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Enabling Adoption of Stress-Tolerant Rice Varieties and Associated Production Management Technologies by Smallholder Farmers in Cambodia

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ABSTRACT

Smallholder rice farmers in four target provinces surrounding Tonle Sap Lake in Cambodia face problems of crop failures and low yields due to biotic and abiotic factors and a lack of suitable seeds and technologies. This paper reviews the status of rice production in the four areas and discusses the approaches to foster wide-scale dissemination and adoption of high-yielding, stress-tolerant rice varieties (STRVs) with resistance to biotic factors and tolerance to drought or floods. Baseline and endline surveys were conducted as well as extensive linkages with stakeholders, capacity-building activities, quality seed production at institutional level, field demonstration, and seed dissemination. The study summarizes data from 1,220 baseline respondents on demographic details, varietal use, knowledge assessment, and needs. The survey showed an aging profile, of which almost 25 percent are women, use of traditional and modern varieties with low yields of 2.5 t/ha, abiotic stress occurrence, and that only 14 percent of farmer respondents have heard about STRVs. In 30 months, training activities, varietal information, and diffusion of seeds reached 13,080 farmers. Results from 339 field trials showed the yield advantage of 1.0 to 1.5 t/ha of STRVs compared with those of farmer's varieties. An endline survey from 424 farmers in 2018 showed recognition for government extension, better awareness of STRVs, high willingness to adopt STRVs at 92.4 percent of the respondents, preferred varietal traits, and additional training activities are needed. The barriers to adoption that were identified were concerns on low market price and marketability. Participatory trials and farmers' field days were effective for early adoption as the visual performance of STRVs increased interest among farmer groups. Key government agencies are needed to promote and sustain registered seed production, availability of STRVs, and crop suitability. The support of the Royal Government of Cambodia and its new seed policy address problems on seed quality and availability.

Keywords: rice, stress-tolerant varieties, adoption, participatory trials, Cambodia

JEL codes: D10, F61, 033

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INTRODUCTION

In Cambodia, agriculture is important as it accounts for 22 percent of the gross domestic product (World Bank 2019). The Agriculture Ministry reported in 2017 that 40 percent of the population work in farming (Royal Government of Cambodia 2019a). Rice is the staple food that covers 90 percent of the cultivated area, and it provides around 70 percent of the total calorie intake (Wang, Pandey, and Velarde 2012). It is grown in all 25 provinces of Cambodia. Of this, around 80 percent of rice production area is under rainfed conditions, prone to drought and floods, and being aggravated by climate change. In addition, significant rice-growing areas in Cambodia are still covered by traditional varieties and landraces that have low productivity. Surrounding the Great Lake, Tonle Sap, are wide plains of four major rice-producing provinces, Pursat, Battambang, Kampong Thom, and Siem Reap, which are targeted for improvement owing to relative land fertility and water availability. In this region, the poverty rate of 45 percent is the highest in the country and is one of the most food-insecure regions in Cambodia. Various efforts are being made to increase agricultural productivity and improve the income in these provinces.

Farmer Households and Agricultural Land Areas in the Four Provinces

The 2013 Census of Agriculture in Cambodia reported that 417,406 farmer households (HH) live in the four provinces, with 928,276 hectares (ha) of agricultural farmlands with an average land size of 2.2 ha per household (Table 1). They are categorized as smallholder farmers as they own small plots of land on which they grow subsistence crops and one or two cash crops and rely almost exclusively on family labor.

Total rice harvest areas in the different seasons for the four provinces are provided in a 2017 report from the Ministry of Agriculture, Forestry, and Fisheries (MAFF). Cambodia has a tropical monsoon climate with defined dry and wet seasons. The harvest area for rice production during the wet season (WS, May to October) 2016 and dry season (DS, November to April) 2017 are as follows: Kampong Thom 278,837 and 15,837 ha, respectively; Siem Reap 186,735 and 20,987 ha, respectively; Battambang 278,837 and 15,837 ha, respectively, and in Pursat 115,851 and 14,073 ha, respectively. Rice production is evidently much higher during the WS. In the four provinces, some farmers also plant in the early wet season (EWS, May to September), relying on rainfall to continue production. EWS planting allows for a second crop, such as rice or vegetables. The early-wet-season rice covers around 0.2 million ha in Cambodia.

The main challenge for smallholder farmers in Cambodia is to increase their productivity per unit area and to raise their family income amidst the challenges of changing climate. However, they lack access to quality seeds and varietal information. The 2017 national average rice production per unit hectare (3 t/ha) is one of the lowest in Southeast Asia. Farmers in the last five years experienced drought and flood, which caused crop damage and losses, and posed risks to food security. The other challenges are the increasing incidence of rice blast disease, and consequently, chemical spraying. This is leading rice farmers in Cambodia to try new varieties that are resistant to biotic factors and tolerant to climate-stress (Eam, Emdin, and Kura 2018).

Table 1. Number of farming households (HH), land use for agriculture, and average area per family in four provinces of Cambodia

Province	Number of Farming HH	Agricultural Land (ha)	Area/HH (ha)
Kampong Thom	120,137.00	374,558.50	1.75
Siem Reap	111,227.00	195,057.65	1.95
Battambang	66,035.00	125,042.06	3.12
Pursat	120,007.00	233,617.80	1.89
Total	417,406.00	928,276.01	2.18

Source: NIS-MoP (2013)

Determinants of Adoption of Modern Rice Varieties

Earlier studies in six provinces in Cambodia looked into varietal characteristics and evaluated some of the econometric determinants of adoption of modern rice varieties (Wang, Pandey, and Velarde 2012; Wang et al. 2012). On the type of variety, only 6 percent of those surveyed grew modern varieties (MV), such as IR504-04 or IR66, and they were largely influenced by traders on the Vietnamese border. Around 20 percent of the farmer respondents grew traditional varieties, 27 percent of them grew improved traditional varieties (iTV, wherein some selection was made) and the rest grew a combination of TV and iTV. The modern varieties were grown during the DS while the traditional varieties continued to be grown during the WS. Significant factors that determine adoption of MVs were land size, land type, irrigation, and distance to market. These findings are related to another study that showed farmers cultivate rice on different lands or field types based on topographical sequence, soil quality, and irrigation source (Gauchan et al. 2012).

