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EFFECTIVENESS OF INFORMATION DELIVERY THROUGH THE AKIS/RD AGRICULTURE EXTENSION MODEL: A PRELIMINARY CASE STUDY IN RICE FARMING SYSTEMS IN TWO DISTRICTS OF THE MOROBE PROVINCE

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ABSTRACT

A preliminary study was done among the rice farmers in two districts of the Morobe Province to examine the efficiency and the interdependency in the flow of innovative information and knowledge to the farmers as the primary recipients. The two study areas concerning training given to farmers and visits by agricultural agencies to farmers showed notable deficiencies and differences. The study showed 58% of farmers in the Wain-Erap Rural Local Level Government (LLG) received information on rice cultivation from friends, relatives and other farmers, while 79% of farmers in the urban and peri-urban LLGs received the same from government organizations. Over 90% of farmers from the rural, urban and peri-urban LLGs reported no visits from all agriculture related organizations. Overall, extrapolations revealed farmer training to be less systematic and non-routine, and visits to the farmers found to be sporadic. This preliminary study provides information that is crucial for further investigation to ensure that the farming communities in PNG are better served, while collaboration and information sharing between key stakeholders, strengthened.

Keywords: AKIS/RD model, information dissemination, rice farmers, case study .

INTRODUCTION

Models of varied structures, compositions and linkages are constructions meant to address certain aspects of practice in any established system. The enterprises of agriculture at subsistence, semi-commercial and commercial scale are promoted and sustained through the engagements in agricultural research, education, and extension. At the centre of this triangular paradigm are farmers, who are the important recipients of information and knowledge.

An agriculture-based 'Knowledge Triangle' model was developed (FAO and World Bank, 2000) and called the 'Agricultural Knowledge and Information Systems for Rural Development' (AKIS/RD) model (Fig. 1). The model reflects the relationship between the key stakeholders including researchers, educators, extension officers, and farmers. The indications of reverse linkages between the stakeholders in the model highlights the importance of interdependency in the flow of innovative information and knowledge meant to initiate change in target recipients (individuals, groups or communities). The AKIS/RD model is being used in the agricultural systems in Papua New Guinea (PNG) to disseminate information and knowledge to farmers and farming communities. In many aspects, the effectiveness of disseminating any innovative technology and associated information depends largely on effective communication within and between the stakeholders.

This research was conducted as a preliminary case study to investigate the dissemination of rice production-related information through the AKIS/RD model. The outcomes of this study were to form the basis for a more elaborate investigation covering a wider scope into the agricultural information

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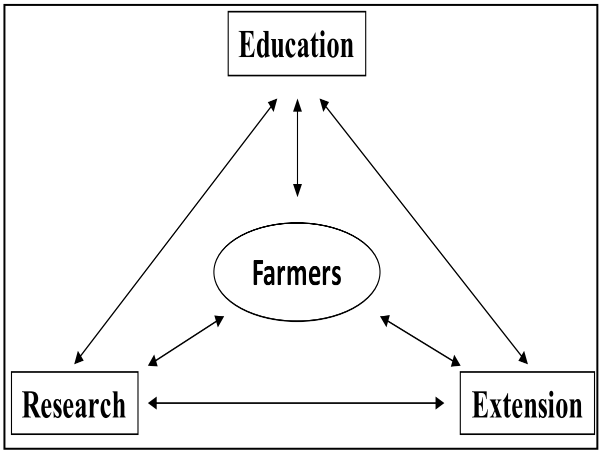

Figure 1: A model for "Agricultural Knowledge and Information System for Rural Development - AKIS/RD (FAO and World Bank, 2000).

dissemination and utilization systems amongst the farming communities in PNG.

MATERIALS AND METHODS

Period, Locations and Participants

This case study was conducted in 2013 and 2014 in the Morobe Province, covering three local level governments (LLGs) in two districts. These LLGs included the Wain-Erap Rural LLG (Nawaeb District) and the Lae-Urban and Ahi-Rural LLGs (Lae District). Follow-up interviews of contact and non-contact farmers were done in 2015 and 2016. The participants were selected using the 'Snowball' sampling technique (Faugier and Sargeant, 1997) because of the unavailability of information regarding the names and location of these rice farmers and that access to these farmers was difficult due to remoteness of the districts. The sample of farmers comprised of both literate and illiterate women, youth and men. This selection method was utilized for a more holistic approach as suggested by Mefalopulos (2007).

Data Collection

Survey

At the start of this case study, a general survey was carried out to gauge a canvas view of the extent of rice production in the Morobe Province. This was done through brief interviews with officers in the Provincial Department of Agriculture and Livestock (PDAL), District Rural Development Officers (DRDOs) and other stakeholders in rice production including contact and non-contact rice farmers, the National Agricultural Research Institute (NARI), Trukai Industries Limited, Taiwanese Agricultural Technical Mission, PNG Women in Agriculture, Agriculture Department of PNG University of Technology (PNGUT) and South Pacific Institute of Sustainable Agriculture and Rural Development of PNGUT; as well as literature on rice information for the Province. The GIS facility at the Lands and Surveying Department of the PNGUT, and databases from PNG Resource Information System, Mapping of Agricultural Systems Project and National Research Institute were used to generate a rice distribution map (Maino, 2014).

Focus group discussion

This form of information acquisition was used according to techniques described by Morgan (1998). Meetings were held with Agricultural officers from the Morobe PDAL, Lecturers at the Agriculture Department of PNGUT, and officers from NARI. Subsequent meetings were separately held with contact and non-contact farmers from the Wain-Erap, Ahi-Rural and Lae-Urban LLGs.

Questionnaire

A questionnaire comprising structured and non-structured questions were prepared and distributed to target groups including PDAL extension officers, researchers, educationists, and farmers. Uniformity in the participants' responses was encouraged in the types of questions set, which also facilitated an accurate assessment of views for comparison between rice farming practices in the three LLGs.

Interviews

Interviews were conducted according to guidelines described by Gill et al. (2008). Interviews were necessary because initial meetings held with DRDOs and farmers in attendance revealed that the farmers had some discomfort in answering questions in the presence of the agriculture officers.

Participatory Development Communication Workshop

Two PDC workshops were run in the first and second phases of data collection. In the first phase, officers from the PDAL, DRDOs, Service Providers and other rice producing stakeholders were brought in for a day's workshop, where discussions were centred on the issue of the extent of rice production in the Morobe Province and the strategies that were currently applied in disseminating information to rice farmers. In the second phase, participants from the three LLGs, as well as officers from the stakeholder organisations, were brought in for two days to participate in a rice training workshop during which activities were centred on discussing the rice production activities in each district as well as identifying the methods applied in disseminating information to promote rice production.

Data Analysis

The data collected from the survey questionnaires, focus group discussions, interviews and participatory research workshop were processed through the interactive model of data analysis described by Miles and Huberman (1994). Microsoft Excel® 2010 version was then used for descriptive data presentation.

RESULTS

Source of Training Received to Grow Rice

This study revealed 58% of farmers in the rural LLG of Wain-Erap received knowledge and skills on ways of growing rice from “others”, while 20%, 17% and 5% received training from research institutions, private sector industries, and government organizations, respectively. This was contrary to the urban LLG of Lae, where training was mostly received from the government organizations (79%), while 6% and 15% was received from the non-government organizations and “others”, respectively. Other agricultural organisations featured less routine or offered no training during single or multiple cultivation seasons (Table 1).

Agricultural Organisations that Visited Farmers

According to the study, over 90% of farmers from the rural, urban and peri-urban LLGs reported no visits from all agriculture related organizations (Table 2). For rice farmers in all LLGs, there were sporadic visits from some agricultural organizations, and this visits were made mainly to distribute rice seeds to contact farmers.

Information Delivery Through the AKIS/ RD Model

This study preliminarily deduced by interpolation information flow between all stakeholders (Fig. 2). The question marks in the model indicated that the level of collaboration and information sharing between these stakeholders needed further investigation. For instance, reduced usage of highly scientific expressions (language and literature) and frequency and the mode of information delivery, respectively. This study showed that stakeholders disseminated innovative information to farmers, whenever and however each one of them felt convenient and appropriate. The broken lines of the model show that communication and information dissemination was sporadic.

DISCUSSION

For any introduced innovation to cause a targeted impact in a targeted community there must be effective communication and a dynamic model for knowledge, skills or information dissemination system. In a linear information transfer system, educationists or researchers would pass on knowledge and skills sets, packaged into user-friendly format, to the extension officers, who would then disseminate these to the farmers for appropriation. In the triangular AKIS/RD model, the key stakeholders, namely educators, researchers and extension officers, as sources of information could independently disseminate these to farmers.

The recent preliminary investigation into the latter model revealed that farmers sporadically received innovative information from the key stakeholders (information sources). In terms of farmer training and farmer visitation, rural farmers appeared to receive these services comparatively less frequently than farmers situated in the vicinity of urban and peri-urban localities. The observations from this study indicated that the source of receiving information on rice production was mostly informal through friends, relatives, other farmers and in some cases, community leaders, such as Pastors of religious denominations.

This observation is consistent with an earlier study conducted on the *two-step flow* communication theory that suggested that ideas often flow from radio and print to the opinion leaders and from them to the less [active] sections of the population (Lazarsfeld and Menzel, 1963). They further stated that people tend to be much more affected in their decision making process by face to face encounters with influential peers than by the mass media, in this case, receiving information and training from agriculture trained personnel or organisations. The farmers in this study felt comfortable working with and relying on the opinion leaders, such as the Service Provider or the Pastor. The reliability of information and knowledge coming from such sources, however, may be debatable.

Table 1: Source of training received by farmers on growing rice

Source	Proportion of farmers receiving some training (%)	
	Lae LLGs[2,3]	Wain-Erap LLG[4]
Agriculture organizations (Govt.)	79	5
Training institutions	0	0
Research institutions	0	20
Private sector industries	0	17
Non-government organizations	6	0
Others[1]	15	58

[1]Relatives, friends and farmer colleagues.
[2]LLG = Local level government.
[3]n = 20; includes Lae urban and Ahi rural LLGs; 6 contact farmers and 14 non-contact farmers.
[4]n = 30; located in the Huon Gulf District; 1 contact farmer and 29 no-contact farmers.

Table 2: Frequency of visits by agricultural agencies to rice farmers

Source	Frequency of visits to farmers (%)					
	Lae LLGs[2,3]			Wain-Erap LLG[4]		
	None	Once	>Once	None	Once	>Once
Agriculture organizations (Govt)	92	7	1	97	3	0
Training institutions	100	0	0	100	0	0
Research institutions	90	0	10	99	0	1
Private sector industries	100	0	0	97	2	1
Non-government organizations	92	5	3	100	0	0
Others[1]	90	0	10	100	0	0

[1]Relatives, friends and farmer colleagues.
[2]LLG = Local level government.
[3]n = 20; includes Lae urban and Ahi rural LLGs; 6 contact farmers and 14 non-contact farmers.
[4]n = 30; located in the Huon Gulf District; 1 contact farmer and 29 no-contact farmers.

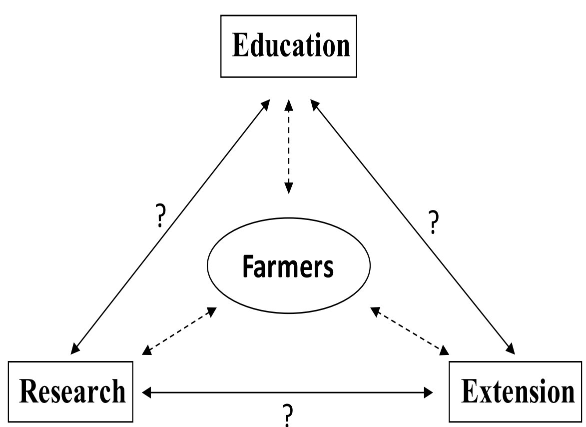

Figure 2: A schematic diagram showing the outcomes of a preliminary study on the application of the AKIS/RD (FAO and World Bank, 2000) model in the rice farming system in the Morobe Province. The question marks in the model indicate that the level of collaboration and information sharing between these stakeholders needed further investigation.

Certain information carried certain data and when these data are received and analysed, translates into meaningful knowledge. When knowledge is appropriated, it creates change. Directed information almost always affects behaviour, a decision or an outcome and leads to increased understanding and decreased uncertainty. This means accuracy, timeliness, specificity, and organisation of information meant to yield meaning and relevance are highly crucial. The recent investigation revealed non-routine visitation from agricultural officers to farmers, a behaviour that often results in untimely dissemination of knowledge and skills required for change, in this instance, within the rice farming systems. This would not be accommodating of the AKIS/RD system (FAO and World Bank, 2000) that suggests that there needs to be an integration of farmers, agricultural educators, researchers and extension officers to harness knowledge and information from varied sources for better farming and improved livelihood.

It was evident from this preliminary findings that linear processes of communicating agricultural knowledge and information such as in the diffusion of innovations process (Rogers, 1995) and the magic bullet or two-step flow of communication (Katz and Larzarsfeld, 1955a and 1955b), which were evident in the manner in which crucial knowledge and information on rice production had been disseminated to farmers in the three LLGs, did not allow for adequate feedback between all stakeholders and thus, could become a serious constraint to enhanced rice productivity.

A more effective consultative and collaborative approach amongst the stakeholders needs to be adopted to assist the improvement of sustainable agricultural practises, in this case, improved production of rice. This idea is strengthened by Waistboard (2008) that all processes of social change must be centred around the receivers of knowledge and information, in this case farmers, and that they must play an active role in making decisions for their development and not be passive recipients of decisions meant to affect them.

For a holistic approach for sustainable development, key stakeholders as highlighted in the AKIS/RD framework (Fig. 1) need to work in collaboration and interact where necessary to ensure information and knowledge were channelled effectively to empower farmers in their development efforts. This study has shown that this collaboration has not been very effective amongst all stakeholders (Fig. 2). This preliminary work has resulted in a progressive elaborate research carried out covering a wider scope to investigate how effective the key stakeholders collaborated to ensure that farmers, as the important end recipients of innovative information, were better served.

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THE RECALCITRANT NATURE OF *Gyrinops ledermannii* SEEDS: NOTES ON DESICCATION TOLERANCE AND LONGEVITY IN STORAGE

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ABSTRACT

Gyrinops ledermannii *Domke (Thymeliaceae) is a commercially renowned eaglewood tree species, whose over-exploitation and cultivation is driven by its valuable aromatic oleo-resinous heartwood or agarwood and its lucrative oil extract. However, there is no information on the seed storage behaviour of the species that can enhance mass propagation efforts to facilitate commercial plantation. This study investigated the recalcitrant nature of* G. ledermannii *seeds, their desiccation tolerance and longevity in storage under ambient room (25ºC), vacuum desiccator (25ºC) and refrigerator (4ºC) conditions. The optimal moisture content for* G. ledermannii *seeds was around 33% (mean germination rate of 85.3%), which was attained at 9 days after harvest (when stored under ambient room condition), however there was no significant differences in daily mean seed moisture content (P=0.62) and germination rate (P=0.15). Contrarily, seeds stored under reduced temperature (refrigerator condition~4ºC) attained significant (P<0.05) mean germination rates, and reduced moisture loss and maintained viability for up to 7 weeks. These findings will support growers to make informed decisions in seed management and propagation to promote its cultivation in* ex situ *plantations.*

Keywords: Gaharu, safe moisture content, seed storage behaviour.

INTRODUCTION

The name "eaglewood" is synonymous with high quality exotic incense, cosmetic and perfumery (Zich and Compton, 2001). Several tree species are commonly referred to as eaglewood trees (Thymelaeaceae, Myrtales, Magnoliopsida) including those of genera *Aetoxylon*, *Aquilaria*, *Enkleia*, *Gonystylus*, *Gyrinops*, *Phaleria* and *Wikstroemia*. Nevertheless, eaglewood trees that possess desirable quality of aromatic, oleo-resinous heartwood or agarwood and their oil extract are from the genera *Aquilaria* and *Gyrinops* (Gunn et al., 2004). The most prominent agarwood-producing species in Papua New Guinea (PNG) is *Gyrinops ledermannii* Domke.

Notably, the Food and Agriculture Organization (FAO) estimated that only 35% of the global agarwood demand, valued between 6-12US$ billion, is currently met (Chetpattananondh, 2012). This discrepancy has exacerbated the unsustainable exploitation of eaglewood tree species to feed this lucrative trade. This phenomenon, so-called "agarwood rush", threatens to decimate their natural populations. Increased rates of illegal and indiscriminate chopping of eaglewood trees in search of agarwood are, apparently, rife in the region (Gunn et al., 2004; Bun and Bewang,

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2005). This situation has consequently compelled the Convention on International Trade of Endangered Species (CITES) for Wild Flora and Fauna to place restrictions on trading of agarwood that are harvested from natural stands (Compton, 2004).

