of PNG. These observations are helpful for sweetpotato farmers when issues of yield decline and management of this pathogenic nematode species are considered.

Keywords: *Meloidogyne incognita*, root-knot nematode, sweetpotato, nematode distribution

INTRODUCTION

Papua New Guinea is a tropical country (6º 00" S; 147º 00" E) with NW monsoon (Dec-Mar) and SE monsoon (May-Oct) and slight seasonal temperature variation (McAlpine and Keig, 1983). PNG has been divided into four rainfall regimes according to the total annual rainfall received: dry subhumid (1000-1500 mm), subhumid (1500-2000 mm), humid (2000-3500), and perhumid (>3500 mm) (McAlpine and Keig, 1983). Distribution of agricultural crops varies based on five agro-climatic zones determined by altitude, and include: zone I (lowlands, 0-600 m), zone II (premontane, 600-1500 m), zone III (lower montane, 1500-1800 m), zone IV (midmontane, 1800-2700 m), and zone V (upper montane, 2700-3200 m) (Gurnah, 1992). Sweetpotato is grown by farmers in zone I through to zone IV (Gurnah, 1992). This distribution of agro-climates in PNG provides an ideal environment for plant pathogens to flourish, including plant-parasitic nematode of the genus, *Meloidogyne*.

In an effort to record the global distribution of *Meloidogyne* spp., eight worldwide geographical regions were mapped and surveyed (Sasser and Carter, 1985). The species *M. incognita* is responsible for extensive economic damage to

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many agricultural crops throughout the world including sweetpotato (Clark and Moyer, 1988). In the Pacific Island nations, *M. incognita* was recorded on a number of crops in the countries and island groups, including Fiji, Kiribati, Niue, PNG, Norfolk Island, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu (Bridge, 1988).

In PNG, a survey was conducted in 1982 (Bridge and Page, 1984) covering two highlands (Southern and Western) and three lowlands (East Sepik, Morobe and East New Britain) provinces. About 10-15% of the sweetpotato gardens in the highlands provinces had serious *Meloidogyne* infestation, with *M. incognita* and *M. javanica* being the dominant species. The survey further revealed that occurrence of *Meloidogyne* was more than 45% in 269 sampled sites from the five provinces. High population counts of *Meloidogyne* were also observed in soil samples obtained from two sweetpotato experimental sites in the Morobe Province (Hartemink *et al.,* 2000).

Biodiversity, tropical ecology and mostly mountainous geography in PNG pose much challenge to offer conclusive status of *Meloidogyne* in farming fields. In reference to the survey in 1982, Bridge (1988) stated that work on plant-parasitic nematodes in the Pacific was not definitive but only the end of the beginning of nematological knowledge. Over the last thirty years, there has been only sporadic research on plant-parasitic nematodes in PNG. There was an increase in sweetpotato cultivation in several lowland provinces (Allen *et al.,* 2001), where incidence and distribution of *M. incognita*, a dominant and serious parasitic nematode, is unknown. A survey was, therefore, conducted in the sweetpotato gardens in lowland provinces to assess the distribution and incidence of *M. incognita*.

MATERIALS AND METHODS

Source of Samples

During the periods from 2011-2012, soil and root samples collected from sweetpotato gardens in eight provinces were assessed for the presence of *M. incognita*. The local level governments (LLGs) were chosen in lowland provinces (Table 1), where there was increased cultivation of sweetpotato (Allen *et al.,* 2001). Gardens were selected randomly and were approximately 5 km from each other. Soil and root samples were collected from one month old gardens. All laboratory assessments for root galls and egg mass as well as population counts in soil samples were done in the Applied Entomology Laboratory in the UniTech Biotechnology Centre (UBC) of PNG University of Technology (PNG UniTech). In 2011, cocoa pods from ten (10) clones (Table 1) were collected from the "Sick plot" field at the Cocoa Coconut Institute PNG (CCIPNG) in Madang. These were used to grow seedlings and leaves were collected for *in vitro* inoculation. However, in 2012, only nine clones (Table 1) were collected from the same location as pods were not available in one clone. Among the clones collected, K 82 was known to be susceptible to VSD, and, therefore, was used as a susceptible check (control). In both years, two to three clean and very healthy looking pods were collected from each clone along with infected twigs and leaves, placed into Glad wrap zip bags® (one clone per bag), labeled and sealed to maintain high humidity while in transit.