Yield advantage and stress occurring in farmers' rice lands were also factors to adoption of MVs. A study on adoption patterns and extent of adoption of new generation MVs of rice in stress-prone rainfed districts of India, Bangladesh, and Nepal showed that most farmers were adopting both old (released before 1990) and new generation (released after 1990) MVs in major portions of their rice area (Gauchan et al. 2011). However, the new generation MVs released after the 1990s were adopted in less proportion of their rice farms in WS, when rice production is often affected by climatic stresses, such as drought, flooding, and coastal salinity. The factors responsible for the low adoption in rainfed stress-prone environments from their survey were attributed to farmers' perception of limited yield superiority and low profitability of the new generation MVs. It is important to match specific MVs to the ecosystem where they are adapted so yield could be optimized. In the same study, the marketability of these new varieties and profit is also a concern for farmers in the same study on their decision to adopt new MVs.

In Central Nepal, another study showed that education, extension, and seed access were key to adoption of new improved rice varieties (Ghimire, Huang, and Shrestha 2015). Also, technology-specific variables (e.g., yield potential and acceptability) were significant for explaining adoption behavior. This implies that considering farmers' preferences to varietal characteristics is important. The findings indicated that increased emphasis on information dissemination, field demonstration, farmers' participatory research, and training programs was vital to popularize new rice varieties and enhance their adoption rate.

Indeed, the adoption behavior of rice farmers relies on various reasons, and it requires an in-depth understanding of sociocultural, demographic, econometric, and environmental factors, as well as farmers' varietal and taste preference (Pandey and Bhandari 2010). A more recent survey in Cambodia on adoption of wet- and dry-season new varieties highlights how the farmer's age, educational level, family size, and extension-related variables influenced the farmer's behavior in selecting wet- and dry-season rice varieties. Use of seed from their own harvest showed a negative effect on adoption, suggesting that access to seed from reliable sources will benefit the farmers by increasing their production and income. Incorporating researchers' and extension officials' message on television and radio programs and implementing educational learning programs may be the policy alternatives to enhance adoption and rice productivity in Cambodia (Pandey and Bhandari 2010; Ghimire and Suvedi 2018). Another study mentioned that limited use of technological innovations and policy constraints had resulted in low adoption of improved rice production technologies in Cambodia (Vuthy 2014; Kleinhenz, Chea, and Hun 2013).

This study was conducted to facilitate and enhance adoption of high-yielding, stress-tolerant rice varieties and associated production management technologies by smallholder farmers in stress-prone areas in four selected provinces around Tonle Sap Lake in Cambodia using several approaches, such as pre- and post-evaluation surveys, conduct of seed production and distribution, demonstration and participatory trials, capacity building, and others, with integrated support of many partners.

METHODOLOGY

The four provinces around Tonle Sap region in this study are Battambang, Pursat, Siem Reap (northwestern areas), and Kampong Thom (inland area). These provinces were identified as priority areas in the Feed the Future Program under the United States Agency for International Development (USAID) (Figure 1).

After identifying target areas prone to drought and flooding, varieties to be used, and partners, for the next two years, the main activities were the following: (1) promotion of stress-tolerant rice varieties (STRVs) through use of leaflets, prints and media, and forums; (2) quality seed production and seed minikit distribution; (3) capacity building of government staff and extension workers, farmers, and seed producers; (4) conduct of participatory farmers' field demonstration trials and farmers' field days; (5) conduct of baseline and endline surveys; and (6) assistance on development of local government's seed policies. The International Rice Research Institute (IRRI) promoted the use of stress-tolerant rice varieties, which had already passed multilocation testing and were officially released by the Royal Government of Cambodia and Cambodia Agricultural Research and Development Institute (CARDI). Their characteristics are listed in Table 2. These 10 varieties are all high yielding and may be used in stress-prone areas. Some of these varieties can be grown for both DS and WS. Meanwhile, photoperiod sensitive varieties or with late maturity are recommended where harvest is made after the flood recedes. Recession rice is defined by CARDI as varieties that can be grown where water recedes along inland valleys and lakes and recommended for planting to replace deep-water rice. This type is usually grown from October to February or March (Makara et al. 2017).

The project distributed seed packs (5, 10, and 20 kg) derived from foundation seeds (FS) of STRVs with accompanying information to farmers, seed producers, and government provincial agricultural offices from 2015 onwards. The local government through its provincial extension workers and the project staff also distributed government certified seeds, generated from FS, in the four provinces. The Ministry of Agriculture, Forestry and Fisheries (MAFF), General Directorate of Agriculture (GDA), and Department of Agriculture Extension (DAE) were involved in planning for agricultural extension services. The Provincial Department of Agriculture Forestry and Fisheries (PDAFF) mostly coordinated the implementation and extension services with support of the district agriculture office (DAO), which assisted in the agricultural development work. To promote capacity building, the project

Figure 1. Map of Cambodia showing Pursat, Battambang, Kampong Thom, and Siem Reap in shaded areas around Tonle Sap Lake

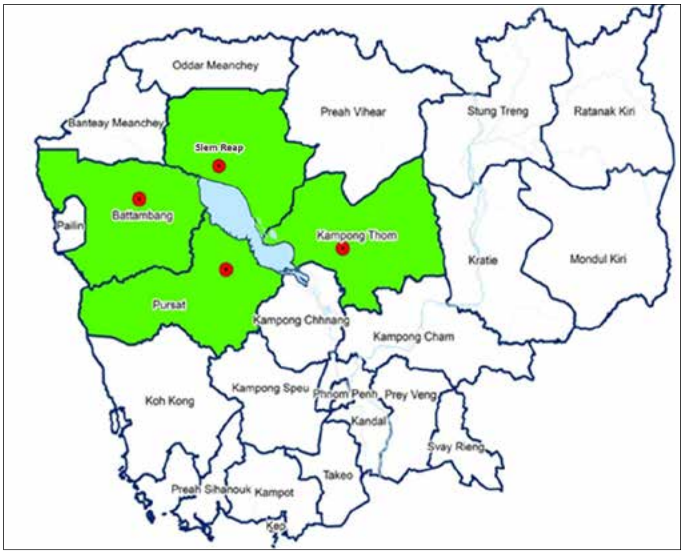


Table 2. Stress-tolerant varieties promoted in four provinces of Cambodia

Variety	Maturity	Plant Height (cm)	Tolerance/ Resistance Traits	Season	Other Special Traits
Sen Pidao	Early	110	Blast	Dry and wet	Aromatic
Chul'sa	Early	93	Blast, Brown Plant Hopper (BPH)	Dry and wet	
CAR14	Early	90	Blast, drought	Dry and wet	
CAR15	Early	100	Blast, BPH (MR)	Dry and wet	
Phka Rumduol-Prang	Early (PS)	120	Flood	Recession	Aromatic
Phka Rumduol	Medium (PS)	171	Flood	Wet	Aromatic
Phka Romeat	Medium (PS)	170	Flood	Wet	Aromatic
CAR4	Late (PS)	173	Flood, drought (MR)	Wet	
Riang Chey	Late (PS)	168	Stagnant flood	Wet	
Damnoeb Sbai Mongkul (DSM)	Late (PS)	160	Flood, drought	Wet	Glutinous