Small scale growers have inadvertently cultivated *G. ledermannii*, mainly from seedlings obtained from natural stands or wildings (Bun and Bewang, 2005). Concerted effort to promote such initiatives by enhancing seedling production techniques will sustainably contribute towards satiating the demand driven by the agarwood rush, and indirectly promote the conservation of the species in the wild. Seeds of eaglewood tree species, however, are recalcitrant (Subiakto et al., 2011), and therefore require immediate sowing to realize better germination rates. Evidently, seed recalcitrancy is a major hurdle in afforestation efforts to promote sustainable large scale cultivation of the species (Gunn et al., 2004; Lata, 2007). A better understanding of factors such as genotype and storage conditions, particularly temperature, can greatly influence seed viability and longevity in recalcitrant seeds (Farrant et al., 1986, 1988). In the closely related species *G. walla*, de Alwis et al. (2016) reported that seeds were able to maintain a high level of viability for up to six weeks at 8°C, while Subiakto et al. (2011) demonstrated that seeds of *Aquilaria crassna* can be stored at 4°C for eight weeks and maintain 42% viability. There is, however, limited published data pertaining to storage and germination of *G. ledermannii* seeds to equip farmers to develop informed strategies to cultivate it.

This paper reports on an investigation conducted to assess the recalcitrant nature of *G. ledermannii* seeds by evaluating, a) the effect of seed drying on viability – desiccation tolerance, and b) effect of storage condition on seed viability - longevity.

MATERIALS AND METHODS

Seed Source

Mature fruits were harvested from 5-7 year old trees that were maintained in a orchard comprising of six provenances grown at Yawalumbo Village (3°29′S, 143°29′E), East Sepik Province, PNG. These six provenances were collected from Ama (4°06′S, 141°39′E), Kubalia (3°47′S, 143°27′E), Yangoru (3°39′S, 143°17′E), Hawaiin (3°29′S, 143°29′E), Maprik (3°37′S, 143°03′E), and Karowari (4°45′S, 143°18′E). The fruits were packed in zip lock bags and transported, six days before the experiments were initiated, to the Department of Forestry laboratory, PNG University of Technology, Lae (146°98'E, 6°41'S), Morobe Province).

Seed Sampling and Pre-treatment

The seeds were manually extracted from the fruits, and a sample of 120-500 seeds was characterized by measuring their length, girth (width) and 100-seed weight. Prior to allotting them to the various treatments in this study, the seeds from the six provenances were mixed to make up the number required for testing. The seeds were then surface sterilized by dipping in 1.5% NaOCl for 3 minutes and then dried by blotting with tissue paper before being treated with 10% Chlorothanlonil® for 5 minutes, and blot-dried to remove excess fungicide.

Trial Designs

Two experiments were conducted concurrently to investigate the effect of seed desiccation and storage condition on viability.

Experiment 1. Effect of seed desiccation on viability

The experiment was conducted following a completely randomized design having three replications of nine drying periods (treatments) relative to the age of the seeds after harvest. These drying periods were coded as; Day-6, Day-7, Day-8, Day-9, Day-10, Day-11, Day-12, Day-13 and Day-14. In preparing the seeds for the treatments, 27 lots of 60 seeds were allotted into prepared aluminium foil (alfoil) packets of dimensions 5 cm × 7 cm, and were labeled accordingly to each treatment and replicates to allow for independence of the data obtained. A total of 180 seeds were used for each treatment. The samples were air-dried at 25°C in a Contherm® digital series incubator (Contherm Scientific Ltd, New Zealand) to simulate ambient room temperature. At the end of each drying period, a sub-sample of 10 seeds from each of the pre-labelled alfoil packets containing the allotted seeds (N=60) for the respective storage conditions were sampled from the three replicates for moisture test, while the remainders (N=50) were respectively germinated to assess their viability.

Experiment 2. Effect of seed storage condition on viability

A 3×8 factorial experiment was conducted following a completely randomized design, with three levels of seed storage treatments and eight levels of storage period or age (week) after harvest, and having three replications. The seed storage treatments consisted of storage under ambient room condition (25°C, 79% RH), vacuum desiccators (~25°C), and refrigerator (~4°C). The storage treatments were nested in eight storage periods, namely; Week-0 (i.e. onset of the trial at 7 days after harvest), Week-1, Week -2, Week-3, Week-4, Week-5, Week-6 and Week-7. The seeds were air-dried under ambient room condition for three days prior to placing them under the different storage treatment regimes. From the 4,050 seeds used, 50 seeds each were allotted into prepared alfoil packets (5×7 cm), as previously described. At the end of each storage period, the respective pre-labeled alfoil packets containing the allotted seeds (N=50) from individual storage condition were sampled for the germination test.

Determination of seed moisture content

Recommended procedures for testing moisture content of oily seeds (ISTA, 1988) were used to determine the moisture content of the seeds after drying. The sampled seeds were weighed and oven-dried in a Turbofan® oven (Turbofan oven, Model E32D4, Moffat Ltd, Australia) at 103°C for 17 hours with the alfoil packets opened. The alfoil ends were then immediately folded shut after drying, and reweighed to obtain their dry weight to determine seed moisture content.

Seed germination test

Seeds were germinated using the sand germination method (ISTA, 1988) to assess their viability. The media was prepared in seed trays having dimensions 24×32×5 cm. Each tray had pebbles (5-10 mm diameter) filled into the first third (base), followed by a thin layer of sand (2-4 mm) in the middle third of the tray, and were finally topped up with fine river sand (<2mm). The surface sterilized seeds were each sown 1cm deep by dibbling. The respective date of sowing and time of germination were recorded. After sowing, the seed trays were placed under ambient nursery (green shade cloth) condition (75% light intensity, 27°C, 80% RH) for germination. Water was applied twice weekly by partially submerging the seed trays in a water trough for 1–2 minutes. Germination was monitored and recorded for two months. And, as soon as the seeds germinated and grew out of the media, the seedlings were transferred onto the rooting media consisting of heat sterilized sandy-loam soil, and reared under optimal nursery condition.

Statistical Analysis

Seed traits (length, width and weight), moisture content and germination count data were collated in Microsoft Excel® 2007. Statistical differences between the sampled seeds collected from the different provenances were tested, for each of the traits, using one sample t-test and 95% confidence interval (CI). The two latter data sets were square root transformed prior to performing the analysis of variation (ANOVA) using the software, Genstat® Discovery Edition (VSNI, 2005). When ANOVA detected significant differences among the treatments, the means were compared using Fisher's least significant difference test. And to elucidate any significant interaction between sources of variation, additional analyses were conducted. Regression analysis was performed using Microsoft Excel® on the generated data for storage conditions to establish any association between seed viability and longevity.

Additionally, to fully utilize the time information obtained from the seed germination test, time-to-event (or survival) analysis (Kaplan and Meier, 1958) was performed in Genstat®, using time since sowing as the time scale (Aalen et al., 2008; Anderson et al., 2016). The replicate mean germination data obtained under each storage condition over time was treated as a continuous event for this analysis. Seeds that did not germinate within the timeframe of the experiment were treated as censored data and given a censoring time that corresponded to the last day of follow-up, i.e. the last day the seeds were checked for germination (i.e. Week 7). To compare response curves for seeds stored under the different storage conditions, log-rank test statistics (Mantel and Haenszel, 1959) for equality of the survival curves in Genstat®, using time since sowing as the time scale (Aalen et al., 2008; Anderson et al., 2016). The replicate mean germination data obtained under each storage condition over time was treated as a continuous event for this analysis. Seeds that did not germinate within the timeframe of the experiment were treated as censored data and given a censoring time that corresponded to the last day of follow-up, i.e. the last day the seeds were checked for germination (i.e. Week 7). To compare response curves for seeds stored under the different storage conditions, log-rank test statistics (Mantel and Haenszel, 1959) for equality of the survival curves was calculated in Genstat®.

RESULTS

Green, dehiscent capsulated fruits of *G. ledermannii* produced 1-2 seeds per fruit on average (*N*=183). The seed length (L) and width (W) ranged from 6.99–7.83 mm and 4.37–5.05 mm giving a L:W ratio range of 0.57-0.68, respectively across the provenances (Table 1). While the 100-seed weight ranged from 1.37–3.09 g (CV = 30.56%). The *t*-test showed significant differences (P<0.001) between the seeds from the different provenances in their length, width, L:W ratio and 100-seed weight, respectively. The 95% CIs for the mean seed traits corroborated these findings and revealed significant differences at the P<0.05 level between the studied seed samples: Seeds obtained from Yangoru were significantly shorter (6.99±0.06 mm), while those collected from Karowari were significantly broader (5.05±0.04 mm) and larger (0.68±0.01), whereas those from Maprik had significantly higher 100-seed weight (3.09±0.01 g) compared to their cohorts, respectively.

Effect of Seed Desiccation on Viability

A rapid decline in the daily mean seed moisture content was evident from Day-6 at 60% to 36.1% the next day and gradually reaching 25% after the next six days at Day-14 (Table 2). Nevertheless, there were no significant differences among the various seed drying periods in their moisture contents (P=0.62) and germination rates (P=0.15).

Effect of Seed Storage Condition on Viability

The different storage conditions had variable effects on seed longevity (Table 3). Albeit, on average, seeds stored under refrigerator condition not only stored longer (up to 7 weeks including the week after harvest), but also expressed significant (P<0.01) and superior viability (mean germination of 33.0±11.3%) over those stored under the standard ambient room condition (22±11.5% over 5 weeks). Contrarily, the mean viability of those seeds stored in the vacuum desiccator (18.4±9.8%) was not statistically different (P>0.05) from that of the standard condition. Apparently, the viability of seeds from the different storage conditions differed significantly (P<0.001) over storage time, but the significant (P<0.001) higher order interaction between storage condition and age took precedence. This association was reflected in the strong polynomial relationships between seed viability and age of seeds that were stored under the different storage conditions as represented by their regression equations: a) ambient room condition, $y=3.47x2–35.47x+89.92$ (r^2=0.98); b) vacuum desiccator as $y=3.43x2–35.38x+77.16$ (r^2=0.98); and c) the refrigerator as $y=1.06x2–19.78x+88.05$ (r^2 =0.97). Further, the log rank test for equality of the survival curves (Fig. 1) of the storage conditions indicated no significant differences ($\chi2$ = 2.39, P= 0.30).

Table 1: Mean seed size and 100-seed weight of *Gyrinops ledermannii* seeds obtained from six provenances in East Sepik Province , Papua New Guinea

Provenance	Sample Size (*N*)	Seed characteristics (±SE)			
		Length (L) (mm)	Width (W) (mm)	L × W ratio	100 –seed Weight (g)
Ama	500	7.83±0.03	4.43±0.02	0.57±0.00	1.37±0.02
Kubalia	120	7.75±0.08	4.45±0.05	0.58±0.01	1.68±0.03
Yangoru	120	6.99±0.06*	4.37±0.04	0.63±0.01	2.29±0.06
Hawaiin	120	7.69±0.07	4.48±0.03	0.59±0.01	1.63±0.10
Maprik	120	7.63±0.06	4.88±0.04	0.64±0.01	3.09±0.01*
Karowari	120	7.43±0.06	5.05±0.04*	0.68±0.01*	2.08±0.21
Mean	-	7.55±0.13	4.61±0.12	0.62±0.02	2.02±0.25
95% CI	-	7.22-7.87	4.31-4.91	0.57-0.66	1.38-2.67
CV(%)	-	4.11	6.13	6.88	30.56

[a]SE = Standard error; CI = Confidence interval; CV = Coefficient of variation.

Table 2: Daily mean moisture content and mean germination of *Gyrinops ledermannii* seeds dried at ambient room condition

Age (Days after harvest)	Seed traits in percentage (±SE %)[b,c]			
	Moisture content (*N*=10)	Cumulative average	Germination rate (*N*=50)	Cumulative average
6	60.0±0	60.0	82.0±1.2	82.0
7	36.1±7.3	48.1	81.3±1.8	81.7
8	33.3±0	43.1	80.7±2.7	81.3
9	33.3±0	40.7	85.3±0.9	82.3
10	28.6±14.7	38.3	70.0±3.1	79.9
11	28.6±14.7	36.7	64.7±6.5	77.3
12	28.6±22.2	35.5	55.3±6.7	74.2
13	25.0±11.1	34.2	60.0±5.0	72.4
14	25.0±11.1	33.2	45.3±6.4	69.4
Mean	33.2±3.6	-	64.9±5.7	-

[a]Ambient room condition at 25°C and 79% Relative humidity; [b]SE = Standard error; [c]Analysis of variance was performed on square root transformed data set - no significant difference in the moisture content (P=0.62) and germination rates (P=0.15) between the different drying periods.

Table 3: Mean germination rates of *Gyrinops ledermannii* seeds stored for eight weeks under different storage conditions

Storage Period (Week)	Germination rates (%) of seeds stored under various conditions (±SE)[a,b]		
	Ambient room condition	Vacuum desiccator	Refrigerator
0	86.0±3.5	80.7±10.3	85.3±3.7
1	66.0±4.2	41.3±4.4	70.0±6.1
2	31.3±4.7	26.7±2.4	62.7±6.4
3	10.0±2.3	15.3±1.8	30.0±3.5
4	4.7±0.7	2.0±0.0	25.3±4.1
5	0	0	14.7±2.9
6	0	0	9.3±1.8
7	0	0	0
Mean	24.8±11.9	20.8±10.1	37.2±11.1**

[a]SE = Standard error; [b]Analysis of variance was performed on square root transformed data set; ** = Significant difference at P<0.001 in storage condition × storage period interaction, but neither of them individually.

DISCUSSION

The optimal moisture content for *G. ledermannii* seeds ranged from 33% to 25%, which was attained at 6–12 days after harvest when dried under ambient room condition. This could be indicative of the safe moisture content for the species, although the germination rate continued to decline during this period from 85.3% to 45%. This trend was also noted in *Aquilaria agallocha* (Kundu and Kachari, 2000) where the decline in seed moisture content continued to affect seed germination, even after drying to the lowest safe moisture content of 30-20%. However, the observations made on the effect of desiccation on viability should be treated with caution as there were no statistical differences among the various seed drying periods in their moisture contents and germination rates. In retrospect, this may be attributed, in part, to the small sample size, short study duration and the plausible confounding genotypic effect of the mixed seeds used. Nevertheless, the general information for drying and storage of *G. ledermannii* seeds is apparent: This may be achieved after nine days of drying at ambient room condition after harvest, to reach an expected mean moisture content of about 33% and a mean viability of about 85% before storing.

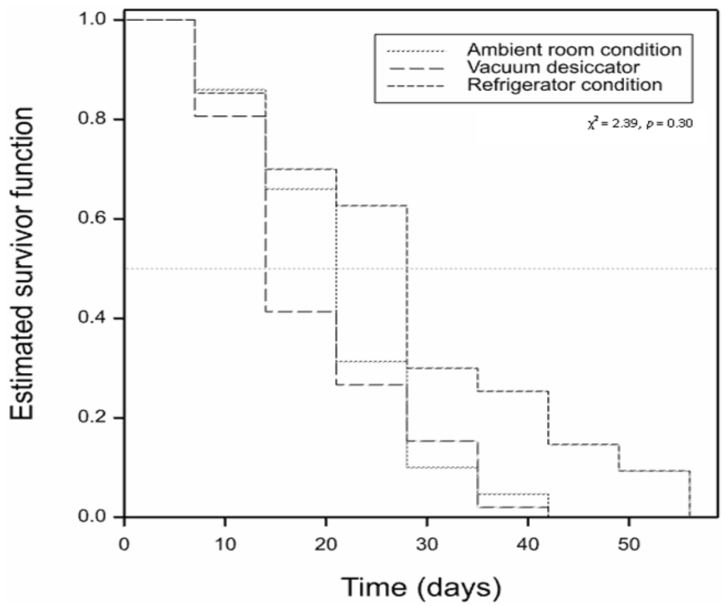

Figure 1: The Kaplan-Meier survivor main effects curve of *Gyrinops ledermannii* seeds stored under ambient room, vacuum desiccator and refrigeration conditions.

Further, the significant relationships between age and viability of seeds stored under the different storage conditions noted in this study reinforces the notion (e.g. Kraak, 1992) that storage under reduced temperature (to ~4°C) tend to slow moisture loss and maintains viability (33%) for up to 8 weeks. Apparently, this observation is similar to the findings of Subiakto et al. (2011) in *A. crassna* and de Alwis et al. (2016) in *G. walla*. The seeds stored under the studied conditions exhibited similar degenerate response patterns in portraying the strong associations between germination rate and age, rendering genotypic effect associated with the mixed seed used negligible.