Collection of Samples

Soil samples were collected at a depth of 20 cm from 20 cores along diagonal transects in sweetpotato gardens, bulked and then mixed. Five sets of composite sample of about 2 kg were retained for each sample for processing in the laboratory. Root samples were randomly collected from 5 sweetpotato plants along the same transect. A total of 110 random samples each were obtained for soil and roots for processing followed by nematode detection using both microscopic and molecular assays.

Nematode Extraction from Soil and Roots

Nematodes were extracted from the soil samples using a modified Baermann's tray technique described by Barker (1985) and Stirling and Stanton (1998). Soil (250 cm^3) was evenly spread on a tissue paper placed over a mesh of wire in a baking tray. Tap water was carefully added from the edge of the tray until the soil was just moist. The preparation was left at room temperature (RT) of about 29^oC for 72 h. A 38 μm Endecott sieve was then used to recover the nematodes by washing the samples into vials. Volume of nematode suspension was standardized and 5 ml of the aliquot was poured into nematode counting slides to determine the population under

Table 1. Provinces and LLGs surveyed

Province	LLGs[1]	Cropping system[2]
District of Bouganville	Buka Urban	Mixed
Central	Rigo Inland	Mixed
	Rigo Central	Mixed
	Rigo Coastal	Mixed
	Hiri Rural	Sole
Madang	Madang Urban	Mixed
	Sumgilbar Rural	Sole
Milne Bay	Alotau Urban	Mixed
	Makamaka Rural	Mixed
Morobe	Ahi Rural	Mixed
	Labuta Rural	Mixed
	Lae Urban	Sole
	Mutzin Urban	Sole
	Nabak Rural	Mixed
	Wampar Rural	Mixed
New Ireland	Kavieng Rural	Mixed
Oro	Higaturu Rural	Mixed
	Kokoda Rural	Mixed
	Popendetta Urban	Mixed
	Buna	Mixed
West New Britain	Hoskins Rural	Mixed
	Mosa Rural	Mixed

[1]LLG = Local Level Government

[2]Mixed = sweetpotato plus other crops in the same garden; sole = sweetpotato alone.

a compound microscope at 40X magnification. Root samples were gently washed under running tap water and then assessed for galls and egg masses under a dissecting microscope at 40X magnification. Roots were rated for galling index (GI) and egg mass index (EI) on a 0-5 scale (Daulton and Nusbaum, 1961; Hartman and Sasser, 1985).

Molecular Detection of *M. incognita*

DNA Extraction

DNA was extracted from individual infective juveniles following the procedure described by Powers *et al.* (2005). An infective juvenile was placed on a sterile cover slip in drops of sterile water and crushed with a sterile pipette tip, while viewing under a dissecting microscope at 40X magnification. DNA was also extracted from eggs and mature females according to procedures described by Dong *et al.* (2001). Eggs and female nematodes were suspended in DNA isolation buffer (100 mM NaCl, 100 mM Tris-HCl pH 8.5, 50 mM EDTA, 1% SDS, 1% ditriothretol, and 100 µg ml-1 Protenase K), and incubated at 65oC for 1 h with occasional agitation. DNA was then extracted with phenol/chloroform mixture, precipitated in isopropanol at RT, and the DNA pellet was washed twice with 70% ice-cold ethanol. The pellet was re-suspended in sterile water and stored at -20^{o}C.

PCR Amplification and Detection of DNA

DNA from random samples of juveniles from soil extracts and mature females and eggs from infected roots were PCR-amplified using species-specific sequence characterised amplified region (SCAR) oligomers developed by Zijlstra *et al.* (2000) with forward and reverse oligonucleotide sequences: (Finc: 5′-CTCTGCCCAATGAGCTGTCC -3′ and Rinc: 5′-CTCTGCCCTCACATTAAG-3′). The PCR reaction condition volumes of 25 µl contained 5 µl crude DNA template (1 µl purified DNA), 2.5 µl 10x pre-stained PCR buffer + Mg2+ (Geneworks), 0.6 µl 10 mM dNTPs, 0.6 µl 10 µM of the forward and reverse primers, 0.5 µl 5 U µl-1 of Taq DNA polymerase (Geneworks), and ddH20 to bring to total volume. The Eppendorf Mastercycler (Eppendorf®) was programmed for 2 min at 94 ^{o}C followed by 35 cycles of 30 s at 94oC, 30 s at 61^{o}C and further synthesis for 3 min at 72^{o}C. The PCR amplified products were electrophoretically fractionated on 1% agarose gel and DNA bands visualized by UV illumination after staining with ethidium bromide (0.5 µg µl^{-1}).