Notes: PS - photoperiod sensitive; MR - moderately resistant

staff conducted numerous training activities for farmers, seed producers, and the government staff (training of trainers) from PDAFF and other agencies about the varieties, proper cultivation, irrigation, weed, fertilizer, and pest management, as well as postharvest technology. A total of 500 field demonstration trials (80 in DS, 420 in WS) was targeted, wherein the promoted varieties were grown side by side with farmer's variety. Moreover, farmer's field days were conducted to promote the varieties to farmers, seed producers, traders, millers, and other groups, including nongovernmental organizations (NGOs), media, higher government officials, and ministries. IRRI conducted the farmers' participatory approach, which involves and empowers the stakeholders in planning the program. The participatory approach enabled the smallholder farmers to plant the new variety in their farm plot and apply the technologies, such as proper field preparation and maintenance. Also, the farmers were able to select and compare side by side the performance of the new varieties with their own variety and practice in an adjacent nondemonstration plot. The project staff collected data on yields of STRVs and farmers' other varieties from three crop cuts of 4 m^2 per plot. On the assistance to develop seed policy, IRRI facilitated intensive knowledge development through several workshops and exposure of higher agriculture ministers to other seed systems in India and the Philippines.

Baseline Survey. The baseline survey was conducted at the start of the project in December 2015. The data were collected through both semistructured and structured interviews with farmers using questionnaires by trained enumerators. Flood and drought incidences gathered through a preliminary geographic information system map were the basis for selecting villages for the baseline survey. For sample size estimate, a 2.6 percent margin of error and assumption of 0.25 standard deviation, 95 percent – Z Score = 1.96 was used. Sample size was determined to equal the $(\text{Z-score})^2$ * StdDev*(1-StdDev) / $(\text{margin of error})^2$. Twenty to 23 villages were selected from each province of Battambang, Pursat, Siem Reap, and Kampong Thom, and 14 farmer respondents were interviewed in each village for a total of 1,220 respondents.

Endline Survey. The endline survey was conducted in January 2018. The conditions set for participants from this survey were that the farmers must have participated in at least one demonstration trial of the project on stress-tolerant varieties (STRVs) in 2016 or 2017, had grown rice in 2016 DS or 2017 WS, and had minimum of three years farming experience. There were 125 demonstration trials conducted per province with 500 farmer participants, but only 424 farmers were available for interview.

Analysis. Descriptive statistics were done on statistical software SPSS/Excel with means for continuous variables and frequencies and or percent for categorical variables from the baseline and endline survey data. No paired test was made on the survey data because the effects were variable. Instead, a more narrative synthesis was done. For 2016 WS varietal yields, the means presented were from survey data from the farmers involved in the demonstration trials. For 2017 WS yield data, actual crop cut was performed. Comparison of means, t-tests between yields of varieties from demonstration (STRVs) and nondemonstration trials (farmer's variety), with at least five plots per variety, was tested using independent groups, unequal variance and at P value < or = 0.05 as parameters.

RESULTS AND DISCUSSION

Enabling Processes

With the assistance of the PDAFF, DAE, DAO, commune, and district leaders, the team convened the rice farmers and conducted the different activities. STRVs were disseminated to 13,080 farmers and seed producers in 31 districts or 148 communes comprising 450 villages. The team shared to villages STRVs knowledge and information through presentations, farmers' forums, and by distributing varietal information leaflets in Khmer prior to seed minikit distribution. Five training modules, both in English and Khmer, were developed and used in capacity building with topics on rice production, seed production, fertilizer management, pest management, and postharvest. Government extension workers, progressive farmers, seed producers, and other private organizations attended these training activities. Field demonstration trials, wherein the promoted varieties were grown side by side with farmer's variety, and farmers' field days were successfully conducted and were attended by farmers, seed producers, traders, and millers among other groups. A total of 6,646 farmers, including 3,010 women, attended 500 field demonstrations and 188 farmers' field days. To ensure supply of quality seeds, 15.7 t of foundation seeds (FS) and 90 t of certified seeds (CS) were produced by CARDI and GDA, respectively. The quality seeds were distributed to trained seed producers and further yielded 310 t of new seeds. Several workshops involving actors and partners for the development of Cambodia's seed policy were conducted, resulting in two documents published by the Royal Government of Cambodia, namely, "National seed strategy of Cambodia (2019–23)" and "Guidelines and procedures for testing, release and listing of crop varieties, manual for rice seed production, seed certification and seed quality testing" (Royal Government of Cambodia 2019a; 2019b).

Demographic Characteristics

Farmers who were in-charge of operations were interviewed in both surveys. In the 2015 baseline survey, more women than men were interviewed and participated in the survey. At the time of the survey, which coincided with the harvest season, most men were out in the field. For the 2018 endline survey, wherein the farmers were selected based on participation in the field demonstration trials, there were more male farmers, but still, a proportion of women (24.5%) participated (Table 3). This showed that women were important in Cambodia's rice production.

The average age of the farmers differed between the baseline and endline surveys, at 46 years old versus 50 years old, respectively. Both surveys showed the aging profile of Cambodian farmers. Education profile showed that a little more than half (53%–54%) reached primary level in both surveys, and close to 20 to 25 percent have reached secondary education.