Moreover, the noted variations in seed size reflect different levels of food storage that can influence germination and growth of plants (Mishra et al., 2014). For example, Shankar (2012) found that greater seed weight (>80 mg) was advantageous for better germination and seedling growth in *A. malaccensis*. Apparently, the fruit dimensions and seed sizes of the *G. ledermannii* provenances studied fell within the ranges that are characteristic of recalcitrant seed types (Marzalina et al., 1994), though the seeds weighed comparatively lighter at around 20mg.

Future studies should take into consideration genotype, seed weight and larger sample size to verify and establish the safe moisture content of the species before storage at reduced temperatures. In the meantime, the recalcitrant nature of *G. ledermannii* seeds can be managed through establishments of nearby and accessible seed orchards to allow immediate sowing to achieve good germination rates. In all, the findings of this study will support growers to make informed decisions in seed management and propagation — a small step that will, by promoting its cultivation in *ex situ* plantations, directly contribute to minimizing its overexploitation in the wild, hence ensuring natural population recovery.

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AMMI ANALYSIS FOR YIELD STABILITY OF 37 PROMISING RICE VARIETIES IN PRELIMINARIES FOR MULTI-ENVIRONMENT TESTING IN PAPUA NEW GUINEA

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ABSTRACT

The need to identify high yielding, widely-adapted varieties to promote rice cultivation among resource-challenged growers in Papua New Guinea (PNG) is being driven by the national effort to reduce import volume. This study was aimed at appraising 37 promising rice varieties based on the Additive Main Effects and Multiplicative Interaction model, and their response for yield stability across several preliminary trials that were conducted on-station to facilitate selection for multiple environment testing (MET) under rain-fed lowland conditions in PNG. The study identified 10 varieties (namely IR64, IR72, Jackson, Viet8, YRL39, NTR426, Sen Pidao, B6144F-MR-6, Takanari and China 1039) that exhibited average stability. Their yields ranged from 3.41 t/ha (Takanari) to 6.80 t/ha produced by variety IR72. Although most of the variation noted for varietal performances was trial-dependent, the responses expressed by these individuals did show reaction norms depicting stable performances across the imposing environments. A genotype may express reaction norms that are not the same under different environments as a result of variable acting environmental cues in the respective environments. These preliminary evaluations do provide useful data that can be used to make early prediction of genotypes that exhibit average stability under on-station testing conditions, and selection for confirmatory MET under rain-fed lowland conditions in PNG.

Keywords: Oryza sativa, *G × E interaction, yield stability prediction*.

INTRODUCTION

Rice (*Oryza sativa* L.) is a source of carbohydrate for approximately half of the world's population, including two thirds of the world's poor (Wang et al., 2012; Timmer, 2013). Its spread across the globe, radiating out of its Centre of Origin in Asia is exacerbated by its intrinsic qualities. Quality, however, is context-specific and consumer preferences are variable with respect to how they perceive and differentiate quality (Waramboi et al., 2003). The natural qualities of rice are embedded in their exotic nature and versatility (DeWit 2002), palatability (Matsue et al., 2001) and storability (Qui et al., 2014). These intrinsic qualities are variably expressed amongst a diverse range of rice varieties and landraces (farmer's varieties).

Rice varieties are generally grouped into two races (also known as "types" or "varietal groups"), namely Japonica and Indica, which have diverged via selection after extensive diversification over time under Japanese and Indian eco-geographies, respectively (Childs, 2004). A third type, Javanica, is a variant of the Japonica types that have been selected over time by the farmers on the Indonesian Island of Java, hence the name (IRRI, 2014). In addition, Nerica, an interspecific hybrid of *O. sativa* and *O. glaberrima* (Atera et al., 2011), is a new member of the rice cohort.

In gradually conforming to the global trend, rice is now becoming a dietary staple in

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Papua New Guinea (PNG) - an emerging economy with a gross domestic product of K8, 806 (Kina 1.00 = 0.23 US$) per year (NSO, 2020). The PNG experience shows that consumption of rice can also be driven by convenience and affordability, as observed in urban households (Gibson, 1993 and 1994) where packaged rice costs around US$0.92 per kg. The latter, on the contrary, is an inauspicious challenge in rural areas where prices can exceed US$2.30 per kg, rendering packaged rice a luxury item. Under such circumstances, subsistence farming of rice inevitably becomes the pragmatic approach to obviate the dearer option.

Several rice landraces have emerged locally in areas, where rice was integrated into the existing cropping systems. These new farmer's varieties are culminations of years of selection conducted by the farmers over seasons, since its introduction over 100 years ago (as suggested by anecdotal evidence). Landraces such as "Waria-sunlong", an indica type rice from Garaina (7° 52´S, 147°8´E), and the Javanica types, "Finsch-brown" and "Finsch-white", from Finschafen (6° 36´S, 147°51´E) in the Morobe Province are good examples (Okpul et al., 2005). In retrospect, such systematic selection of landraces was also observed on taro (*Colocasia esculenta*) in the Province (Okpul et al., 2004).

Local rice production, nonetheless, is in its fledgling stage and its productivity is unable to sustain the local demand (Mills, 2002), which has plausibly exceeded the 300,000 tons per annum reported by PNG-AGRINEWS (2011). In addressing this discrepancy, the Government endorsed the National Rice Policy of 1998 and the National Food Security Policy (2000-2010) that recognises rice as a vital component of food security. In response, stakeholders, such as Trukai Industries Limited (TIL) and the National Agricultural Research Institute (NARI) among others, have promoted its cultivation in an effort to reduce import volume. There is, however, the looming need to identify new rice varieties with higher yield potential and wide-adaptability in order to improve average farm yield, and promote its cultivation among resource-challenged growers under prevailing heterogeneous environments of the country.

Evaluation of rice varieties under PNG conditions was pioneered by Sumbak (1977). His and most other works to date (e.g. Wohuinangu and Kapp, 1982; Lin, 1993; Sajjad and Kumar, 1993; Sajjad, 1995; Okpul et al. 2005; Malangan and Komolong, 2007) have evaluated varietal performances on-station and in farmer's fields (i.e. multiple environments testing, MET) based on agronomic traits. The MET conducted by Okpul et al. (2005) evaluated 10 varieties across five sites to identify four stable varieties (namely, IR19961-23-2-2, N6-94, Salumpikit and Azucena) based on their yield stability using Finlay and Wilkinson (1963) regression model. Notwithstanding, as a plant improvement strategy, MET, remains a challenge in PNG, whose ruggedly undulating terrains concoct a range of environments that render increasing number of test sites, and associated management parameters.

Generally, MET begins with the evaluation of a number of genotypes on-station. The best lines are then selected for evaluation in several prevailing environments (genotype × location or genotype × location × year) to determine their respective "norm of reaction" (Griffiths et al., 1996) or how the performances of genotypes varies in dependence to the environment, in order to establish the magnitude of such dependence by explaining the genotype by environment interaction, GEI (Malosetti et al., 2013). A reaction norm manifests the form of the set of phenotypes that can be produced by an individual genotype exposed to different environmental conditions (Schlichting and Pigliucci, 1995).

This study was aimed at appraising thirty-seven rice varieties based on Additive Main Effects and Multiplicative Interaction (AMMI), and the Finlay and Wilkinson (1963) regression model to establish their norm of reaction for yield stability across several preliminary on-station trials that were conducted to facilitate early prediction for yield stability and selection for MET under rain-fed lowland conditions in PNG.

MATERIALS AND METHODS

Site Selection

A series of five trials was conducted under lowland rain-fed conditions in the Morobe Province (Table 1) from 2013 to 2014 at the PNG University of Technology's Agriculture Farm (146°98'E, 6°41'S), NARI's Bubia farm (146°54'E, 6°40'S) and TIL's Gabmatzung farm (146°46'E, 6°34'S). The trial sites receive mean annual rainfall ranging from 1550 – 3789 mm and average daily temperature of 26.3°C.

Rice Varieties

Thirty-seven promising rice varieties were evaluated in this series of trials (Table 2). Three of the most widely used varieties in PNG, namely IR19961-23-2-2 (NR1), N6-94 (NR9), and Taichung-Sen 10 (TCS-10) were used as controls, while the remaining 34 varieties were recently introduced by TIL.

Study Design

Each of the five trials was laid out using a randomized complete block design with three replications. Individual varieties were planted either by drilling or directly sown using EarthWay® Precision Garden Seeder (Model 1001 -B, EarthWay Products Inc.) in plots to a plant density of around 20,000 plants per ha.

Top dressing of NPK (12 N:12 P:17 K), Urea (46% N), Muriate of Potash (50% K) and triple superphosphate (21% P) fertilizers was applied in three split applications at a rate of 60:40:40 of N:P:K per ha, respectively in each trial. Weeds were controlled manually, while insect pests were controlled monthly using either Maldison-500® or Karate® 2.5 EC following the respective manufacturer's recommendations.

Statistical Analysis

Grain yield data were collected according to the Standard Evaluation System (IRRI, 2002), and was adjusted to the standard moisture content of 14% for statistical analyses. The adjusted grain yield data were analysed using the software Genstat® Discovery Version, 2nd Edition (VSN, 2005). Analysis of variance (ANOVA) was initially performed on individual trials. Those trials whose ANOVA detected significant differences among the varieties were subjected to Levene's test for homogeneity of variance prior to being pooled for combined ANOVA. Subsequently, those trials that had similar variances were combined and further subjected to the joint ANOVA-ordination procedure following the Additive Main effects and Multiplicative Interaction (AMMI) model (Zobel et al., 1988; Gauch and Zobel, 1996; Gauch and Zobel, 1997). Two biplots were generated from the AMMI model by plotting the most informative of the interaction principle component axis (IPCA1) against varietal grain yield (also referred to as AMMI1), and the other (AMMI2) plotting the two most informative interaction principle components axes (IPCA2 vs. IPCA1) in depicting the performances of the rice varieties under the three trial conditions. Finally, when the pooled analysis detected significant GEI, the varieties were further evaluated using the AMMI biplots and stability parameters.

AMMI stability value

The AMMI stability value (ASV) was calculated following the method of Purchase et al. (2000) using the formula:

$$ASV = \sqrt{\left[\frac{\mathrm{IPCA1}_{SQ}}{\mathrm{PCA2}_{SQ}}(\mathrm{PCA1}_{score})\right]^2 + (\mathrm{IPCA2}_{score})^2}$$

The ASV measure is useful to quantify and classify genotypes according to their yield stability that is relatively based on the distance of the varieties from point zero on the scatter diagram plotting IPCA1 vs. IPCA2. In this analysis, varieties having ASV measures approaching zero are considered to be more stable in their performances after a series of trials.

Stability and adaptability analysis

Following Finlay and Wilkinson (1963) regression model, the mean genotype performance at each trial were evaluated relative to the group mean of the respective trials. This provided information on the consistency or the norm of reaction that characterises a variety's response across the trials, and its relationship with the means of all the varieties in the respective trial conditions. Under this model, a

Table 1: Features of the on-station trial sites

Trial code	Year	Site[a]	Culture condition	Altitude (m.a.s.l)	Rainfall (mm)
Trial-1	2013	PNGUT Agriculture farm	Rain-fed	40	3789
Trial-2	2013	NARI farm	Irrigated	65	2870
Trial-3	2014	Gabmazung - TIL farm	Rain-fed	73	1550
Trial-4	2014	Gabmazung - TIL farm	Rain-fed	73	1550
Trial-5	2014	PNGUT Agriculture farm	Rain-fed	40	3789

[a]NARI = National Agricultural Research Institute; PNGUT = Papua New Guinea University of Technology; TIL = Trukai Industries limited; m.a.s.l.= metres above sea level.

Table 2: Thirty-seven promising rice varieties that were used in this trial series[a]

No.	Variety code	Variety name	Source	Origin	Type
1	NR1	IR 19961-23-2-2	NARI	IRRI	I
2	NR9	N6-94	NARI	PNG	I
3	T1	IR64	TIL/Australia	IRRI	I
4	T2	IR72	TIL/Australia	IRRI	I
5	T3	Doongara	TIL/Australia	Australia	I/J
6	T4	Jackson	TIL/Australia	USA	TJ
7	T5	Cypress	TIL/Australia	USA	TJ
8	T6	Jefferson	TIL/Australia	USA	TJ
9	T7	Lemont	TIL/Australia	USA	TJ
10	T8	Fado	TIL/Australia	Spain	TJ
11	T9	Gavina	TIL/Australia	Spain	TJ
12	T10	Marisma	TIL/Australia	Spain	TJ
13	T11	Fin	TIL/Australia	Australia	TJ
14	T12	Pandan Wangi (7)	TIL/Australia	Indonesia	TJ
15	T13	Viet 1	TIL/Australia	Taiwan	TJ
16	T14	Viet 4	TIL/Australia	Vietnam	TJ
17	T15	Viet 5	TIL/Australia	Vietnam	TJ
18	T16	Viet 8	TIL/Australia	Vietnam	TJ
19	T17	YRL39	TIL/Australia	Australia	J
20	T18	NTR426	TIL/Australia	Australia	I
21	T19	Cocodrie	TIL/Australia	USA	TJ
22	T20	Sen Pidao	TIL/Australia	Cambodia	I
23	T21	Yunlu 29	TIL/Australia	China	J
24	T22	B6144F-MR-6	TIL/Australia	Indonesia	I
25	T23	PSBRC 9	TIL/Australia	IRRI	I
26	T24	Takanari	TIL/Australia	Japan	I/J
27	T25	Tachiminori	TIL/Australia	Japan	J
28	T26	IRAT 109	TIL/Australia	Africa	J
29	T27	Diamante	TIL/Australia	South America	J
30	T28	IR 78877-048-B-B-2	TIL/Australia	IRRI	I
31	T29	IR 79913-B-176-B-4	TIL/Australia	IRRI	I
32	T30	ULP RI7	TIL/Australia	IRRI	I
33	T31	Muncul	TIL/Australia	Indonesia	I
34	T32	Vandana	TIL/Australia	India	I
35	T33	China 1039	TIL/Australia	India	I
36	T34	WAB 450-I-B-P-38-HB	TIL/Australia	Africa	J
37	TCS-10	Taichung-Sen 10	ROC-TATM	Taiwan	TJ

[a]NARI = National Agricultural Research Institute, PNG = Papua New Guinea, TIL = Trukai Industries limited, ROC-TATM = Republic of China –Taiwan Agricultural Technical Mission, IRRI = International Rice Research Institute, and Types of rice indicating Indica (I), Japonica (J) or Tropical Japonica (TJ) types.

Table 3:Result of the individual trial and pooled analysis of variance of promising rice varieties in three different trials

Source of variation	Degree of freedom	Mean squares[a]	Proportion of variation Explained (%)[b]	Variance Component (±SE)
Treatments	95	12.21**	78.87	
Environments (E)	2	232.68**	31.64	2.29±2.33
Replicate (within E)	6	3.99	1.6	0.78±0.25
Genotypes (G)	31	13.56**	28.58	0.92±0.35
G x E	62	4.43**	18.65	
IPCA 1	32	6.08**	13.22	
IPCA 2	30	2.67*	5.44	
Error	186	1.55	19.55	
Total	287	5.13		

[a]Significant differences observed at P<0.01 (**) and P<0.05 (*) are indicated; [b]Proportions are based on the total sum of squares.