RESULTS

PCR Detection

The species-specific bi-directional oligomers

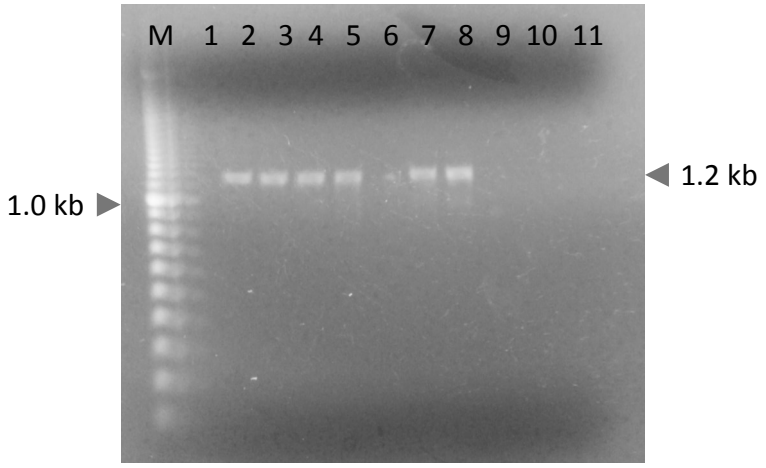

Figure 1. Typical amplified products using Finc/Rinc primers for *M. incognita*. M: Geneworks DNA marker; 1: Negative control; 2: Buka Urban; 3: Sumgilbar Rural; 4: Alotau Urban; 5: Lae Urban; 6: Kavieng Urban; 7: Kokoda Rural; 8: Hoskins Rural; 9: Rigo Inland; 10: *M. javanica*; 11: Healthy sweetpotato root.

produced expected DNA bands of 1.2 kbps when fractionated on 1% agarose gel (Figure 1) for all samples except those collected from Rigo and Kavieng.

Galls, Egg Mass and Juvenile Counts

The composite soil samples collected within the vicinity of the plants were processed for juvenile counts and the results are presented in Table 2. The lowest and highest disease ratings for GI and EI in the sampled root systems ranged from 0 to 5. The juvenile population from soil samples ranged from 0 to 720 per 250 cm^3 soil. Type of cropping system did not appear to influence the index ratings and population counts, as low and high scores were recorded from both cropping systems.

Incidence and Distribution of *M. incognita*

The presence of *M. incognita* in the soil and root samples of sweetpotato collected from 22 LLGs in 8 provinces of the lowland region of PNG are presented in Table 3. *M. incognita* was present in all samples collected from 20 LLGs in 7 provinces not in those collected from the Rigo Inland LLG (Central Province) and Kavieng Urban LLG (New Ireland Province). Incidence of *M. incognita* from five random samples using DNA-based PCR detection ranged from 0 to 100% with 8 and 3 out of 22 LLGs recording over 50% and 100% incidence, respectively. The molecular detection revealed widespread distribution and high incidence of *M. incognita*. No clear trend was observed in the distribution and incidence of *M. incognita* in relation to the annual rainfall regimes reported for each location, as low and high counts of juveniles and gall and egg mass indices were recorded both in areas of low and high precipitation.