Participants in the endline survey had 7 percent higher number of those who reached

Table 3. Profile of rice-farmer respondents, farmland properties, and source of income shares from baseline (2015) and endline (2018) surveys in four provinces of Cambodia

Description	Baseline	Endline
Sample size	1,220	424
Number of male farmers	508	320
Number of female farmers	712	104
Average age of farmers	46	50
Percentage with primary education	54%	53%
Percentage with secondary education	19%	26%
Average number of household members	4	5
Average years of farming experience	27	32
Percentage of land-owned	95.98%	89.70%
Percentage of land leased	4.02%	11.30%
Average number of parcels	2.1	3
Average size of farmlands (in hectares)	2.0 ha	1.26 ha
Percentage with draft animal	17%	15%
Percentage with farm tractor	72%	71%
Percentage with irrigation pump	25%	54%
Share of income from rice	36%	61%
Share of income from livestock	23%	13%
Share of income from others	41%	27%

secondary education than in the baseline survey; and farmers who participated in the field demonstrations had more years of farming experience. The average number of household members was four in the baseline and was five in the endline survey. Most farmers (90% and higher) in both surveys owned their farmlands. The average number of parcels owned by farmers slightly differed at 2.1 ha per family with mean parcel size of at least 2.0 ha for the baseline survey; and was 3.0 ha per family for endline survey with smaller mean parcel size of 1.2 ha. For their land preparation needs, few farmers (15%–17%) in both surveys owned and used their draft animals, and more farmers (71%–72%) had farm tractors. Noticeably, the majority of farmers (54%) had access to irrigation in the endline survey as compared with 25 percent of the farmers from the baseline survey. Table 3 also shows the proportion of income derived from rice and livestock, among other sources. From the endline survey, farmer participants in the demonstration trials derived 61 percent of their income from rice farming; 13 percent from livestock, raising cows, pigs, chicken, duck, and others; and 27 percent was largely from work as laborer or from remittances. During the dry season, farmers would find work elsewhere.

Access to Services

Most farmers from the baseline survey had access to financial institutions such as banks and credit cooperatives or microfinance as compared with farmers in the endline survey (Table 4).

Generally, more baseline respondents also had access to farm machinery and repair, whereas for the farmers in the endline survey, they indicated access to service providers for farm machineries. This shows a changing scenario of increased availability of service providers that were not reported two years earlier. More farmers from the endline survey had access to agrochemicals dealer, government agricultural office, NGO, self-help group, and commune agriculture.

Stress Occurrence and Knowledge on STRVs

The baseline study indicated that the farmers had at least experienced drought and or submergence within the last five years (2010–15). The farmers reported that drought had occurred twice in the past five years. Drought commonly occurred in July to September, 35 days after the rice crop was established. It lasted for about 56 days with an estimated loss of 43 percent of production. On flooding, farmers described that submergence also had occurred twice in the past five years. It commonly occurred in September, 41 days after the rice crop was established. The water depth was about two meters for about 28 days, and it resulted in an estimated 51 percent loss of production. These findings were similar to the response of

Table 4. Percentage of respondents with access to services from the baseline (2015) and endline (2018) surveys in four provinces of Cambodia

Description	Baseline	Endline
Agrochemicals/inputs dealer	84.34	90.80
Bank	83.85	32.55
Commune agriculture	0.00	1.65
Credit cooperative/microfinance	82.13	26.42
Farm machinery repair and maintenance	71.64	62.74
Government agricultural office	54.75	87.50
Nearest market selling agricultural products	86.56	95.05
NGO	32.54	51.65
Self-help group	21.89	29.01
Others		
Service provider of farm machinery for crop establishment	–	51.18
Service provider of farm machinery for harvesting	–	63.92
Service provider of other farm machinery	–	29.95

farmers from the endline survey. The farmers in the 2018 survey attributed their crop losses to drought or submergence that had occurred once or twice in the last five years. The actual periods of drought were from April to June in 2016 and in May to June 2017. Flooding occurred once in August 2016.

In the baseline survey, only 14 percent of 1,220 interviewed farmers had heard of STRVs. When asked to name these varieties and identify their traits, almost all, except for CAR 1 (released in 1994) and Riang Chey (released in 1999), were traditional varieties (Table 5).

Forty-four farmers claimed to have grown drought-tolerant varieties for 15 years while 49 farmers said they had grown flood-tolerant varieties for 20 years. Two varieties, Beungkok and Chmar, from survey results were both drought- and flood-tolerant. The yields of traditional varieties were low with a mean yield of 2.24 t/ha, while the average yield for all modern varieties was 2.5 t/ha from the baseline survey. Traditional varieties were continually grown because farmers preferred their taste and quality. Among the modern varieties grown and their yields were: Phka Rumduol (2.21 t/ha), Riang Chey (2.07 t/ha), CAR9 (2.14 t/ha), Sen Kra Ob from Thailand (2.59 t/ha), IR504-04 from Vietnam (3.82 t/ha), and Malis Praing (2.61 t/ha).

Top Modern Varieties (MVs) from the Baseline Survey

The popular MVs vary by season and a few common varieties are widely grown in all provinces. In 2015, the survey in four provinces revealed the top six MVs and percent area coverage in the survey sites as follows: Phka Rumduol (33%), IR504-04 (24%), Riang Chey (13%), CAR9 (6%), Sen Kra Ob (6%), and Malis Praing (4%). These top six MVs covered 85 percent of total rice area in the survey sites. The baseline survey showed that the six MVs were adopted by the following percentage of farmers in these seasons: 69 percent in WS, 97 percent in DS and 92 percent in EWS. Adoption of MVs was highest during the DS. In addition to IR504-04 and Sen Kra Ob for DS, the other MVs mentioned and used were OM4900, CAR1, CAR3, and CAR9. Very few farmers had tried growing some of the STRVs such as Sen Pidao, CAR14, and CAR15 with their seeds coming from CARDI or farmer-to-farmer prior to this project.

Table 5. Varieties perceived to be stress-tolerant from the 2015 baseline survey

Rice Varieties	
Drought-tolerant	**Flood-tolerant**
Srov Popeay	Neang Stoung
CAR 1	Srov Popeay
Chmar	Beungkok
Neang Minh	Kunlong Phnom
Beungkok	Bongkok Thngun
Phka Prolith	Chmar
Kong Klay	Srov Vear
Riang Chey	

Sources of Knowledge and Training Needs

In the baseline survey, the farmers' sources of knowledge were commonly from other farmers and from the media. The endline survey asked 424 farmers about their sources of knowledge before, during, and after 2015 (Table 6). For 2015 and earlier, their knowledge sources were more commonly from other farmers and from media. Only 4 percent mentioned IRRI or PDAFF as their sources of knowledge. After the project involvement, when asked in the 2018 survey, 92 percent of the respondents attributed their knowledge to IRRI or PDAFF, from training manuals and leaflets (61%), and from farmer-to-farmer (24%). This showed the growing recognition of the role of government and IRRI as sources of new knowledge for rice seeds and technology.

When asked about their training needs, 86.6 percent (367 of the 424 farmers) felt that they needed more training courses to improve their agricultural knowledge for the future (Table 7). The two top-ranking topics for training and percentage of farmers were seed production (40.3%) and fertilizer management (18.9%). The other topics needed were pest management (7.3%), weed management (6.6%), seed selection, and chemical management (both at 3.8%).