Table 4: Mean grain yield of 32 rice varieties evaluated in five trials conducted between 2013 and 2014

Variety Code[a]	Variety name	Mean grain yield (t/ha)[b]	Stability parameter[c]		
			ASV	*b*	r^2
T1	IR64	4.74*	0.19	1.03	0.97
T2	IR72	6.80**	3.46	1.88	0.91
T3	Doongara	3.09*	23.21	-0.08	0.03
T4	Jackson	3.86	0.28	1.17	0.96
T5	Cypress	2.57*	0.32	1.22	0.92
T6	Jefferson	2.46*	1.04	1.46	0.93
T7	Lemont	2.63*	0.4	1.19	0.99
T8	Fado	3.19*	0.34	1.23	0.91
T9	Gavina	2.41*	0.62	1.35	0.78
T11	Fin	1.94*	2.54	0.83	0.99
T12	Pandan Wangi (7)	3.91	2.55	-0.14	0.27
T13	Viet 1	4.03	0.69	0.5	0.91
T15	Viet 5	4.05	1.12	0.42	0.38
T16	Viet 8	4.96*	0.54	1.38	0.89
T17	YRL39	4.39	1.03	1.43	0.68
T18	NTR426	5.10*	0.86	1.94	0.94
T19	Cocodrie	1.87*	0.5	0.63	0.66
T20	Sen Pidao	4.60*	0.23	0.77	0.95
T21	Yunlu 29	2.51*	0.43	1.01	0.83
T22	B6144F-MR-6	5.04*	0.18	0.87	0.96
T23	PSBRC 9	5.58**	2.17	0.1	0.02
T24	Takanari	3.41	1.04	1.49	0.99
T25	Tachiminori	3.77	11.97	2.09	0.94
T26	IRAT 109	3.00*	0.49	1.23	0.99
T27	Diamante	2.03*	0.78	1.38	0.94
T28	IR 78877-048-B-B-2	5.64**	21.89	-0.19	0.13
T30	ULP RI7	3.68	4.34	0.61	0.91
T31	Muncul	3.01*	0.54	0.6	0.6
T32	Vandana	2.83*	4.77	1.78	0.94
T33	China 1039	5.09*	1.32	2.19	0.96
T34	WAB 450-I-B-P-38-HB	2.65	9.69	0.45	0.78
NR1	NR1 (Control)	3.95	1.04	0.19	0.32
Mean±SE		2.98±0.16	3.14±1.02	0.87±0.10	

[a]Varieties T10, T14 and T29 were excluded from the final analysis.
[b] *, ** = indicates significant differences from the control (NR1) at 1% (LSD = 1.51 t/ha) and 5% (LSD = 0.58 t/ha) level of probability, while underlined are those varieties that had significantly higher yields than the control.
[c]Stability parameters include the AMMI stability value (ASV), regression coefficient (*b*, r^2) generated using Finlay and Wilkinson (1963) model.

stable genotype is defined as one whose response to different trial condition was characterized by above average performance (high mean) and average stability (*b* = 1.0).

RESULTS

Thirty-two of the 37 rice varieties that had complete replicate mean data, excluding varieties T10, T14, T29, NR9 and TCS-10 were analysed. And, heterogeneity of variances among data obtained from the five trials was corrected with the exclusion of trials 2 and 5. Subsequently, the mean grain yield data from three trials were combined for the joint ANOVA-ordination procedure of AMMI.

The AMMI analysis was able to detect significant ($P<0.01$, $P<0.05$) differences among the treatment (variety) and interaction sources of variation (Table 3). The differences in the grain yields of the tested varieties averaged 2.98 t/ha, and ranged from 1.87 t/ha (T19) to 6.80 t/ha produced by variety T2 (Table 4). Evidently, about 79% of the total variation (sum of squares) on the rice grain yields of the studied genotypes was due to the treatments. The genotypic variance component estimate, σ^2_g was lower (0.92±0.35) than that for the environment, σ^2_e (2.29±2.33, explaining 31.64% of total sum of squares) but surpassed the estimated GEI variance component (σ^2_{ge} = 0.78±0.25, explaining 18.65% of the total variation), setting a low degree of genetic determination (h^2_b = 0.23). The first IPCA accounted for 71% while the second IPCA accounted for 29% of all the variation explained by GEI.

AMMI analysis of GEI – differential genotype responses

The AMMI1 biplot (Fig. 1) revealed that trials 1 (E1) and 4 (E3) produced the lowest rice grain yields. Moreover, varieties T1, T2, T4, T7, T8, T11, T12, T16, T17, T20, T21, T22, T24 and T26 expressed responses that were close in proximity to the IPCA1 axis. However, varieties T7, T8, T11, T21 and T26 had yields that were significantly ($P<0.05$) lower than the control (Table 4). A similar pattern was displayed by the AMMI2 biplot (Fig. 2), where the diversity in the environments was reflected by their values scattered far out from the point of origin, while the varieties displayed differential responses to the imposing environments. The stable varieties that had higher yields and whose IPCA scores positioned them closer to the point of origin included T1, T4, T7, T22, T24, and T26. Apart from variety T11 and T21, all the other varieties that displayed stability in the AMMI bi-plots also portrayed stable performance as shown by their ASV measures, which were around or less than 1.0 except for varieties T2 (3.46), and T12 (2.55).

Analysis of GEI – Finlay and Wilkinson stability model

Assessment based on Finlay and Wilkinson (1963) regression model revealed 12 varieties namely, T1, T2, T4, T8, T16, T17, T18, T20, T22, T24, T26, and T33 (Table 4) had regression coefficient, *b*, approaching unity. Besides, varieties T2, T12 and T33 had ASV measures greater than 2.0.

DISCUSSION

Ten promising rice varieties, whose reaction norms depicted above average yield and stable performance across the trials, were selected for confirmatory MET in PNG.

The variation in grain yields observed in this study disclosed the magnitude and influence of the components, particularly the high influence of E as corroborated by the low degree of genetic determination (h^2_b = 0.23). Such is indicative of a higher level of variability in the conditions imposed by these trials on the varieties. Similar studies have shown that the manifestation of environmental influence on crop yields in MET is, in most cases, of a higher magnitude in comparison to other sources of variation, accounting for a higher portion of the total variation (e.g. Augustina et al., 2013).

Apparently, the wide placement of the environmental effect scores in comparison to the closer placement of the varietal effect scores conforms to the similar pattern observed in the magnitude of explained variability. In comparison to the control, varieties T1, T2, T4, T12, T16, T17, T20, T22 and T24 expressed responses that were characteristic of stable varieties, as indicated by their proximity to the IPCA1 axis, which reflect a small imposition on the GEI (de Oliveira et al., 2014). In all, although most of the variation noted for varietal performances was trial-dependent, the responses expressed by several individuals did show reaction norms depicting stable performances across the imposing environments. Normally, a genotype may express responses that are not the same under different environments as a result of variable acting environmental cues in the respective environments (Schlichting and Pigliucci, 1998; Fusco and Minelli, 2010).

Based on extrapolations derived from the ANOVA, AMMI, and the Finlay and Wilkinson (1963) regression model, 10 varieties namely, T1 (IR64), T2 (IR72), T4 (Jackson), T16, (Viet8) T17 (YRL39), T18, T20, T22, T24, and T33 (Table 5)

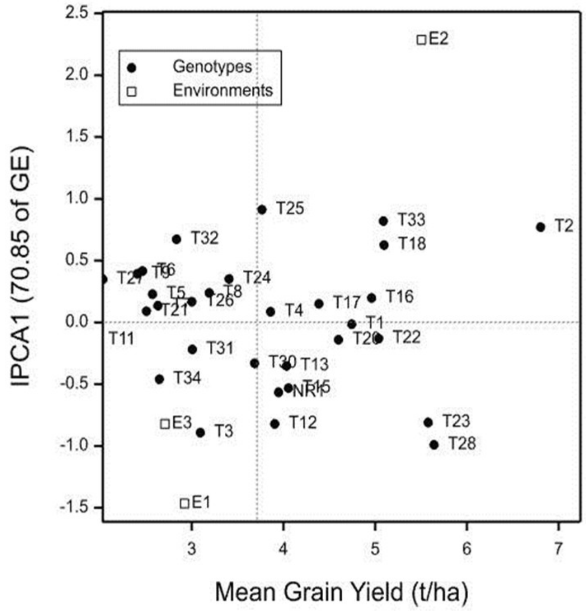

Figure 1: AMMI1 biplot for mean grain yield (t/ha) vs. IPCA1 in 32 rice varieties from three trials conducted in Lae, Morobe Province.

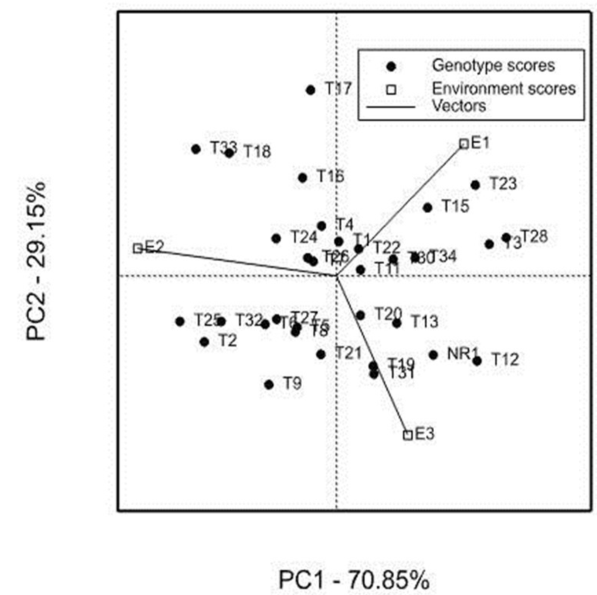

Figure 2: AMMI2 biplot showing the two main axes of interaction (IPCA2 vs. IPCA1) depicting the performance-based distribution of 32 rice varieties from three trials conducted in Lae, Morobe Province.

Table 5: The best-performing rice varieties selected from for advanced trials

Variety name[a]	Mean plant parameters							Grain shape
	Plant height (cm)	Number of tillers	Panicle length (cm)	No. spikelet/ panicle	1000-grain weight (g)	Days to maturity	Grain yield (t/ha)	
IR64	71.33	21	23.10	125.90	16.80	143	4.74	Slender
IR72	71.00	25	26.90	141.70	17.40	143	6.80	medium
Jackson	86.67	15	26.80	313.40	15.40	146	3.86	Slender
Viet 8	78.33	19	24.80	273.30	13.20	142	4.96	Medium
YRL39	85.33	24	22.90	198.30	14.60	128	4.39	Slender
NTR426	92.00	21	24.80	198.30	16.90	142	5.10	Medium
Sen Pidao	77.00	37	22.90	141.30	17.10	129	4.60	Slender
B6144F-MR-6	101.67	26	21.90	235.00	18.10	142	5.04	Medium
Takanari	79.33	13	30.10	228.00	19.90	143	3.41	Medium
China 1039	102.33	23	26.80	207.30	18.80	128	5.09	Medium
Mean±SE	82.62±2.76	22±20	25.10±0.73	206.25±17.99	17.28±1.03	138.60±2.07	4.80±0.26	

[a]SE = Standard error.

(YRL39), T18 NTR426), T20 (Sen Pidao), T22 (B6144F-MR-6), T24 (Takanari), and T33 or China 1039 (Table 5) have been identified as genotypes showing promise in conferring average stability, and were selected for the confirmatory MET in the country. The highest yielder, variety T2 or IR72 (6.80 t/ha) had medium grains and was the shortest in stature amongst the selected varieties. On the other hand, the other medium grained variety T24 or Takanari yielded the lowest (3.41 t/ha) of the elite lines, but was noted to have longer panicles (30.10 cm) and the highest 1000-grain weight (19.90 g). Takanari is indeed a high-yielding modern variety commonly grown in the temperate Kanto region of Japan (Taylaran et al., 2009). Its poor performance may be attributed to differences in the environmental condition, but nonetheless it was able to maintain its renown features of longer panicles and heavier grains in this study.

Further tests are required for consistent conclusions. These preliminary outcomes provide useful data that can be used to make early prediction of genotypes that exhibit average stability under on-station testing conditions, and selection for confirmatory MET.

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Niugini Agrisaiens

DETERMINANTS OF TECHNICAL EFFICIENCY OF SMALLHOLDER RICE FARMING IN MADANG DISTRICT OF MADANG PROVINCE, PAPUA NEW GUINEA

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ABSTRACT

Improvements to the local rice production efficiency would reduce imports and raise family food security. This study evaluated technical efficiency and the effects of its determinants on smallholder rice farming in Madang District of Madang Province, Papua New Guinea. An input-oriented data envelopment analysis (DEA) technical efficiency model was first estimated using farm input-output data collected. The DEA technical efficiency scores derived were later regressed against selected farm-specific factors in a Tobit regression model. The predicted DEA mean technical, pure technical, and scale efficiencies were 0.59, 0.94, and 0.65, respectively. These results show that technical inefficiency was present in smallholder rice farming. Scale inefficiency, caused by most farmers (95%) operating in the increasing returns to scale region of production, contributed most of the technical inefficiency (35%). Tobit regression results indicate that training has a positive and significant effect on scale efficiency. Farm size, although non-significant, also had a positive effect on scale efficiency. Additionally, training and farm size were found to have the greatest marginal effects on scale efficiency. The management option to improve technical efficiency, family food security, and local rice production is to improve scale efficiency through farm expansion, farmer training, encouraging women participation in rice farming, and adequately resourcing the extension system followed in smallholder rice farming.

Keywords: Technical efficiency, input-oriented data envelopment analysis, family food security, smallholder rice farming, Tobit regression, scale efficiency.

INTRODUCTION

Rice is consumed worldwide. In Papua New Guinea (PNG), rice consumption has grown since introduced in the 18th century. Today, it is considered a household staple (Sofe and Odhuno, 2016). However, consumption is import-dependent and at a considerable cost to society. Because of the rising import cost, governments, over the years, advocated local rice production (DAL, 2007). However, despite these efforts, local production accounts for only 2% of the total rice supply (DAL, 2007; Bourke and Harwood, 2012; Sofe and Odhuno, 2016). An important agronomic attribute required for rice production is climate, and PNG has suitable climatic conditions prevailing throughout the country. Thus, the climate is not a significant agronomic issue for rice production in the country.

With the favorable climate, the lack of local rice production could be adduced to two inter-related issues. First, by policy, rice production was initially made a smallholder-based industry (DAL, 2007). Later, the production modality was shifted from smallholder to commercial mechanized production (DAL, 2007). In between these are other models (Sofe and Odhuno, 2016). While the outcomes of these policy stances are yet to be realized, the shifting policy stance has caused insufficient integration of rice into the smallholder food production systems practiced

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(Sofe and Odhuno, 2016). Although the stances encouraged rice production at various levels, the production modalities have not delineated the likely economic benefits to both the suppliers and consumers.

Although the importance of growing rice locally is much talked about, a few studies conducted suggest that PNG has no comparative advantage in commercial rice production (Kannapiran, 1993; Kannapiran et al., 1993; Kannapiran et al., 1999). An essential economic issue arising from these studies is producing and making rice available to local consumers at a cost lower than imported rice on the one side, and an economic profit for the producer, on the other. The comparative advantages gained at the farm level are often lost when rice is moved from the production site to the consumer centers (Kannapiran et al., 1999). A study by Manus and Halim (2010) that evaluated smallholder rice production indicates that rice import substitution may only be possible if rice is produced, traded, and consumed in the local producing communities. In this regard, the model that may likely be economically feasible is the mandate based on smallholder production, where farmers produce rice for family food security and sell the surplus within the production localities. The benefits of adopting this model are: production is part of family food production systems, it is a storable grain, production to maintain family food security is assured, the product system will help farmers avoid making large capital investments, and the surplus is immediately sold in local villages at prices lower than commercially produced or imported rice.

While there are clear benefits to be gained from local rice production, improved production and cost savings can be made at the farm level, besides others, by improving factor productivity and technical efficiency of smallholder production. Given the government support services such as agricultural research and extension, quality rice seeds, and rice milling services, these factors are considered essential to improving the country's competitiveness of smallholder-based rice production.

As part of the smallholder-based rice production mandate, the national government has supported a couple of provinces through the Department of Agriculture and Livestock (DAL) to introduce and help farmers in village communities innovate rice into their food production systems. Despite the efforts to promote food security and reduce the rising import bill, no study was conducted to evaluate the productive efficiency of rice production in village communities. However, a study by Overfield (1998) in household coffee production in Benabena of Eastern Highlands Province indicates that farmers were technically inefficient caused by misallocation of inputs. The farm-specific factors male labor and education have a strong positive influence on technical efficiency, while household size has a strong negative influence. However, the extent to which farmer education and household size influence technical efficiency in rice production are yet to be established. Therefore, this study is undertaken to investigate technical efficiency and determine the sources of technical efficiency of smallholder rice farmers in the Madang district of Madang Province. Thus, it is an attempt to generate technical information useful to extension officers to help farmers improve local production for family food security and save foreign exchange from rice imports.

MATERIALS AND METHODS

Location and Sampling

The study was conducted in Madang Province. The province has seven districts, of which Madang District was purposely selected for this study. The district holds the Madang city, which is the administrative center of Madang Province. It has two local level governments (LLGs), the Transgogol and Amenob. These LLGs are located around Madang city, and the drive into the city would be less than an hour. Of the two LLGs, rice is grown in Tidup village (2 farmers), Derin village (7 farmers), and Vidar village (1 farmer) of Transgogol LLG and Opi village (11 farmers) in Amenob LLG. Thus, there are a total of 21 farmers growing rice in these villages. As observed, the largest concentration of farmers is in Opi village. Regardless, the total rice -growing population in the district is 21 farmers. Thus, they were all selected for the study.