DISCUSSION

A comprehensive survey to establish the status of diseases, incidence and distribution of certain pathogens is an essential routine activity in crop disease research and development programs. Routine surveys facilitate research focus involving disease forecasting, epidemiological studies, and predictions of yield losses. The importance of plant-parasitic nematode species in the genus *Meloidogyne*, in terms of distribution, host range and serious effects on crop productivity triggered the establishment of the International Meloidogyne Project (IMP) in 1975 (Sasser and Carter, 1985). The most evident damage to crops occur in warm areas because: (i) higher temperatures and longer growing seasons result in more generations/year, high nematode populations leading to more crop damage, (ii) greater number of susceptible crops/year results in higher nematode build-up, (iii) more damaging species, like *Meloidogyne incognita*, occur in warmer areas, and (iv) more severe disease complexes occur in warmer areas (Mai, 1985).

PNG is situated in the warm tropical region of the world (McAlpine and Keig, 1983) and its agro-

Table 2. Presence of galls, egg masses, and juveniles of *Meloidogyne incognita* in root and soil samples

Province	LLGs[1]	Cropping system[2]	Roots[3]		Juvenile count (per 250 cm[3])
			GI	EI	
District of Bouganville Central	Buka Urban	Mixed	3	3	35
	Rigo Inland	Mixed	0	0	0
	Rigo Central	Mixed	2	2	75
	Rigo Coastal	Mixed	3	3	66
	Hiri Rural	Sole	2	2	10
Madang	Madang Urban	Mixed	3	3	70
	Sumgilbar Rural	Sole	2	2	50
Milne Bay	Alotau Urban	Mixed	4	4	120
	Makamaka Rural	Mixed	2	2	44
Morobe	Ahi Rural	Mixed	3	3	104
	Labuta Rural	Mixed	3	2	67
	Lae Urban	Sole	4	3	96
	Mutzin Urban	Sole	4	3	250
	Nabak Rural	Mixed	4	4	300
	Wampar Rural	Mixed	5	5	720
New Ireland	Kavieng Rural	Mixed	0	0	0
Oro	Higaturu Rural	Mixed	2	2	30
	Kokoda Rural	Mixed	3	2	110
	Popendetta Urban	Mixed	3	2	72
	Buna	Mixed	4	3	200
West New Britain	Hoskins Rural	Mixed	5	3	105
	Mosa Rural	Mixed	3	3	78

[1]LLG = Local Level Government
[2]Mixed = sweetpotato plus other crops in the same garden; sole = sweetpotato alone.
[3]GI = Gall index; EI = Egg mass index.

climatic conditions are conducive for pathogens to thrive and cause substantial yield losses in agricultural crops. The current survey to assess the status of *M. incognita* in the sweetpotato gardens in the lowland provinces of PNG revealed wide distribution and high incidence of this serious soil-borne pathogen. This observation is consistent with a report that four major species of *Meloidogyne* (*M. incognita*, *M. javanica*, *M. arenaria* and *M. hapla*) account for more than 95% of the root-knot nematodes received from agricultural soils from over 70 countries in eight geographical regions in the tropics (Sasser and Carter, 1985). Root-knot nematodes are prevalent in the Pacific Island nations with *M. incognita* and *M. javanica* the most dominant species, occurring on almost all 19 crop species assessed (Bridge, 1988). In PNG, *M. incognita* and *M. javanica* were found to be prevalent in sweetpotato gardens in two lowlands and three highlands provinces

Table 3. Distribution and incidence of *Meloidogyne incognita* in sweetpotato gardens in sampled lowland areas of Papua New Guinea

Province	LLGs[1]	Distribution[2]	Incidence[3] (%)	Rainfall regime[4] (av mm/yr)
District of Bouganville	Buka Urban	+	20	2000-3500
Central	Rigo Inland	nd	0	1000-1500
	Rigo Central	+	60	1000-1500
	Rigo Coastal	+	40	1000-1500
	Hiri Rural	+	40	1000-1500
Madang	Madang Urban	+	20	2000-3500
	Sumgilbar Rural	+	20	2000-3500
Milne Bay	Alotau Urban	+	40	1000-1500
	Makamaka Rural	+	20	1000-1500
Morobe	Ahi Rural	+	40	>3500
	Labuta Rural	+	40	1000-1500
	Lae Urban	+	100	>3500
	Mutzin Urban	+	100	1500-2000
	Nabak Rural	+	40	>3500
	Wampar Rural	+	100	1000-1500
New Ireland	Kavieng Rural	nd	0	2000-3500
Oro	Higaturu Rural	+	60	2000-3500
	Kokoda Rural	+	40	2000-3500
	Popendetta Urban	+	20	2000-3500
	Buna	+	60	2000-3500
West New Britain	Hoskins Rural	+	80	2000-3500
	Mosa Rural	+	60	2000-3500