STRV Performance in 2017 WS Participatory Trials

The farmer participants in the 2017 WS demonstration (demo) trials were asked about the varieties they had previously grown in 2016 WS and their obtained yields. In the four provinces, 7 to 11 different varieties were grown during 2016 WS. The number of traditional varieties that are mentioned as compared with those of modern varieties were as follows: in Battambang (4:3), Pursat (3:5), Kampong Thom (4:6), and Siem Reap (4:7). Yields of traditional varieties were low in 2016 WS ranging from 1.2 to 2.5 t/ha except for Neang Khon and Sra Nge. In 2017

Table 6. Sources of knowledge on stress-tolerant rice varieties from the 2018 endline survey

Knowledge Source	% of Farmers	
	2015 and earlier	2016–17
Experience/recommendation from traders, producers	6.8	9.4
Farmer-to-farmer	17.2	24.3
Publication (e.g., agriculture magazine)	1.9	1.9
Dealers of input supply	7.3	8.0
Media (radio/TV)	12.5	17.0
IRRI/PDAFF training	4.3	92.2
Training manuals (booklets, leaflets provided during the training)	5.2	61.3

WS, the farmers involved in participatory trials were given quality seeds and at least three training activities. They were asked to plant their own variety and apply their own technologies in an adjacent nondemo plot. A total of 420 demo plots of STRVs were established in the four provinces and yield from crop cuts were taken from 339 trials. The number of demo field trials for STRVs were as follows: Sen Pidao (8), CAR14 (8), CAR15 (23), CAR4 (2), Damnoeb Sbai Mongkul (9), Riang Chey (25), Phka Rumduol (247), and Pkha Romeat (17). Three flood-tolerant varieties, Riang Chey, Phka Rumduol, and Phka Romeat, were picked by farmer participants and comprised 85 percent of the 2017 WS trials. Data on rice yields from demo and nondemo plots are presented in Figure 2 and in Appendix Table 1. T-tests were conducted between mean yields of varieties from demo and nondemo plots of 2017 WS trials from varieties having $n \geq 5$.

Battambang Province. The top-performing varieties from the 2017 WS demo plots were Phka Romeat (5.2 t/ha), DSM (4.22 t/ha), and CAR15 (4.34 t/ha). T-test results showed that the varieties from the demo plots, Phka Rumduol, CAR15, and Riang Chey, outperformed the varieties from the nondemo plots, Phka Rumduol, Neang Khon, and OM4900. Certified seeds of Phka Rumduol in demo plots performed better than farmer's variety with the same name in nondemo plots. No significant difference in yield, however, was found for Phka Rumduol and Riang Chey (from the demo plots) when compared with Sen Kra Ob (nondemo plot), a recent popular variety from Thailand, while CAR15 significantly showed better yields than Sen Kra Ob. Varieties Phka Rumduol and Riang Chey both have long maturity duration at 170 days, while Sen Kra Ob and CAR15 are both moderately early-maturing varieties at 120 days. Of 79 farmers, two farmers had CAR15 in demo plots with high yields of 5.8 and 5.1 t/ha each, while their traditional variety, Sra Nge in nondemo plots had low yields of 1.0 and 1.2 t/ha only.

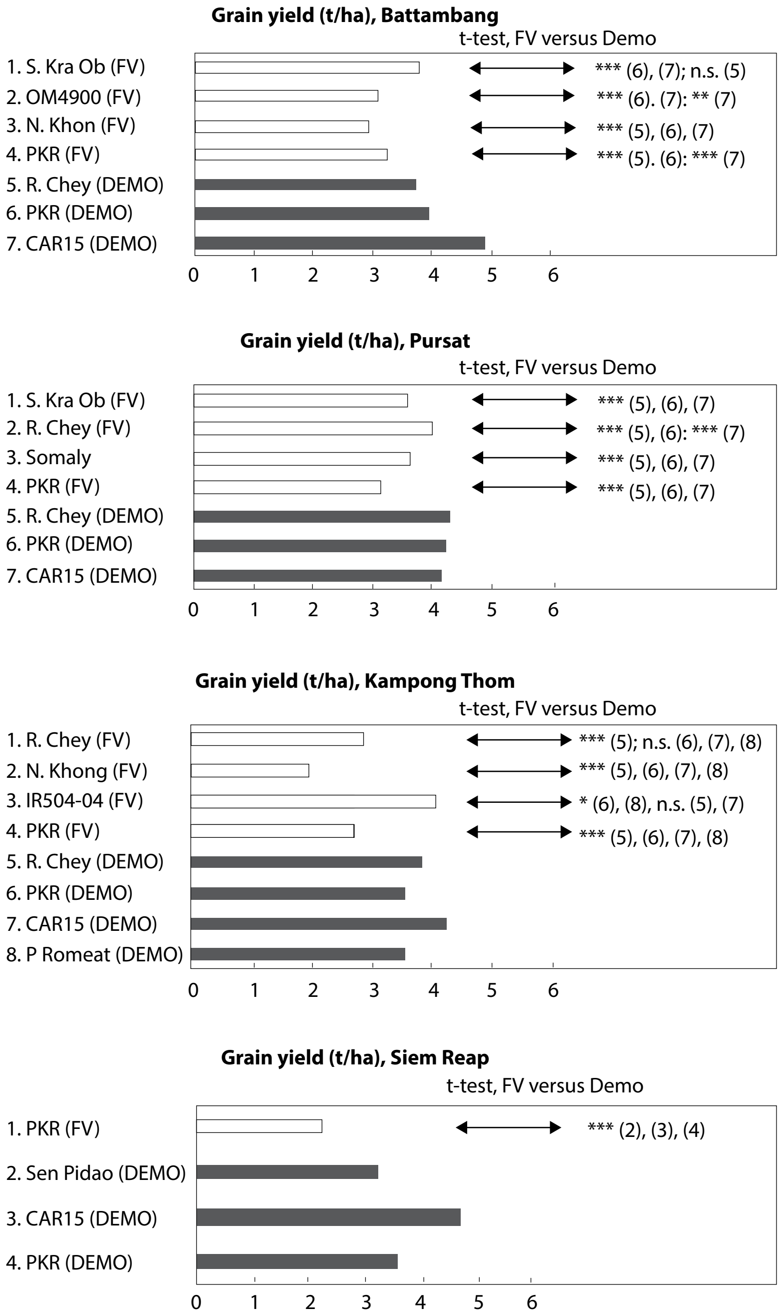
Table 7. Training courses needed by farmers, 2018