Data

To help address the research question, the data required for this study were the data on inputs, outputs, and farm-specific socioeconomic factors. The variables of these data sets were assumed to have influenced production efficiency. Thus, the input-output data is required to understand the levels of technical efficiency there is in smallholder rice farming, while the farm-specific factors on the levels of their influence on technical efficiency. These data were collected from the farmers using a structured questionnaire as an interview instrument.

Eventually, the questionnaire was orally administered, and the responses were recorded. The data collected between January and March 2019 were for the production year 2018.

Analytical Methods

The study used two methods to analyze the smallholder farm data: data envelopment analysis (DEA) to predict farm level technical efficiency and Tobit regression analysis to assess the effects of selected farm-specific factors on technical efficiency.

Data envelopment analysis

Given the production technology, technical efficiency is an index or a score measuring the extent to which inputs available to a farmer are optimally combined to produce a given level of output or the extent to which an optimal feasible level of output is produced with a given set of inputs (Farrell, 1957, Coelli, 1996). The former is an input-oriented measure, while the latter is an output-oriented measure (Farrell, 1957, Coelli, 1996, Zulfiqar et al., 2017). However, technical efficiency is a relative measure that compares the efficiency level of one farm relative to all the other farms in the study sample (Farrell, 1957) or the best practice production frontier (Helfand and Levinen, 2004).

The measurement of technical efficiency is conducted using two approaches: parametric and non-parametric (Farrell, 1957). The parametric approach uses the econometric technique. The most popular functional form used is the stochastic frontier production function with a composed error term proposed by Aigner et al. (1977) and Meesusen and van den Broeck (1977). This study uses the non-parametric approach. The estimation method most popular in this measurement stream is the data envelopment analysis (DEA), a mathematical technique based on linear programming (LP) (Charnes et al., 1978). As technical efficiency is a relative measure, a DEA is estimated n times, one for each farmer in the sample. The technical efficiency score of one farmer is then compared to others relative to the production frontier. A farmer is technically efficient if it is located on the frontier and inefficient if it has an efficiency score of less than 1. Unlike the parametric approach, DEA does not require a priori specification of the functional form to specify the relationships between the inputs and outputs. In so doing, the specification of the distributional assumptions of the technical inefficiency error term required in frontier functions are avoided (Coelli, 1995). DEA is applied across diverse industries, including agriculture, to analyze technical efficiency using cross-sectional farm data. Recent applications in agriculture are observed in Pang et al. (2016), Zulfiqar et al. (2017), and Tipi and Yildiz (2010).

The DEA model, first proposed by Charnes et al. (1978), assumed constant returns to scale (CRS). However, in the actual production operations, farmers face imperfect information and financial constraints, making them operate at a less than optimal scale (Coelli et al., 1998; Ali and Seiford, 1993), a situation the CRS DEA model was not designed to analyze. The CRS DEA model was later modified to variable returns to scale (VRS) DEA (Banker et al., 1984). The estimation of the VRS DEA model would provide pure technical and scale efficiency measures. The former efficiency measure indicates if the farmer is using factor inputs in optimal proportions in rice production, while the latter measure indicates if the farmer is operating at optimal scale in rice farming (Tipi and Yildiz, 2010; Zulfiqar et al., 2017). Scale inefficiency arises due to farmers operating either at increasing returns to scale or decreasing returns to scale. As the approaches to addressing these scale inefficiencies are different, their identification at the estimation stage determines the cause of action to take in production. For example, an expansion/reduction of the scale of operation would be the likely cause of action if the farmer was found operating in the increasing/decreasing returns to scale region of production, respectively.

The DEA model is flexible and can handle multi-input, multi-output, or multi-input single-output production situations. In rice farming, farmers produce a homogenous product, milled rice, using multiple inputs. However, farmers face incomplete production, milling and marketing information, and cash constraints to buy farm inputs. When faced with these production constraints, farmers manipulate inputs to produce a given level of output. This study, therefore, uses an input-oriented VRS DEA model (Banker et al., 1984) and examines the pure and scale efficiency levels of rice farmers.

VRS DEA Model

The VRS DEA model for the i-th rice farmer producing a single output and using m inputs is given as

$$\text{S.t} \quad \begin{aligned} &\min_{\theta}, \lambda^{\theta} \\ &-y_i + Y\lambda \geq 0 \\ &\theta_{xi} - X\lambda \geq 0 \\ &NI'\lambda = 1 \\ &\lambda \geq 1 \end{aligned} \qquad [1]$$

where, y_i and x_i are output produced and a *(m x 1)* vector of input set used by the *i*-th farm, *Y*, denotes the *(n x 1)* vector of outputs produced by n farms, *X*, the *(m x n)* matrix of inputs used by n farms, *NI*, a *(n x 1)* vector of ones, λ, a *(n x 1)* vector of constants or weights attached to each efficient producing farm, and θ is a scalar. The value of θ is the technical efficiency score for the *i*-th farm. This value varies between 0 and 1. A θ value one indicates that the *i*-th rice-producing farm is on the frontier and therefore technically efficient. The VRS DEA linear programming model provided in equation (1) is estimated n times to obtain an efficiency score for each rice farm.

The VRS DEA model (Equation 1), when estimated, calculates the overall technical efficiency (TE_{CRS}) and pure technical efficiency (TE_{VRS}). Later, scale efficiency (SE) is calculated residually as a ratio of overall technical efficiency (TE_{CRS}) to pure technical efficiency (TE_{VRS}). The computation of scale efficiency for the *i*-th farm was done as:

$$SEi = \frac{TE_{i,CRS}}{TE_{i,VRS}} \qquad [2]$$

where, $SE_i = 1$ indicates that the ith farmer is scale efficient and operating at the CRS region of production. A $SE_i \leq 1$ indicates that the *i*-th farm is scale inefficient. Scale inefficiency would suggest that the farmers are producing at increasing or decreasing returns to scale, which needs further investigation. An additional DEA was, thus estimated after substituting the convexity constraint $NI'\lambda \geq 0$ in equation (1) with the non-increasing returns to scale restriction $NI'\lambda \leq 1$. If the estimated non-decreasing returns to scale technical efficiency (TE_{NIRS}) score equates (TE_{VRS}), the *i*-th farmer operates at decreasing returns to scale. Conversely, if these efficiencies are unequal, the *i*-th farm operates at increasing returns to scale.

To obtain the DEA efficiency scores of the farmers, the DEA model given in Equation 1 was estimated using the computer program DEA 2.1 developed by Coelli (1996). The efficiency scores were computed based on CRS and VRS assumptions.

Tobit model

Another interest of the study was to assess the influences of farm-specific factors on technical efficiency. The assessment is done in a two-step procedure where the DEA technical efficiency scores were first estimated. In the second step, these efficiency scores were regressed against selected farm-specific factors in the Tobit inefficiency model, a model first proposed by Tobin (1958). The estimation of the VRS DEA model in equation 1 suggests that scale inefficiency exists in rice farming._In this case, we specify the Tobit inefficiency model for the *i*-th rice farmer as:

$$SE_i = \delta_0 + \delta_1 Z_{i1} + \delta_2 Z_{i2} + \delta_3 Zi_3 + \delta_4 Z_{i4} + .\delta_5 Z_{i5} + \delta_6 Z_{i6} + \delta_7 Z_{i7} + \omega_1 \qquad [3]$$

Where the subscript, i denotes the *i*-th farmer in the sample; *SE* represents the scale efficiency scores; Z_s denotes farm-specific factors: extension visits, education, training, experience, family size, gender, and farm size for the *i*-th farmer respectively; δs are unknown parameters to be estimated; ω is a random error, assumed to be normally distributed. As the DEA scale efficiency scores vary between 0 and 1, the dependent variable in equation (3) is considered a limited dependent variable, and it is censored at the top for Tobit regression. Given that the dependent variable is a measure of technical inefficiency, a farm-specific factor with a positive coefficient will have a negative effect on technical efficiency and a negative coefficient otherwise.

Variable Specification

The summary values for the input-output variables used in the VRS DEA model of equation (1) and the variables in the Tobit inefficiency model of equation (2) are given in Table 1. The dependent variable of the DEA model is total production, milled rice, and it was measured in kilograms. The independent variables were the area of land planted to rice, measured in hectares; family labor measured in man-days, which denotes the amount of work done by family members in the activities associated with rice production; and transport costs are measured in PNG Kina. Transport costs are used for transporting paddy rice from harvested field to homestead and from there to the milling sites.

The independent farm-specific variables in the Tobit inefficiency model are extension visits, education, training, experience, family size, gender, and farm size. Extension visits to farmers is a dummy variable, where extension received = one and zero; otherwise, education level is measured in the number of years spent in obtaining a formal education; training is a dummy variable = 1 if the training was received and zero, otherwise; experience is measured in the number of years of rice cultivation; family size denoted the number of members in a family; gender is a dummy variable = 1 if the rice farmer is a male, and zero, otherwise; and farm size is the area of land planted to rice and is measured in hectares.

The VRS DEA model of equation (1) was estimated using DEAP 2.1, a computer program developed by Coelli (1996). The computer program Shazam was used to obtain the maximum likelihood estimates of variables in the Tobit inefficiency model. It is worth pointing out that the DEA efficiency scores are more sensitive to data, especially the inclusion of outliers than the number of observations (Coelli et al., 2005). In this case, although our sample size is small, the results are a fair reflection of the reality of smallholder rice production in the Madang District.

RESULTS AND DISCUSSION

Table 1 summarizes the inputs used, the output produced, and the rice farmers' farm-specific attributes. Milled rice, on average, was 124 kg and was produced using an average farm area of 0.16 hectares. This is equivalent to 775 kg of milled rice per hectare. The average family labor input and transport cost were 16 man-days of labor and K14 per farm.

Of the farm-specific factors, only 33% of the farmers received extension visits from the agricultural extension officers, while 67% did not access extension visits. In training, about 48% received training, and 90% of the farmers are male. Farmers, on average, have a family size of 5 members with seven years of education and five years of experience. These statistics indicate that rice production is male-dominated, with education up to grade 8 and less than five years of experience.

Although rice was introduced more than ten years ago, its adoption into the food production systems of the farmers is low. Of the study sample, eight farmers grew rice for more than ten years, four between 5 and 10 years, and nine less than two years. The farmers who grew rice for more than ten years are model farmers in the rice-growing villages. These farmers grew rice consistently and have considerable experience. The accumulated knowledge is then passed onto the new rice farmers in the villages. The Madang provincial rice extension officers (PREOs) know these experienced rice farmers, and they work through these model farmers to bring new extension information to them. The model farmers, in turn, bring farmer needs to the attention of the PREOs. Thus, the model farmer plays a coordinating role between the farmers and the extension officers. In this kind of extension system, the frequency of extension visits from extension officers is considerably reduced. This is the reason for 67% of the farmers not receiving extension visits from extension officers. Furthermore, rice milling machines are established in Madang city and are easily accessible to all farmers to mill their produce. Farmers eat what they produce with the surplus sold to other villagers in the village communities.

Technical Efficiency

The input-oriented DEA scores of overall technical TE_{CRS}, pure technical TE_{VRS} and scale efficiencies for the sample rice farmers are presented in Table 2. The mean scores for overall technical, pure technical, and scale efficiencies predicted were 0.60, 0.94, and 0.65, respectively. The overall technical efficiency score of 0.60 indicates that farmers were technically inefficient in rice production. This finding is consistent with the findings of Overfield (1998), Tung (2013), and Linh et al. (2015). The inefficiency, which amounts to 41%, is substantial in smallholder rice farming. This result implies that farmers used a combination of inputs in amounts higher than required and need to reduce them by 41% without affecting their current production levels. Of the 41% technical inefficiency, pure technical efficiency contributed 6%, and scale inefficiency 35%. Therefore, if the farmers could eliminate scale inefficiency, they could, on average, improve the technical efficiency of rice production from 0.60 to 0.94, a substantial improvement of technical efficiency by 35%.

Pure technical efficiency would indicate farmers' ability to manage resources used in their farm operations at optimal levels. The mean pure technical efficiency of 0.94 indicates that rice

Table 1: Summary Values of input-output and farm-specific attributes

Variable	Mean	Minimum	Maximum	Standard Deviation
A) Input –output:				
Milled rice (kg)	124	8	495	136
Area (ha)	0.156	0.0075	0.40	0.11
Family labor (MD)[1]	16	5	45	9.2
Transport costs	14	6	45	10.5
B) Farm-specific:				
Education levels (years)	6.7	1	13	3.1
Experience (years)	4.6	1	18	3.9
Family size	5.4	1	15	3.0
Extension visits	Received = 33%		Not receive = 67%	
Trainings	Received = 48%		Not received = 52%	
Gender	Male = 90%		Female = 10%	

[1]MD = Man day

Table 2: Estimated mean scores of technical, pure technical, and scale efficiencies of smallholder rice farmers

Efficiency category	Mean	Minimum	Maximum	Standard deviation
Overall technical efficiency	0.60	0.26	1.00	0.25
Pure technical efficiency	0.94	0.73	1.00	0.09
Scale efficiency	0.65	0.26	1.00	0.26

farmers managed inputs at or near-optimal levels. These outcomes are evident in the distribution of the predicted pure technical efficiencies in Fig. 1, where the efficiency levels were 0.70 and higher. Thus, although 14 farmers needed to make some improvements, the farmers were managing the use of their inputs well.

Scale efficiency, on the other hand, indicates the size of the farm operation. The mean scale efficiency score of 0.65 indicates that farmers were scale inefficient. This finding agrees with the findings of Tung (2013) and Linh et al. (2015). The distribution of scale efficiencies presented in Fig. 1 shows that 12 farmers (57.14%) have efficiency scores less than 0.80, 8 farmers (38.09%) have efficiency scores between 0.80 and 1.00, and 1 farmer (4.76%) was scale fficient. The broad distributions of scale efficiencies indicate that scale inefficiency was a significant problem in the operations of smallholder rice production and needed to be addressed.

The existence of scale inefficiency suggests that farmers faced different returns to scale in their farm operations. As indicates in Table 3, 95% of the farmers faced increasing returns to scale while the remaining 5% faced constant returns to scale in their production operations. As scale efficiency is directly related to the size of the farm operation, 95% of the farmers were operating farm sizes less than the optimal size required. The farmers facing increasing returns to scale stand to benefit by increasing the areas they cultivated. This finding agrees with the finding of Tung (2013). On the other hand, there is nothing to gain for farmers who faced constant returns to scale by increasing or decreasing their present scale of operation.

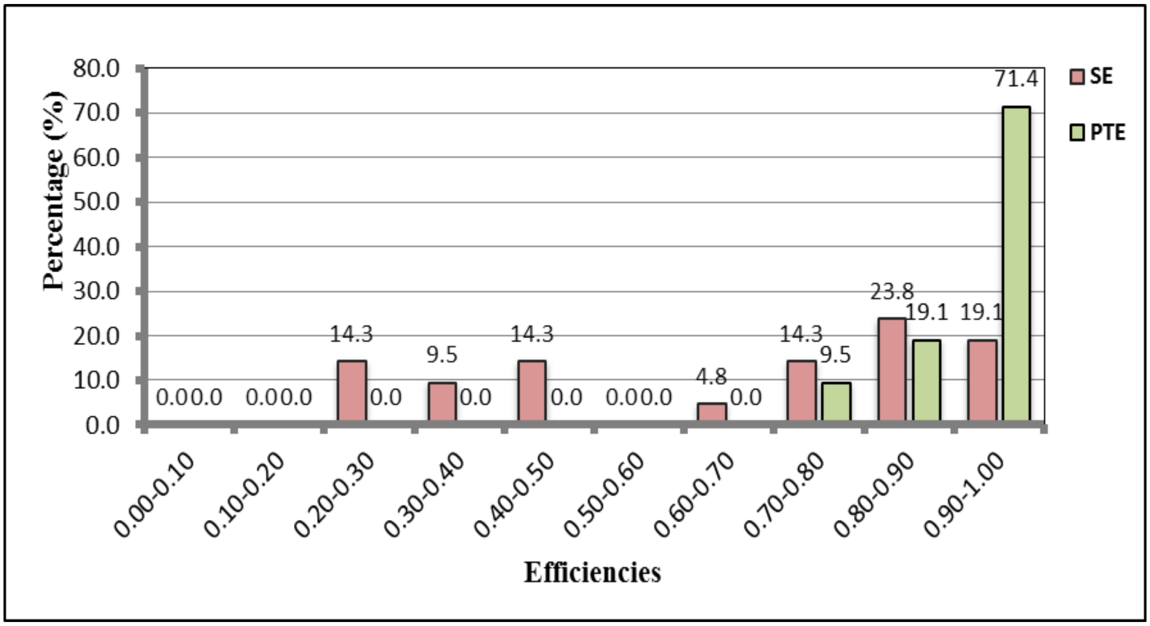

Figure 1: Frequency distribution of predicted pure and scale efficiencies of rice farmers (SE = Scale efficiency, PTE =. Pure technical effciency.).

returns to scale in their production operations. As scale efficiency is directly related to the size of the farm operation, 95% of the farmers were operating farm sizes less than the optimal size required. The farmers facing increasing returns to scale stand to benefit by increasing the areas they cultivated. This finding agrees with the finding of Tung (2013). On the other hand, there is nothing to gain for farmers who faced constant returns to scale by increasing or decreasing their present scale of operation.