[1]LLG=Local level government

[2]+= M.incognita was detected; nd= M.incognita was not detected by PCR assay

[3]Population of *M. incognita* in five samples tested by PCR assay

[4]Rainfall regime for surveyed areas according to McAlpine *et al.* (1982) cited in Bleeker (1983)

surveyed, with *M. incognita* being the dominant one (Bridge and Page, 1984). Geographical distribution of *Meloidogyne* spp. is dependent on host range, temperature, precipitation, soil composition, and other ecological characters (Sasser and Carter, 1985). *Meloidogyne incognita*, *M. javanica*, and *M. arenaria* (warmer climate species) inhabit areas with average annual temperatures between 15 and 33°C; and in low rainfall regimes (≤ 500 mm/year), abundance is two-thirds and one-third for *M. javanica* and *M. incognita*, respectively (Taylor *et al.,* 1982). Generally, root-knot nematodes occur most frequently in soils with less than 10% clay, less than 30% silt, and at least 60% sand (Sasser and Carter, 1985).

In PNG, there are no extremes of very high or very low temperatures. The lowland areas surveyed are located in the altitudes between 0-600 m with mean daily maximum and minimum temperatures of 32°C and 23°C, respectively (McAlpine and Keig, 1983). These areas have an average annual rainfall regime of 1000 - >3500

mm (McAlpine et al., 1982), a precipitation range ideal for sweetpotato cultivation (Gurnah, 1998). Sweetpotato prefers soils that are fertile, welldrained and of sandy loam texture as heavy clay loams reduce tuber quality (Titus, 2008). Specific texture of soil in the survey locations of the current study was not determined, but sweetpotato farmers in PNG often improve the soil structure through tillage and other farming practices to grow this crop (Bourke and Harwood, 2009). In these agro-climatic conditions, *M. incognita* can be seen to thrive as reflected in the observations on its distribution and incidence in the current survey. This is expected since root-knot nematodes can occur anywhere the host plants grow (Sasser and Carter, 1985).

Cropping systems, such as cropping sequences, crop rotation schemes, mixed cropping and sole cropping of resistant crop varieties have been employed as management practices to reduce populations of *Meloidogyne* spp. (Sasser and Carter, 1985). Mixed cropping system, where multiple crop species are planted in the same garden has multiple benefits and is the cropping system widely used in PNG (Burke and Harwood, 2009). This observation is consistent with the current study, where mixed cropping system was seen to be dominant in twenty two LLGs surveyed in the eight lowland provinces. Factors, such as soil tillage, slash-and-burn shifting cultivation practice and mixed cropping, which are common in PNG, may influence populations of *M. incognita* as evident in the wide population distribution recorded from the present study.

Sweetpotato is commonly planted with crop species that are either non-hosts or, "less important or less well known" hosts (Bridge, 1988). Apart from edible crop species, presence of weed species can also influence parasitic nematode populations, including *M. incognita* in the food gardens (Ardakani and Mirinejad, 2013). A survey in Fiji, revealed 45 and 11 weed species as potential hosts and non-hosts to *Meloidogyne* spp., respectively (Singh *et al*., 2010). In PNG, information on alternative hosts or non-hosts species of edible crops and weed species is an area that needs to be explored.

The current survey and detection revealed widespread distribution and high incidence of *M. incognita* in 22 LLGs covering eight lowland Provinces. This distribution was not uniform and may be attributed to the agro-ecological conditions, cropping systems and availability of alternative host and non-host plant species. The complex tropical geography and biodiversity coupled with largely subsistent agriculture system in PNG offers an ongoing challenge for research scientists to compile conclusive status on plant-parasitic nematodes. The observations of this study should assist farmers and interest groups associated with sweetpotato and its cultivation in this country.

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Chartier, P. and Catsky, J. (1999). Photosynthetic systems: conclusions. In *Photosynthesis and productivity in different environments*, 425 – 433 (Ed J.P. Cooper). Cambridge: Cambridge University Press.

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