Training Topic	Number of Responses	% of farmers
Weed management	28	6.6
Seed selection	16	3.8
Seed purification	1	0.2
Seed production	171	40.3
Postharvest management	3	0.7
Pest management	31	7.3
Land preparation	6	1.4
Fertilizer management	80	18.9
Disease management	6	1.4
Crop establishment	9	2.1
Chemical management	16	3.8
Total	**367**	**86.6**
No training is needed	57	13.4

Pursat Province. The top-performing varieties in the demo plots were CAR4 (5 t/ha), Riang Chey (4.98 t/ha), and CAR14 (4.8 t/ha). CAR4, released in 1995 by CARDI, is continued to be favored by a few farmers. According to CARDI, the CAR14 variety is moderately tolerant to drought or 10 days submergence, but it is moderately susceptible to brown plant hopper. Varieties in the demo plot, Phka Rumduol, CAR15, and Riang Chey, outperformed varieties in the nondemo plots, Phka Rumduol, Sen Kra Ob, and Somaly. Riang Chey in demo plots, which had a slightly better yield than the variety with the same name in nondemo plot, was not found significantly different. Six of the 75 farmer participants obtained yields of less than 1 t/ha in their nondemo plots.

Kampong Thom Province. The top-performing varieties in the demo plots were CAR4 (5 t/ha), CAR15 (4.43 t/ha), and DSM (4.1 t/ha). DSM is a special glutinous rice and grown only during the WS. T-tests showed that the varieties in the demo plots (Phka Rumduol, CAR15, Riang Chey, and Phka Romeat) outperformed three varieties in the nondemo plots (Phka Rumduol, Neang Kong, and Riang Chey), but not IR504-04. Neang Kong, a traditional variety with yields of 3 t/ha in 2016

Figure 2. Grain yields of farmers' varieties (FV) in nondemonstration plots and supplied institutional seeds in demonstration plots (Demo) in four provinces in Cambodia



Notes: T-tests no. of sampling $\geq$ 5; n. s. - not significantly different; ***, **, * - significantly different at * = 0.001, 0.01, 0.05, respectively

WS and 2.93 t/ha in 2017 WS in Battambang, showed a low yield of 1.94 t/ha in Kampong Thom province. Out of the 81 farmer participants, three obtained good yields of Phka Rumduol of about 3.6, 3.6, and 3.2 t/ha each from their demo plots, but severely had low yields of only 0.48, 0.80, and 0.29 t/ha respectively, from variety with the same name in their nondemo plots. Extremely low yields may occur due to several reasons such as geographic location, biotic, and abiotic factors.

Siem Reap Province. The top-performing varieties in the demo plots were CAR15 (4.65 t/ha), Riang Chey (4.30 t/ha), and CAR14 (3.86 t/ha). Three varieties (Phka Rumduol, CAR15, and Sen Pidao) by t-test significantly outperformed Phka Rumduol in the nondemo plots. Other varieties had only 1 to 2 field plots and could not be included in the t-tests. However, their yields were also presented.

During the 2017 WS, only a few nondemo trials with poor yields were severely affected with stress. The traditional varieties had lower yields than modern varieties, such as IR504-04 and Sen Kra Ob, which performed well. The participatory trials showed that most varieties in the WS demo trials showed a yield advantage of 1.0 to 1.5 t/ha than those in nondemo plots. The mean yield advantage of STRVs was 1.7 t/ha. In terms of sales, paddy rice in 2018 sold for 1,000 riels (USD 0.25) per kg and 1,200 riels (USD 0.30) per ton for premium fragrant rice. So, 1 t/ha more yield multiplied by USD 0.25 is USD 250 to USD 300 (for premium rice) additional income.

Farmers' Preferred Varietal Traits

The farmers from the endline survey were asked about specific varietal traits that they preferred (Table 8). Ranked based on their rate of responses, around 23 percent of the farmers reported that they preferred a variety with long and slender grains, followed by traits of heavy grains, high head rice recovery, and good eating quality, with percentage of respondents at 18.4, 15.3, and 14.9 percent, respectively. Other preferred traits included translucent grains, soft grains, pleasant smell of newly harvested crop, long stems, high-volume expansion, and aromatic (pendant-scent).

The rice varieties in the demo plots performed better than the farmer's variety with the same name in nondemo plots. However, no significant difference in yield was found for Phka Rumduol and Riang Chey (from the demo plots) when compared with Sen Kra Ob (nondemo plot), a recent popular variety from Thailand, while CAR15 significantly showed better yields than Sen Kra Ob. Both Phka Rumduol and Riang Chey are late-maturing varieties at 170 days, while Sen Kra Ob and CAR15 are both moderately early-maturing varieties at 120 days. Of 79 farmers, two had CAR15 variety in demo plots with high yields of 5.8 and 5.1 t/ha each, while their traditional variety, Sra Nge, in nondemo plots showed low yields of 1.0 and 1.2 t/ha only.

Pursat Province. The top-performing varieties in the demo plots were CAR4 (5 t/ha), Riang Chey (4.98 t/ha), and CAR14 (4.8 t/ha). CAR4, released in 1995 by CARDI, continues to be favored by a few farmers. According to CARDI, CAR14 variety is moderately tolerant to drought or can withstand 10 days submergence, but it is moderately susceptible to brown plant hopper. Varieties in the demo plot, Phka Rumduol, CAR15, and Riang Chey outperformed varieties

Table 8. Important traits perceived by farmers and percentage, 2018

Traits	Responses	
	Number	%
Long and slender grains	98	23.11
Heavy grains	78	18.40
High head rice recovery	65	15.33
Good-eating quality	63	14.86
High-volume expansion	39	9.20
Aromatic (pendant-scent)	35	8.25
Translucent grains	31	7.31
Soft grains	22	5.19
Pleasant smell of newly harvested crop	16	3.77
Long stems	15	3.54

in the nondemo plots, Phka Rumduol, Sen Kra Ob, and Somaly. Although Riang Chey in demo plots had a slightly better yield than the variety with the same name in nondemo plots, they were not found significantly different. Six of the 75 farmer participants got yields of less than 1 t/ha in their nondemo plots.