Determinants of Scale Efficiency

Given the scale inefficiency problem in smallholder rice production, further investigation was done to determine the farm-specific factors that influenced it. Table 4 presents the estimated Tobit regression coefficients and the marginal effects of the farm-specific factors investigated. As the dependent variable in equation (3) represented scale inefficiencies, scale inefficiency and scale efficiency are inversely related, where a negative coefficient indicates an efficiency increase and vice versa. The sizes and signs of the coefficients estimated were as expected. The estimated marginal effect of the Tobit model was high at 97.11.

The Tobit scale inefficiency model results indicate that extension visits and gender were positive while education, training, experience, family size, and farm size were negative. The estimate for training was, however, found to be significant ($P<0.05$). The positive estimate of extension visits indicates that farmers who received extension visits were scale inefficient than those that did not receive such visits. This result was expected, clearly showing the extension model's impact on rice farming in the study area. This extension model is such that extension information from the extension officers is channeled to farmers through the model rice farmers located in the rice-growing villages, and farmer problems are channeled to extension officers, again, through the model farmers. The model farmers, in this case, play a coordinating role between the extension officers and the farmers. In this arrangement, the model farmers are always with the farmers, reducing the frequency of extension visits to farmers. It was thus not surprising to observe that those farmers who grow rice under the guidance of the model farmers tend to be scale efficient. The marginal effect of an additional visit of an extension officer would, on average, increase scale inefficiency by 7%.

The positive coefficient of gender indicates that male farmers tend to be less scale efficient than female farmers are. This result is not surprising as female farmers traditionally spend more time in food gardens daily. Therefore, the addition of rice into their production systems receives similar attention than their male counterparts. In this regard, increased women's

Table 3: Summary of returns to scale of rice farmers

Characteristics	Number of farmers	Percent (%)	Mean farm size	Mean output (kg/ha)
Constant returns to scale	1	4.76	0.40	0.66
Decreasing returns to scale	0	-	-	-
Increasing returns to scale	20	95.24	0.14	0.11

Table 4: Tobit regression parameter estimates of inefficiency effects of scale efficiency

Variable	Coefficient	Standard Error	T-test	Marginal Effects
Constant	0.73	0.20	3.62	0.70
Extension visits	0.07	0.11	0.67	0.07
Education	-0.01	0.12	-0.96	-0.01
Training	-0.34	0.12	-2.71**	-0.33
Experience	-0.00	0.01	-0.20	-0.00
Family size	-0.02	0.02	-1.44	-0.02
Gender	0.07	0.17	0.40	0.06
Farm size	-0.48	0.49	-1.00	-0.47
Log-likelihood function	4.62			

participation in family rice production is essential. The marginal effect of adding an additional female head farmer would reduce scale inefficiency by 6%.

The negative coefficient of education indicates that the farmer who has received more years of schooling tends to be more scale efficient than farmers with less schooling. This result shows that farmers require formal education to communicate with extension officers and understand the written production information. Therefore, the marginal effect of an additional year of education would, on average, increase scale efficiency by 1%.

The negative coefficient of training indicates that farmers who attended more training in rice production were scale efficient than those who attended less training. The marginal effect of an additional training program would, on average, increase scale efficiency by 33 %. Essentially, farmer training has a significant productivity effect on scale efficiency.

The negative coefficients of experience and family size suggest that farmers with more experience and larger families tend to be more scale efficient than farmers with less experience and smaller family sizes. Although these results were expected, the marginal effects of an additional year of experience and an additional unit of a family member would have a negligible effect on scale efficiency.

The negative coefficient of farm size indicates that farmers with larger farm sizes tend to be more scale efficient than farmers with smaller farm sizes. The marginal effect of an additional hectare of area cultivated would, on average, increase scale efficiency by 47%. Although non-significant, farmers who have larger farm sizes would have more significant productivity increases in rice cultivation. In this case, an expansion of farm size with more farmers' training would improve scale efficiency.

Tung (2013) and Linh et al. (2015) reported technical inefficiencies in rice production in Vietnam caused by scale inefficiencies. The scale inefficiencies are caused by increasing returns to scale. These findings agree with the findings of this study. Farmers thus needed to increase their scale of farm operations. Scale inefficiency in Tung's (2013) study was influenced by ethnicity and gender. In the study by Linh et al. (2015), scale inefficiency was affected by age, family size, extension services, and access to milling services. The findings of some of the farm-specific factors reported in this study agree with the findings reported by Tung (2013) and Linh et al. (2015). An area that requires consideration in future modeling work is to include the access to rice milling services attribute, as the factor directly influences rice production in Madang.

Conclusion

Rice is produced to serve dual purposes; food security for the farming family, and reduce rice imports at the national level. However, smallholder farmers in Madang district faced substantial overall technical inefficiency in rice production caused by scale inefficiency due to most farmers (95%) operating in the increasing returns to scale region of production. In this case, the scale of smallholder farm operations must be adjusted upward. The Tobit regression analysis shows that farmer training significantly affects scale efficiency, followed by, although non-significant, farm size. As they have the greatest marginal effects on scale efficiency, a production strategy that focuses more on farmer training and expanding farm sizes would reduce scale inefficiency and improve rice production in the Madang District.

Furthermore, as female rice farmers were found scale efficient, a strategy to empower more women in rice production is encouraged. Moreover, as the frequency of extension visits by the extension officers is reduced, the model farmers fill the void and ensure that they are always on hand working closely with the rice farmers. Therefore, part of the production strategy for farm expansion and improving rice production in the district is to resource these model farmers adequately.

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SOIL PRODUCTIVITY AND RESOURCE USE EFFICIENCY OF SMALLHOLDER TARO FARMERS IN TAVEUNI ISLAND, FIJI

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ABSTRACT

In continuous cultivation, soil fertility, an essential soil productivity factor for supporting taro production, is gradually lost. Farmers mitigate this production problem using inorganic fertilizers. This study evaluated the effect of NPK on soil productivity, and the resources use efficiency of the inputs used in the smallholder taro production for export in Taveuni Island, Fiji. Cross-sectional input-output and price data collected were used to estimate a Cobb-Douglas production function for Indigenous and Indo-Fijian farmers. The production functions estimated explained 69 and 89% of the variations in output, taro, on the Indigenous and Indo-Fijian farms, respectively. The elasticity of cultivated area for both groups was positive and highly significant (P<0.01), indicating a significant soil productivity effect on production using NPK. The elasticity of NPK for Indigenous farmers, was positive and significant (P<0.10), while the elasticity of hired labor was negative and highly significant (P<0.01) on Indo-Fijian farms. The scale coefficients, 0.82 and 0.69, show diminishing returns to scale on Indigenous and Indo-Fijian farm operations, respectively. NPK, on both farm groups, was under-utilized while Glyphosate®, family, and hired labor, over-utilized. Since NPK used enhanced soil productivity, expanding the cultivated area with increased use of NPK would help farmers to adjust efficient utilization of other inputs, thereby improving the resource use efficiency and industry production at no additional cost to society.

Keywords: Smallholder taro farmers, Cobb-Douglass production function, resource use efficiency.

INTRODUCTION

Like many developing countries, agriculture plays an important role in the economy of Fiji. The sector, while providing for the livelihoods of 50% of the nation's population (0.9 million) dwelling in the rural sector, it contributes 9% of the total Gross Domestic Product (GDP), employs 28% of the total workforce, and accounts for 41% of the total export earnings (Ministry of Primary Industries, 2012). Among the crops grown, taro (*Colocasia esculenta* (L.) Schott) accounts for 1.19% of the total agricultural contribution to the country's GDP (Ministry of Primary Industries, 2012).

In the mid-1990s, taro production and export activities flourished as Fiji took advantage of the taro leaf blight (*Phytophthora colocasiae*) epidemic that destroyed the taro industry of Samoa in 1993 (Sundar, 2016). Thereafter, Fiji was a major exporter of taro in the Pacific with 93% market share in New Zealand, 66% in Australia, and 3% in the United States of America (Ministry of Primary Industries, 2012), with an export value of 20 to 23 million Fijian dollars per annum (Sundar, 2016). Taro has, thus, become a significant export income earner for rural smallholder farmers and the national economy.

In the past decade, the export volume of taro has, after peaking in 2011, declined (AECOM, 2018). The declines were caused by unfavorable weather and pests and diseases. The most serious of the pests, is the taro beetle (*Papuana uninodis*), which burrows into the taro corms in the ground. Even worse, fungal infections cause the attacked

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corms to rot, making the affected corms unmarketable (Biosecurity Authority of Fiji, 2014; Lal, 2008). Field losses, caused by the taro beetle, were estimated at 67% and is thus considered a threat, not only to the taro industry but to the environment, ecology and the well-being of Fijians as well (Lal, 2008).

Given the serious threat to the taro industry, ways to mitigate the production risk posed by the pest were considered. Among these, were to use chemical and cultural management practices. These practices, however, require setting up appropriate quarantine policies, as a mechanism to reduce its spread. Additionally, these efforts require expanding considerable amount of resources, with significant funding commitments were expected from the government of Fiji. While pursuing these options, taro production for export was shifted to the Island of Taveuni, where it is free from this pest (Lal, 2008).

The shift has seen Taveuni Island producing 70 percent of A-grade taro for export. The area, however, has production problems of its own, among others, decreasing soil fertility due to continuous cultivation of taro and invasion of weeds (Sundar, 2016). Weeds, some of which were imported as Fiji opened up to international taro trade, compete with taro for space, sunlight and soil nutrients. Soil nutrient depletions and weed infestations, which were considered as the most important factors affecting soil productivity, cause decreased production. They are, thus, considered a source of productive inefficiency in taro production. A strategic agronomic practice introduced to farmers to mitigate these problems was for the farmers to use NPK, an inorganic fertilizer, to support soil productivity and use a herbicide, particularly Glyphosate®, to control weeds.

The government of Fiji provides support to taro farmers in the form of agricultural extension and funding to research institutions to develop production technology and production techniques. These government supports were considered the most important elements for agricultural development and dissemination of research results (Belete et al., 1991; Pickett, 1991). At the farm level, taro farmers allocate their resources among production alternatives, even when faced with soil nutrient depletions and weed infestations. In this case, the resources allocation decisions of a farmer are an important issue. As farmers receive support from the national government, evaluating the issue has important policy implications for agricultural development and resource use in the country (Hopper, 1965,and Parasar et al., 2016). Where farmers operate efficiently, continued government support is necessary to introduce new resources, new techniques and skills to farmers. However, when faced with productive inefficiency, it is then useful for farmers to shift resources out from taro farming to alternative cropping activities, which increase output and income at no additional cost to society (Hopper, 1965, Parasar et al., 2016, and Okello et al., 2019),

Findings indicate that resource use inefficiencies arise from inappropriate input combinations, where inputs used are either under -utilized or over-utilized, and such inefficiencies are reduced by using more of the under-utilized inputs to improve production and use less of the over-utilized inputs to save costs (Hopper, 1965; Eze, 2003; Mbanasor, 2002; Olayide and Heady, 1982; Okon, 2005; Afroz and Islam, 2012; Parasar et al., 2016; Okello et al., 2019). While farmers, given the declining soil fertility, use NPK fertilizer to influence taro production and Glyphosate® to reduce weeds from competing with taro for soil nutrients, no study was conducted to evaluate how efficiently farmers were using NPK fertilizer and Glyphosate® in combination with other inputs, and the productive effect of NPK fertilizer use on soil productivity of areas planted to taro. The objectives of this study were, therefore, to (i) assess the productive performances of factor inputs used and (ii) resource use efficiencies of these inputs in taro production and export in Taveuni Island.

MATERIALS AND METHODS

Location and Sample

The study was conducted in Taveuni Island, which is located north east of the capital city of Suva, Fiji (Fig. 1). This area was purposively chosen for the study because it produces 70% of the total A-grade taro production for export. There was a total of 3,400 farmers growing taro and 85% of them were Indigenous Fijian farmers. The Indo-Fijian farmers make up the remaining taro growing population. These farm groups were, thus, stratified based on ethnicity when sampled. Although the total taro growing population was known, the sampling frame with the list containing the names of the farmers was not available. And, too, the farmers were observed to be widely dispersed and faced with time and funding limitations, it was not possible to conduct a survey of the taro growing population and create the sampling frame. Faced with these constraints, purposive sampling of the farmers was done. With the help of the extension officers stationed on the Island, a study sample of 60 farmers were selected with 30 farmers from each producer group.

Data and Variables

The information required for this study were the input-output farm data and the relative prices for these inputs and outputs. These data were collected from the sample farmers by interviews using an orally administered structured questionnaire as an interview instrument. The data, collected between August and September in 2016, was for the 2015 production season. The variables used for the analysis of the data collected were the output taro, as the dependent variable and the inputs land, family labor, hired labor, NPK fertilizer and Glyphosate® used in taro production, as the dependent variables.

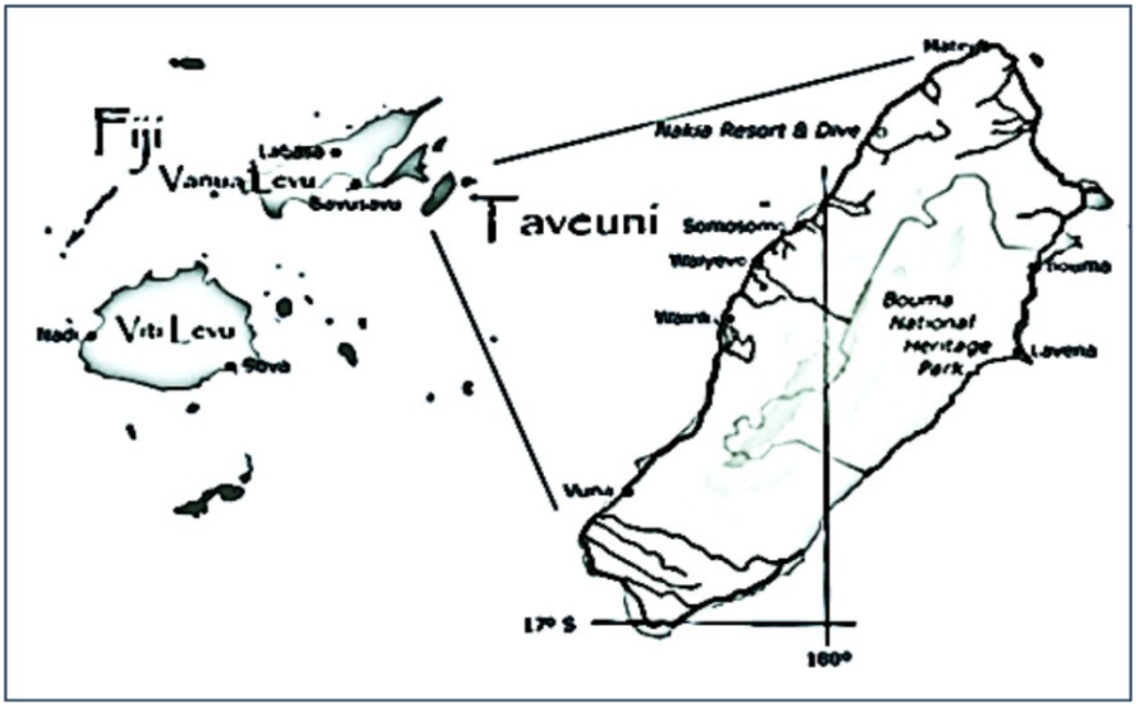

Figure 1: Map of Fiji (Source: https://lh3.googleusercontent.com/).

Table 1 presents the summary values of the variables used in the analysis. This information indicate that Indigenous farmers cultivated a mean area of 0.27 ha with a mean production of 2.51 metric tonnes (MT) while the Indo-Fijian farms planted a mean area of 0.46 ha and harvested a mean output of 4.14 MT. On the basis of land use per farm, Indigenous farmers cultivated a mean area of one and half times lower than Indo-Fijian farmers. A similar trend was observed with output, with higher output produced on Indio-Fijian Farms. Although Indo-Fijian farmers cultivated proportionately larger areas of land and producing proportionally larger outputs, when output was converted to per hectare basis, both farm groups produced an estimated output taro of 9 MT per ha apiece. Clearly, the variations in the outputs produced between the two groups of farms were due to the variations in the factor input intensities used.

The level of NPK fertilizer used indicates that the cost of using this input increased with farmer group and Indo-Fijian Farmers used about two times higher than Indigenous farmers. When converted to per ha basis, the total cost of NPK fertilizer used on the Indigenous and Indo-Fijian farms were F$656.81 and F$846.39 per ha, respectively, indicating that Indo-Fijian farmers, on average, used more NPK than Indigenous farms. The cost of Glyphosate® used, on average, also increased by farmer group with a cost of F$433.17 per ha on Indo-Fijian farms compared to Indigenous farms at the cost of F$306.66 per ha. For labor, the farmer groups used hired and family labor and their use by both groups increased with

Table 1: Summary statistics of taro farmers

Variables	Mean	Minimum	Maximum	Standard Deviation
(A) Indigenous farmers				
Output (MTs)	2.51	0.40	6.00	1.41
Area (ha)	0.27	0.02	0.80	0.21
Hired labor (MDs)#	9.10	4.00	20.00	4.18
Family labor (MDs)	3.83	2.00	16.00	2.74
NPK Fertilizer (Kg)	88.67	20.00	160.00	45.08
Glyphosate (L)	6.90	2.00	10.00	2.86
(B) Indo-Fijian Famers				
Output (MTs)	4.14	1.70	13.00	2.42
Area (ha)	0.46	0.20	1.60	0.31
Hired labor (MDs)	10.73	5.00	24.00	4.28
Family labor (MDs)	10.70	4.00	20.00	4.59
NPK fertilizer(kg)	194.67	80.00	400.00	118.25
Glyphosate (L)	14.80	5.00	40.00	8.06

#MDs = Man-days. A man day of work is equal to 8 hours of work by an able-bodied worker.

areas cultivated. Of the total man-days of labor requirements, Indigenous farmers appear to have used two times more hired labor than family labor while Indo-Fijian farmers appear to have used about the same amount of hired labor as family labor. However, when compared between the farm groups, Indigenous and Indo-Fijian farmers used about the same amount of hired labor. An observation made about the production practices followed is that the sample farmers used the same inputs and plant the same varieties of taro. The government provides research results in technology, such as better varieties of taro, better use of fertilizers and chemicals and extension services to support smallholder taro production for export.

Estimation Approach

Resource use efficiencies are evaluated using several approaches, mostly under the assumed conditions of profit maximization and perfect competition. They include the production function approach (Hopper, 1965), the self-dual cost and profit functions (Kalirajan, 1981, Adesina and Djato, 1996), the unit profit functions (Yotopoulos and Lan, 1976) and the data envelopment analysis (DEA) under the condition of constant returns to scale (Charnes et al., 1978, Fare et al., 1985: Fare et al., 1994). Where the farms are assumed to face different production technologies and input-output prices, the unit profit function is often used. The focus in the later approach is to compare the resource use efficiencies of small farms relative to large farms. In the application of self-dual cost or profit functions, the production function is indirectly derived once these functions are estimated. The DEA model has the capability to, in addition to estimating resource use efficiencies, measure technical and economic efficiencies. This study followed the production function approach and used the Cobb-Douglas production function as it is popularly used and that it fulfills the assumptions of the smallholder taro production data, that regardless of farm group, farmers face the same production technology and the same input-output market prices.

Analytical Procedures

Descriptive and quantitative procedures were used to analyze the data collected. Descriptive analysis involved the computation of the means, minimum, maximum values and the standard deviations. These statistics were used to characterize, as shown in Table 1, the taro farmers. For the quantitative analysis, a linearized Cobb-Douglas production function was fitted and the parameter estimates obtained were used to determine the level of output responses from the inputs used. The model specified for the taro farmers using five inputs is given as:

$$LnY = A + b_1 LnX_1 + b_2 LnX_2 + b_3 LnX_3 + b_4 LnX_4 + b_5 LnX_5 + e \quad [1]$$

where, Y is output of taro combs (total production) in metric tonnes, X_1 is the area cultivated in meters squared, X_2 is hired labor in man-days, X_3 is family labor in man-days, X_4 is NPK in kilograms, X_5 is Glyphosate® in litters, *"A",* the intercept and *"b_s"* the regression coefficients, are to be estimated and *e* is the error term.

The elasticities of production for examining the productivity of inputs used in taro production are the regression coefficients, obtained directly from estimating equation (1). A positive and higher value of an estimated elasticity would indicate a higher productivity effect of the factor input used.

The level of resource use efficiency was evaluated by equating the value of marginal product (VMP) to marginal factor cost (MFC) of input X_i as:

$$VMP = MFC \quad [2]$$

The VMP and MFC are calculated as:

$$VMP = P_y (Ep.\frac{\bar{Y}}{\bar{X}}) \quad [3]$$

and,

$$MFC = P_{x_i} (Ep.\frac{\bar{Y}}{\bar{X}_i}) \quad [4]$$

where $(Ep.\frac{\bar{Y}}{\bar{X}_i})$ is the marginal product (MP) evaluated at the geometric mean level of input $\bar{X}_i$ And output $\bar{Y}$. *Ep* is the elasticity of production coefficient of input $\bar{X}_i$ and P_y is the unit price of output and $\bar{X}_i$ is the unit price of input P_{xi}.

Dividing both sides of equation (2) by MFC, the resource use efficiency index (RUEI) is calculated as:

$$RUEI = VMP / MFC \quad [5])$$

The resource use efficiency index (RUEI) of equation (5) was used to evaluate the efficiency levels of the inputs used. An index of RUEI = 1, indicates that input X_i was used at the optimal level, while an index of RUEI > 1, or RUEI < 1, indicate under-utilization and over-utilization of input X_i respectively. As indicated by Hopper (1965), Eze (2003), Mbanasor (2002), Olayide and Heady (1982), Okon (2005), Afroz and Islam (2012), Parasar et al. (2016), and Okello et al. (2019), use more of input X_i to improve output when it is under-utilized and less of it to save costs when it is over used. Equation (1) was estimated by ordinary least squares (OLS) using the Econometric Software, Shazam.

RESULTS AND DISCUSSION

Factor Productivity

The estimated elasticity coefficients for the variables of the Cobb-Douglass production function are given in Table 2. These estimates, which indicate the partial productivity levels of the inputs used in taro production, have the expected signs and sizes. The adjusted coefficients of multiple determinations (*Adj,* R^2) of 0.69 and 0.90 indicate that 69 and 90 percent of the variations in output of Indigenous and Indo-Fijian farms were explained by the inputs used in taro farming. Clearly, these results show that the Cobb-Douglas production function fitted, for each farm group, adequately captured the variations in output from the underlying data sets used.

The elasticity coefficients for Area of 0.52 and 0.81 for Indigenous and Indo-Fijian farms were, respectively, greater in sizes, positive, and highly significant ($P<0.01$). This result indicates that Area planted was highly productive as a 10 percent increase in area planted increased taro production on Indigenous and Indo-Fijian farms by 5.2 and 8.1 percent, respectively. Compared to Indigenous farms, area cultivated to taro on Indo -Fijian farms was highly productive. Nonetheless, the higher partial productivity of areas cultivated indicate that soil productivity was enhanced by using NPK fertilizer. The use of NPK fertilizer is therefore essential for supporting taro production. The elasticity coefficient of NPK fertilizer was, however, positive and significant ($P<0.10$) on Indigenous farms while it is negative and not significant on Indo-Fijian farms. These results suggest that, compared to Indo-Fijian farms, the use of NPK fertilizer on Indigenous farms increased productivity by 3.09 percent as this input was increased by 10 percent.It is significant to note that the elasticity coefficients

Table 2: Elasticity coefficients (EC) for variables based on the Cobb-Douglas production function for taro farmers in Taveuni Island, Fiji

Variable	Indigenous Farmers (EC±SE)	Indo-Fijian Farmers (EC±SE)
Constant	2.53±0.73	1.98±0.61
Area	0.52±0.10***	0.81±0.06***
Hired Labor	-0.08±0.15	-0.25±0.07***
Family labor	0.18±0.16	-0.11±0.08
NPK Fertilizer	0.31±0.18*	0.02±0.05
Glyphosate®	-0.12±0.19	0.08±0.07
No. of observations	30	30
Degrees of freedom	24	24
Adjusted R^2	0.69	0.90
Sum of elasticities#	0.82	0.69

*, **, and *** indicate significant levels at 10, 5 and 1 percent respectively. # the sum of the elasticities indicate the nature of returns to scale. SE = Standard error.

this input was increased by 10 percent. It is significant to note that the elasticity coefficients of hired labor for Indigenous farms and Indo-Fijian farms were negative. These results suggest a productivity decline of using hired labor on both Indigenous and Indo-Fijian farms.

The family labor elasticity coefficient for Indigenous farms was positive but negative for Indo-Fijian farmers. The productivity decline of family labor on Indo-Fijian farms is, however, significant ($P<0.05$), indicating that family labor has a significant negative impact on output taro. The increased use of both hired and family labor may reflect the intensive nature of taro cultivation during peak periods. Given the decline in hired labor productivity, a cost saving strategy would be to use family more intensively and use hired labor only when required, especially during the peak labor requirement periods of land preparation and planting and harvesting and grading.

The elasticity coefficient of Glyphosate® was negative for Indigenous farmers with a productivity decline of 1.14 percent in output for an increase in the input by 10 percent. On the Indo-Fijian farms, the elasticity coefficient for Glyphosate® was positive. This result suggests that Glyphosate®, although not significant, was productive with increases, although small, in output of up to 0.21 percent, as its use was increased by 10 percent. As the use of NPK and Glyphosate® could cause harm to soil ecology, they are to be used at recommended levels.

Returns to Scale

The sum of the elasticities of the inputs computed provides a measure of the returns to scale in taro farming. The results (Table 1) indicate diminishing returns to scale in the farming operations of the Indigenous and Indo-Fijian farms. These results suggest that the opportunity to maximize profit exists for these farmer groups.

Efficiency of Resources Use

The geometric means, value of marginal products and the resources use efficiency indices (RUEI) for the taro producing farm groups are given in Table 3. The efficiency indices indicate that, for both farm groups, NPK was under-utilized while hired labor; family labor and Glyphosate® were over-utilized. Hired labor was used during peak labor requirement periods. As both hired labor and family labor were over used, they require downward adjustments by using less of these inputs in taro production. The over-utilization of labor, although, reflect the intensive cultivation practices during peak periods, a cautious approach to save costs and improve output is to make family labor dependent production and resort to hired labor as the need for it arises. The use of Glyphosate®, although helped weed control and saved labor during critical production periods, its use in quantities higher than needed may be detrimental to the environment, particularly the micro-organisms in the soil. The helpful practice is to use at levels recommended by the Department of Primary

Table 3: Geometric means (GM), marginal value products (MVP), marginal factor costs (MFC), and resource use efficiency indices (RUEI) of taro farmers

Input[a]	GM	VMP	MFC	RUEI
(a) Indigenous				
Hired labor (MD)	8.19	0.052	0.411	0.127
Family labor (MD)	3.29	0.300	2.353	0.128
NPK Fertilizer (Kg)	76.98	0.022	0.017	1.275
Glyphosate® (L)	6.25	0.100	0.473	0.212
(b) Indo-Fijian				
Hired labor (MD)	9.71	0.107	0.844	0.128
Family labor (MD)	9.97	0.230	1.81	0.127
NPK Fertilizer (Kg)	163.75	0.001	0.0008	1.275
Glyphosate® (L)	12.97	0.058	0.273	0.213

[a]Labor is measured in man days (MD; 1 MD = 8 man hours).

Industry. The levels of fertilizer used by both farm groups were less than required. This result suggests that the quantities of this input must be increased. The findings of over-utilization and under-utilization of inputs in this study are in variance with the findings reported by Belete et al. (1991), AECOM (2018), Hopper (1965), Eze (2003); Mbanasor (2002), Olayide and Heady (1982), Okon (2005), Afroz and Islam (2012), Parasar et al. (2016), and Okello et al. (2019).

It is important to note that, since no price information on land was available, it was not possible to determine the level of efficiency of its use in taro farming.

Conclusion

On smallholder taro farms in Taveuni Island, farmers faced a range of non-ideal situations; falling soil fertility from continuous cultivation, invasion of new weeds, and the ways resources were allocated to cropping alternatives in these situations meant, farm management decisions involve choosing better ways to optimize production. There is a need to understand the practical constraints on smallholder farms and provide relevant information for the development and sustenance of the taro export industry. The results of this study show that land had a positive and significant productivity effect on output, both on the Indigenous and Indo-Fijian farms. While NPK fertilizer had a positive and significant productivity effect on output on Indigenous farms, it was positive but non-significant, on Indo -Fijian farms. These findings indicate that the use of NPK had increased the soil productivity of the cultivated areas, and made land more productive. The use of NPK fertilizer is thus, a necessary input in producing taro for export. However, resource use inefficiency was prevalent in smallholder taro farming, with NPK fertilizer under-utilized while family labor, hired labor and Glyphosate were over-utilized. As land was productive, a farm expansion program with increased use of NPK fertilizer on smallholder farms would improve the use of other inputs at no additional cost to society. To realize these improvements on smallholder taro farming, it requires a committed involvement of the government agricultural extension officers is required to plan and train farmers with new skills in resource use to manage their inputs more effectively. As the study samples used were small, further work is required to validate the findings of this study.

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Niugini Agrisaiens

DETERMINANTS OF BENEFICIARY KNOWLEDGE AND ATTITUDE TO LEATHERBACK TURTLE CONSERVATION IN LABBABIA, MOROBE PROVINCE, PAPUA NEW GUINEA

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ABSTRACT

The purpose of this paper was to investigate beneficiary knowledge, attitude, and the socio-economic characteristics that influenced beneficiaries in Lababia village, off the Huon Coast of Morobe Province. The data on beneficiary knowledge, attitude, and selected socio-economic characteristics collected from sample beneficiaries were analyzed using, for knowledge, a 3-point Likert type scale with 20 knowledge statements, a 5 -point Likert type scale with 12 attitude statements for attitude, and Pearson's Moment correlation to determine the relationships of knowledge and attitude with the socio-economic characteristics of beneficiaries respectively. The results indicated that the beneficiaries have a high level of knowledge and a favorable attitude towards the conservation project. Furthermore, the correlation analysis indicates that farm size (livestock) was significant (P< 0.10) but negatively related to attitude, while extension contact was significant (P<0.10) and positively related to beneficiary attitude. For knowledge, farm size (livestock) was significant (P< 0.10) and positively related to knowledge. In contrast, farm size (nests), annual income (turtle, fish), and extension contacts were significant (P< 0.10) but negatively related to knowledge, indicating that improved knowledge is required to look after nests and improve income.

Keywords: Leatherback turtle, socio-economic characteristics

INTRODUCTION

The leatherback turtle is listed as a critically endangered species. It faces many threats, and the most important ones are (i) harvesting of females or eggs at the nesting sites, (ii) deaths resulting from commercial fishing activities (Donoso and Dutton, 2010; Nada and Casale, 2011), and (iii) destruction to or degradation of habitat (Donlan et al., 2010). The threats are shown to be dependent on species, location, and life history phases (Wallace et al., 2010; Wallace et al., 2011). Of particular importance is setting up conservation programs in locations where turtles frequent to lay eggs. They are easy prey to predators and harvesters in these places during the breeding migration and inter-nesting periods (Mortimer, 2000).

Papua New Guinea (PNG) is home to several nesting sites in Manus, East Sepik, West Sepik, Milne Bay, and Morobe Provinces. Among these sites, the Huon coastline beaches of Morobe Province have the largest nesting leatherback turtle population in PNG and one of the largest in the Western Pacific (Kinch, 2006). These turtles are, however, vulnerable to human predators, poaching, and collection of eggs for subsistence or commercial (Spring, 1982; Bedding and Lockhart, 1989; Hirth et al., 1993) or other factors such as females being too slow to move onshore or offshore when coming to lay eggs including depredation by dogs (Kinch, 2006), and even pigs.