Kampong Thom Province. The top-performing varieties in the demo plots were CAR4 (5 t/ha), CAR15 (4.43 t/ha), and DSM (4.1 t/ha). DSM is a special glutinous rice and is grown only during the WS. T-tests showed that the varieties in the demo plots (Phka Rumduol, CAR15, Riang Chey, and Phka Romeat) outperformed the three varieties in the nondemo plots (Phka Rumduol, Neang Kong, and Riang Chey), but not IR504-04. Neang Kong, a traditional variety with yields of 3 t/ha in 2016 WS and 2.93 t/ha in 2017 WS in Battambang, showed a low yield of 1.94 t/ha in Kampong Thom province. Looking at details from the 81 farmer participants, three farmers obtained good yields of Phka Rumduol of about 3.6, 3.6, and 3.2 t/ha each from their demo plots but had severely low yields of only 0.48, 0.80, and 0.29 t/ha respectively, from variety with the same name in their nondemo plots. Extremely low yields may occur due to several reasons such as geographic location, as well as biotic and abiotic factors.

Siem Reap Province. The top-performing varieties in the demo plots were CAR15 (4.65 t/ha), Riang Chey (4.30 t/ha), and CAR14 (3.86 t/h). Three varieties (Phka Rumduol, CAR15, and Sen Pidao), by t-test, significantly outperformed Phka Rumduol in the nondemo plots. Other varieties had only 1 to 2 field plots and could not be included in the t-tests. Their yields were also presented. From 2017 WS, only a few nondemo trials with poor yields were severely affected with stress. The traditional varieties had lower yields than the modern varieties. Modern varieties IR504-04 and Sen Kra Ob also showed good performance.

The participatory trials demonstrated that the most varieties in the WS demo trials showed a yield advantage of 1.0 to 1.5 t/ha than those in the nondemo plots. The mean yield advantage of STRVs was 1.7 t/ha. In terms of sales, paddy rice in 2018 sold for 1,000 riels (USD 0.25) per kg and 1,200 riels (USD 0.30) per ton for premium fragrant rice. A direct estimate would translate that a 1.0 t additional yield multiplied by USD 0.25 would translate to USD 250 to USD 300 (for premium rice) additional income per hectare.

Willingness and Barriers to STRV Adoption

Most farmers (92.45% or 392 of 424), who received institutional seeds for field demo in the four provinces, reported that they were willing to adopt STRVs in the future; only 7.55 percent were unwilling. Table 9 lists farmers' reasons for not adopting STRVs with the percentage of respondents as follows: low price (46.9%), no market demand (37.5%), not resistant to pests and diseases (6.3%), no access to market information resulting in dependence on traders for prices (6.3%), and unpurified seed (3.1%).

Aside from willingness to grow STRVs, 9.7 percent of 424 farmers across the four provinces reported that they were willing to grow in their nondemo plots the same variety that they grew in their demo plots, predominantly, Phka Rumduol, Riang Chey, CAR15, and DSM. Only 20.29 percent of the farmers were not willing to grow the same variety in their nondemo plots. Generally, most farmers preferred to grow four main varieties such as Sen Kra Ob, Sen Pidao, Phka Rumduol Prang, and IR504-04. Meanwhile, a few farmers preferred to grow other varieties such as Phka Romeat, CAR6, CAR9, and Neang Khong.

SUMMARY

Smallholder farmers, especially those in the rainfed lowland areas around Tonle Sap, are the most vulnerable to the challenges of the changing environment. The demographic profile of rice farmers in the four provinces of Battambang, Pursat, Siem Reap, and Kampong Thom showed an aging population with nearly 25 percent women farmers. They rely on rice farming for most of their income, own few farm machineries, and depend

Table 9. Barriers to adopting STRVs and percentage of respondents, 2018

Reasons for Non-Adoption	Responses	
	Number	%
Low price in the market	15	46.9
No market demand	12	37.5
No access to market information resulting in dependence on traders for prices	2	6.3
Not resistant to pests and diseases	2	6.3
Unpurified seed	1	3.1

on rainfall for production. These farmers with few (2–3) small parcels of land, each measuring two hectares or less, have experienced crop losses due to drought or flooding in the last five years. The yields of traditional and modern varieties, Phka Rumduol, IR504-04 (from Vietnam), Riang Chey, Malis Praing, and Sen Kra Ob (from Thailand), were similar and low (<2.50 t/ha). Most farmers preferred the taste of traditional varieties and may explain why they continue to be grown. A small percentage, 14 percent of baseline respondents, claim to know about stress-tolerant rice varieties and farmers' knowledge on modern varieties or technologies commonly came from other farmers, or from media. This indicates the importance of experts and trained extension staff to provide proper knowledge on suitable varieties and their associated technologies. Response to adoption of various listed technologies showed use of direct seeding and machinery, and with access to most services available.

While CARDI and MAFF released high-yielding varieties, smallholder farmers needed access to seeds, proper agricultural information, and other various support. To enable adoption of STRVs, the project worked on a chain of processes that needed integrated support from different partners. Together with government agencies (CARDI, PDAFF) and private seed producers, foundation and quality seeds were produced. Seed minikits, leaflets, prints, and media were all necessary. Farmers' field days and forums were used to popularize varieties to farmers, millers, traders, and others, and these activities required support from government, district officials, commune leaders, and public and private organizations. Many intensive capacity-building activities, such as training of trainers for government extension workers and seed producers, was prioritized to develop government and local resource organizations. The farmers' training included topics on STRVs, rice and seed production, irrigation, fertilizer and pest management, and postharvest technologies.

Farmers who are better educated have greater ability to process and use technologies suitable to their farms and must be given necessary attention by policy makers (Mariano, Villano, and Fleming 2012). The involvement of several partners, especially PDAFF, contributed to the awareness and adoption of several management technologies. The Royal Government of Cambodia through the project's assistance has recently released a new policy on seed system to address the shortage of quality seeds (Royal Government of Cambodia, 2019a; 2019b).

An innovation is more likely to be adopted when it has a high relative advantage, perceived superiority, and can be tested and learned before adoption (Pannell et al. 2006). Farmers' participatory trials (80 farmers in DS, 420 in WS) were performed. To evaluate the STRVs' relative advantage, yield data were collected in 2017 WS. Using quality seeds of STRVs and associated technologies applied in demonstration plots resulted in significantly higher yields than those from nondemonstration plots in the four provinces. Yields in demonstration plots ranged from 3.6 to 5.0 t/ha. The important traits of Phka Rumduol, Riang Chey, and DSM's are their photoperiodsensitivity and flood tolerance. These varieties can tolerate stagnant flooding and their late-flowering trait enables farmers to harvest once the water level subsides. CAR15 is nonphotoperiod-sensitive, has an early maturity of 90 to 100 days, blast-resistant, and can be grown in both dry and wet seasons on nonflooded areas. The moderately early-maturing varieties are advantageous because they can be harvested earlier and less exposed to stress environments.