The Western Pacific Regional Fisheries Management Council (WPRFMC) has set up leatherback turtle recovery projects in the Western Pacific. One of them is located in the Huon Coast of Morobe Province. The recovery project in the Huon Coast, funded by WPRFMC, involves the village communities of Lababia, Busama, Paiawa, and Labu Tale. The agreement

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for this project was for the communities involved to patrol and monitor the beaches regularly to protect the laying mothers', egg nests, and nesting sites from predators. The villagers are paid wages, salaries, and small contracts as benefits for their efforts. A part of the project objective is to educate and make the communities aware of the importance of Leatherback Turtles as a critically endangered species, the set up as a community conservation initiative, and the intrinsic value of conservation work. The project communities are remote, and access to income through the sale of marine products and garden produce is low. Therefore, the conservation project appears to be helpful where some form of income is realized by beneficiaries who are engaged.

While a few studies were conducted related to the conservation project (Kinch, 2006), no study was done to evaluate beneficiary knowledge, the attitude of the beneficiaries to the leatherback Turtle conservation project, and the factors that influence these beneficiary attributes. The aim of the study was, therefore, to generate information in this direction. The specific objectives of the study were to evaluate (1) the beneficiary knowledge levels of the project, (2) the beneficiary attitude to the conservation project, and (3) the socio-economic factors that influenced beneficiary knowledge and attitude to the conservation project. The information generated is vital to conservation work in PNG.

METHODOLOGY AND DATA

The Study Sample and Variables

The study was conducted in Lababia, the largest of three villages located along the Huon Coast of Morobe Province coastlines. Lababia village was purposively selected because it has the largest contingent of beneficiaries among 2000 people. Given the large population, it was impossible to establish the sample frame, a limitation imposed by resource and time constraints. Given these shortcomings, about 50 beneficiaries were purposively selected and interviewed, using an interview schedule as an interview instrument. The data collected were on independent and dependent variables. The independent variables were age, education, family size, farm sizes of crops, livestock and number of nests, incomes from employment, sales of crops, livestock, fish and turtle products, extension contacts received, information sources used, and levels of travels beyond their villages were collected from the beneficiaries. The dependent variables were beneficiary knowledge and attitude to the conservation project.

Measurement of Independent Variables

*Age (X_1)***:** The age of an adult male was used to categorize the sampled beneficiaries into young (16-30 years), the middle (31-50 years), and the old (51-75 years) age groups and a score of 1, 2, and 3 was assigned to young, middle and old age groups respectively.

Education (X_2): The beneficiaries were categorized into illiterate, primary, secondary, and tertiary groups based on the number of years completed in formal schooling. A score of 0, 1, 2, and 3 was assigned to illiterate, primary, secondary, and tertiary groups, respectively.

Family size (X_3): Family size refers to the total number of individuals in the beneficiaries family who live and eat together. Given the family sizes, the respondents were categorized into small (1-5 persons), medium (6 to 10 persons), and large (<10 persons) groups, and each group, in that order, was assigned a score of 1, 2 and 3 respectively.

Farm size (number of egg nests) (X_4): Farm size refers to the number of Leatherback turtle egg nests managed by the respondents. The beneficiaries were divided into groups with small farms (with less than four nests), medium (with nests between 4 and 5), big (with 6 to 10), and large farms (with more than ten nests). Each of these groups was assigned a score of 1, 2, 3, and 4, respectively.

Farm size c) (X_5): It refers to hectares of a crop grown. Based on cropping areas, beneficiary farms were categorized as small farms (of 0.01 ha to 0.05 ha), medium (0.051ha to 0.06 ha) and large (with <0.061ha) farms. Each group was assigned a score of 1, 2, and 3, respectively. This scoring process was repeated for each crop grown, and the scores for each crop were then added up to obtain the total score for each beneficiary.

Farm size (livestock) (X_6): Farm size concerning livestock is measured in the number of herds of livestock reared by the beneficiaries. Based on this measure, the beneficiary farms were classified into small (with less than four herds), medium (with 4 to 5 herds), and large (with more than five herds) of livestock. Each group was assigned a score of 1, 2, and 3, respectively. This scoring system was undertaken for each type of livestock and the scores for each type of livestock were then added up to obtain the total score for each beneficiary.

Annual income (wages, salaries, and contract)(X_7): This variable refers to the total annual income, in thousands of PNG Kina, earned by the respondents and members of their families. Respondents who earned K5 000 and less were grouped as low-income earners, between K5 000 and K10 000 as medium, and more than K10 000 as high earners. Each group was assigned a score of 1, 2, and 3, respectively. The total scores obtained for each group for wages, salaries, and contracts were then added up to obtain the total income score.

Annual income (fish, turtle eggs)(X_8): For annual income from marine fish and turtle products, respondents were categorized into low earners with income levels of less than K500, medium with income levels from K500 to K1, 000.00, and high earners with income levels higher than K1, 000.00. Each category was assigned a score of 1, 2, and 3, respectively. The total scores obtained for each type of earnings were then added up to obtain the total income score for this income variable.

Annual income (crops and livestock) (X_9): For annual income from crops and livestock, respondents were categorized according to the level of incomes received from these sources as small for income levels of less than K500, medium with an income level from K500 to K1, 000.00 and high for incomes higher than K1, 000.00. For each income source, a score of 1, 2, and 3 was assigned for small, medium, and large farm categories. The total score for this income variable was obtained by adding up assigned scores for crops and livestock.

Cosmopoliteness (X_{10}) and cities. A 3-point Likert-type scale was used to determine the cosmopoliteness of the beneficiaries. First, each respondent was asked to indicate the frequency of visits to selected locations with responses never, occasionally, and frequently. Each response received a score of 0, 1, and 2 for never, occasionally, and frequently, respectively. The scores for each respondent received were then added up to get the cosmopoliteness score of the respondent.

Information source used (X_{11}): Information source used was measured in terms of the number of times the project community could access or source information related to their project from outside. A 5-point Likert-type scale was used to determine the extent of access to information used by the beneficiaries. Each respondent was asked to indicate the frequency at which information sources were used with responses never, rarely, sometimes, often, and most often. Each response receiving a score of 0, 1, 2, 3, and 4 were assigned to for, never, rarely, sometimes, often, and most often, respectively. The scores for each respondent received were then added up to measure the extent of information received.

Extension contact (X_{12}): Extension contact was measured in terms of the number of contacts the respondent was able to receive with respect to on-farm advice, trainings, field days, demonstration etc., from different extension agents or organizations responsible for providing the technical advice in connection with the project. A 3-point scale was used to determine the level of extension contact of the beneficiaries. First, each respondent was asked to indicate the frequency of visits with response choices of 'never', 'occasionally', and 'frequently', which were scored as 0, 1, and 2, respectively. The scores received for each source of information were then added up to measure the extent of extension contact of the respondents.

Measurement of Dependent Variable

Beneficiary knowledge and their attitude towards turtle conservation were the dependent variables. The attitude was measured using a 5-point Likert-type scale with 12 statements (6 were positive, and six were negative). Each statement was read to and received from the respondents with responses as "strongly agreed, agreed, undecided, disagreed and strongly disagreed." Weights assigned to these responses were scores of 5, 4, 3, 2, and 1 for positive statements and scores of 1, 2, 3, 4, and 5 for negative statements. The scores received for each statement were summed up to obtain the attitude score for each respondent. The possible attitude score would vary between 0 and 60, with 30 as the mid-point. According to the Likert principle, the "30" is the point of no opinion or neutral. The mid-point was then used to categorize the respondents into favorable and unfavorable groups.

Beneficiary knowledge of conservation was assessed by using a 3-point Likert-type scale with 20 questions. The respondents responded to each of the questions asked as having "high knowledge, medium knowledge, and low knowledge." A score of 3, 2, and 1 were assigned to high knowledge, medium knowledge, and low knowledge, respectively. The scores for each question were then added up to get the total score for each beneficiary. The knowledge score for the beneficiaries could vary from 0 to 60, where 0 indicates no knowledge and 60 indicates high knowledge. Given the knowledge scores, the beneficiaries were categorized into three groups with high knowledge, medium knowledge, and low knowledge.

RESULTS AND DISCUSSION

Selected Characteristics of the Project Beneficiaries

Summary statistics of selected socio-economic characteristics of the project beneficiaries given in Table 1 indicated that the majority of the participating beneficiaries are the young-aged group (54%) followed by the middle-aged group (34%). These groups together make up 88 percent of the beneficiaries. Although 92 percent of the beneficiaries received formal schooling in education, most of them (66%) obtained primary education. Most farmers had smaller families (54%), while 42 percent of them had medium family sizes. These groups together made up 96 percent of the sampled farms. Farm size concerning the number of nests indicated that 84 percent of the beneficiaries had nests ranging from 4 to 15. Thus, the medium, big and large categories owned most of the nests with the medium and large with most nests.

For farm size in cropping, most beneficiaries (56%) have medium farm sizes ranging from 0.051 to 0.06 hectares, followed by the beneficiaries with large farm sizes (32%) of greater than 0.061 hectares. A significant aspect noted was that the beneficiaries' farm crops did not exceed one hectare. Farm size concerning livestock, the majority of the beneficiaries (94%) had a small number of livestock of 1 to 3 heads kept for special occasions, such as feasts during Christmas. Incomes for the beneficiaries were derived from (i) wages, salaries or from small contracts, (ii) crops and livestock, and (iii) from fish and turtle products (eggs and meat sometimes). The majority of the beneficiaries earned, from these sources (96% from sources (i), 92% from sources (ii), and 74% from sources (iii)), a small income of less than K5, 000. As expected, incomes from participating beneficiaries were low as they had fewer opportunities to sell at distant markets. For information, the majority of the beneficiaries had rarely (70%) received the required information from various sources, while for extension, 96 percent of the beneficiaries occasionally received extension contacts. Similarly, about 88 percent have occasionally left to travel beyond their village. Given very few contacts made beyond their village together with very little extension contacts and sources of information made available and with limited schooling, the majority of the beneficiaries in the project was, in general, low.

The Attitude of the Beneficiaries toward the Conservation Project

Table 2 gives the distribution of attitude scores of the beneficiaries. The attitude of the beneficiaries was measured by computing an attitude score which could vary between 0 and 60. However, the observed attitude score varied between 24 and 56, with a mean of 39.28 and a standard deviation of 5.67. The summary distribution of attitude scores in Table 2 indicated that only 6 percent of the beneficiaries possessed an unfavourable attitude to the turtle conservation project. Although the project had ceased operation, the positive attitude to the conservation project by the majority (94%) of the beneficiaries suggested a solid desire to protect the turtles, the nesting environment, and the eggs laid even in the absence of policy to regulate the harvesting of eggs as well as turtles.

Knowledge of the Beneficiaries of the Conservation Project

Table 3 presents the distribution of the knowledge scores of the beneficiaries. The beneficiaries' knowledge was measured by computing a knowledge score that could vary between 0 and 60. However, the observed knowledge score varied between 31 and 60, with a mean of 48.04 and a standard deviation of 8.68. The summary distribution of knowledge scores in Table 3 indicated that all (100%) the beneficiaries have an excellent knowledge of the conservation project activities. This suggests a strong desire to learn and participate in protecting the turtles, the nesting environment, and the eggs laid even in the absence of policy to regulate the behavior of the beneficiaries.

Relationship of the Selected Characteristics of the Project Beneficiaries to Attitude and Knowledge

Table 4 presents the estimated Pearson's moment correlation coefficients of the socio-economic attributes of the beneficiaries. For attitude, the correlation coefficients of age, annual income (wages, salaries, and contracts), annual income (crops), information sources, and extension contacts are positive. In contrast, education, family size, farm size (nests), farm size (livestock), cosmopoliteness, and annual income (turtle and fish) were negative. For knowledge, age, education, farm size (livestock), annual income (wages, salaries, contracts), cosmopoliteness, and annual income (crops) are positive. In contrast, family size, farm size

Table 1: Characteristics of the project beneficiaries

Characteristics	Categories	Frequency	Percent	Mean	Standard Deviation
Age (Years)	1	27	54	1.58	0.702
	2	17	34		
	3	6	12		
Education (Years)	0	4	8	1.2	0.606
	1	33	66		
	2	12	24		
	3	1	2		
Family size (number)	1	26	52	1.54	0.613
	2	21	42		
	3	3	6		
Turtle farm size (No. of nests)	1	8	16	2.78	1.148
	2	15	30		
	3	7	14		
	4	20	40		
Crops farm size (ha)	1	6	12	2.2	0.639
	2	28	56		
	3	16	32		
Livestock farm size (Heads)	1	47	94	1.06	0.24
	2	3	6		
	3	0	0		
Cosmopoliteness	0	4	8	0.96	0.348
	1	44	88		
	2	2	4		
Income (contract, wage & salary) (PNG Kina))	1	48	96	1.04	0.198
	2	2	4		
	3	0	0		
Crops & Livestock Income (PNG Kina)	1	46	92	1.12	0.435
	2	2	4		
	3	2	4		
Fish and turtle income (PNG Kina)	1	37	74	1.26	0.443
	2	13	26		
	3	0	0		
Information sources	0	0	0	1.34	0.557
	1	35	70		
	2	13	26		
	3	2	4		
	4	0	0		
Extension contacts	0	2	4	0.96	0.198
	1	48	96		
	2	0	0		

Table 2: Distribution of beneficiaries according to their attitude on turtle conservation

Categories	Beneficiaries		Mean	Standard deviation
	Number	Percent		
Unfavourable (24-30)	3	6.00	39.28	5.67
Favourable (31-40	22	44.00		
Highly favourable (41-56)	25	50.00		
Total	50	100		

Table 3: Distribution of beneficiaries according to their knowledge on turtle conservation

Categories	Beneficiaries		Mean	Standard Deviation
	Number	Percent		
Low (0-30)	0	0.00		
Medium (31-45)	18	36.00	48.04	8.68
High (46-60)	32	64.00		
Total	50	100		

Table 4: Estimated correlation coefficients of selected characteristics on attitude and knowledge

Selected Characteristics	Coefficients of Correlations[a]	
	Attitude	Knowledge
Age	0.128	0.053
Education	-0.011	0.154
Family size	-0.039	-0.035
Farm size (no. of turtle nests)	-0.189	-0.327*
Farm size (crops)	-0.257	-0.047
Farm size (livestock)	-0.339*	0.279*
Cosmopoliteness	-0.237	0.098
Annual income (wages, salaries and contracts)	0.117	0.070
Annual income (crops)	0.061	0.005
Annual income (turtle and fish)	-0.127	-0.342*
Information sources	0.212	-0.170
Extension contact	0.333*	-0.299*

[a]Significance at 5 percent level of probability in indicated by *.

[nests], farm size [crops], annual income (turtle, fish) are negative.

In beneficiary attitude, the correlation coefficient for farm size (livestock) is negative but significant, suggesting that the increase in the number of herds of livestock looked after significantly decreased beneficiary attitude to the turtle project. This implied that beneficiaries required a lesser number of livestock heads for more focused attention on the conservation of the turtle program. However, the correlation coefficient for extension contact was positive and significant, which suggested that given adequate extension contacts regarding the conservation programs, it has helped beneficiaries build positive attitudes to protecting leatherback turtles enlisted as engendered species.

For knowledge, the correlation coefficients farm size (nests), annual income (fish and turtle), and extension contacts were, although significant, negative. These results were unexpected but suggest that as knowledge increases, beneficiaries tend to have less extension contact, adversely affecting turtle protection. This may imply that the beneficiaries focus their attention away from protecting the turtle to other activities. This outcome may be supported since the correlation coefficient for turtle to other activities. This outcome may be supported since the correlation coefficient for farm size (livestock) is positive and significant, implying that the livestock production may be increased by increasing beneficiary knowledge. Given that the participation level in conservation programs is low, increased attention is given to livestock production. These findings show that farm size (livestock) and extension are important beneficiary attributes influencing attitude to the conservation project. In contrast, farm size [nests], farm size (crops), annual income (turtle, fish), and extension contact are important factors influencing beneficiary knowledge.

Conclusion

The study evaluated the beneficiary knowledge and attitude toward the leatherback turtle conservation project in the Morobe Province, PNG, and determined the extent to which beneficiary socio-economic characteristics influenced their knowledge and attitude to the project. The results revealed that beneficiary participation in the conservation project is dominated by young and middle-aged beneficiaries, educated up to grade 8, have smaller family sizes, have small to medium farm sizes (nests) and occasionally receive extension information leave their villages. The result that farm size (livestock) was significant but negatively related to attitude while farm size (nests), annual income (turtle, fish] and extension contacts were significant but negatively related to knowledge indicates that improved knowledge is required to manage the leatherback turtle nests better and earn improved incomes. The most critical areas requiring particular attention were beneficiary training, improved extension contacts, and improved coordinated efforts between the management of the conservation project and the beneficiaries. In the hindsight, a proportionally larger income from turtle products may suggest that the beneficiaries are harvesting turtles and their eggs, contrary to project agreements and needs to be addressed.

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