High-quality seeds from a reliable source as an advantage was demonstrated when varieties with same name but obtained from different sources were grown. To ensure high quality and better yield, use of certified seeds from reliable producers must be continuously promoted. This also relates to a previous study in Cambodia that suggested that use of seeds from reliable sources would benefit production (Ghimeri and Suvedi 2018). In addition, findings from another study in the same four provinces demonstrated the importance of appropriate nutrient management to achieve higher yields (Kong et al. 2019).

Drought-tolerant CAR4 and CAR14, performed well in Pursat province. The drought-tolerant varieties may also address conditions where water becomes less available toward the reproductive phase. This is termed as terminal drought. Selection of suitable varieties for a particular location, season, soil type, and growing condition would be possible with farmers' trials prior to adoption. The moderately early-maturing variety Sen Pidao performed well and outperformed the late-maturing variety Phka Rumduol in Siem Reap. Two other modern varieties, IR504-04 and Sen Kra Ob, where no new quality seeds were given showed good yields (3.6 to 4.0 t/ha) in Battambang, Pursat, and Kampong Thom but not in Siem Reap, indicating that in 2017 WS, a favorable growing condition (no drought, flooding or blast), and together with farmer's experience and management would likely be the causal factors for the good yield. The WS trials also showed a few examples of poor yields (<1 t/ha) in nondemonstration plots and perhaps due to severe biotic and abiotic stress aside from location.

The endline survey of 424 respondents showed that most (92.45%) farmers were willing to adopt STRVs and 79.7 percent of them were willing to plant the same variety from their demonstration plots. This showed that demonstration farms are important extension tools in disseminating and promoting technologies. This was also shown in another study where some adopters linked to extension and demonstration farms were significantly higher than non-adopters without demonstration farms (Ghimeri and Suvedi 2018). The traits that are important to farmers from the endline survey are long, slender, and heavy grains followed by high-head rice recovery and good-eating quality. The reasons cited by a few non-adopters are mainly low price and absence of market demand for their product. Value-chain management and policies to address these can increase the rice export potential of Cambodia.

CONCLUSION

This study determined that smallholder farmers in the four provinces surrounding Tonle Sap Lake could improve their rice yield by adopting better varieties and management technologies. Identification of farmers, seed dissemination, capacity building, participatory trial, and involvement of extension workers, seed producers, and stakeholders are all part of the adoption process. These activities have since become part of the Royal Government of Cambodia's new policy on use and production of quality seeds. It would be useful, nonetheless, for a post-adoption evaluation study to be undertaken after five years to examine the progress in sustaining the use of quality seeds in Cambodia.

ACKNOWLEDGMENT

The author thanks USAID; the Royal Government of Cambodia and MAFF; the Department of Agriculture, the Philippines; the Ministry of Agriculture and Farmers' Welfare, India; CARDI; Dr. H. Webber; Mr. E. Tumpang; and Ms. S. Yath.

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APPENDIX

Appendix Table 1. Grain yield (t/ha) from 2017 wet season (WS) and t-tests between demonstration (demo) and non-demonstration (nondemo) plots' mean varietal yields of entries with n≥5 (other varieties' (n<5) mean yields are shown)

BATTAMBANG					PURSAT					KAMPONG THOM					SIEM REAP				
Demo		Non-demo			Demo		Non-demo			Demo		Non-demo			Demo		Non-demo		
Variety	Yield	Variety	Yield	t-test	Variety	Yield	Variety	Yield	t-test	Variety	Yield	Variety	Yield	t-test	Variety	Yield	Variety	Yield	t-test
PKR	3.92	vs. PKR	3.24	***	PKR	4.21	vs. PKR	3.13	***	PKR	3.56	vs. PKR	2.68	***	PKR	3.5	vs. PKR	2.21	***
		vs. N. Khon	2.93	***			vs. S. Kra Ob	3.58	***			vs. IR504-04	4.06	*	CAR15	4.67	vs. PKR	2.21	***
		vs. OM4900	3.07	***			vs. Somaly	3.61	***			vs. N. Kong	1.94	***	Sen Pidao	3.22	vs. PKR	2.21	***
		vs. S. Kra Ob	3.77	n.s.	R. Chey	4.98	vs. PKR	3.13	***			vs. R. Chey	2.85	n.s.					
CAR15	4.86	vs. PKR	3.24	***			vs. S. Kra Ob	3.58	***	CAR 15	4.43	vs. PKR	2.68	***					
		vs. N. Khon	2.93	***			vs. Somaly	3.61	***			vs. IR504-04	4.06	n.s.					
		vs. OM4900	3.07	***			vs. R. Chey	3.98	n.s.			vs. N. Kong	1.94	***					
		vs. S. Kra Ob	3.77	***	CAR15	4.14	vs. PKR	3.13	***			vs. R. Chey	2.85	***					
R. Chey	3.72	vs. PKR	3.24	*			vs. S. Kra Ob	3.58	***	R. Chey	3.86	vs. R. Chey	2.85	n.s.	Others:				
		vs. N. Khon	2.93	*			vs. Somaly	3.61	***			vs. PKR	2.68	***	CAR 14	3.86	Neang Pich	1.63	
		vs. OM4900	3.07	**			vs. R. Chey	3.98	n.s.			vs. IR504-04	4.06	n.s.	DSM	2.87	P. Rumdeng	2.05	
		vs. S. Kra Ob	3.77	n.s.								vs. N. Kong	1.94	***	R. Chey	4.30	S. Kra Ob	2.10	
Others:					Others:					P. Romeat	3.58	vs. R. Chey	2.85	n.s.	P. Romeat	2.90	Sen Pidao	2.34	
Sen Pidao	3.87	R. Chey	3.06		CAR4	5.00	CAR9	5.12	5.12			vs. PKR	2.68	***			R. Chey	3.00	
CAR14	3.87	Sra Nge	2.28		CAR14	4.80	IR504-04	3.70	3.70			vs. IR504-04	4.06	*			P. Romeat	1.65	
DSM	4.22	P. Malis	3.00		DSM	4.30	Kha Khney	3.70	3.70			vs. N. Kong	1.94	***			P. Doung	2.50	
P. Romeat	5.20	Koun Chin	1.50				P. Malis	3.60	3.60	Others:							Neang Ming	2.80	
										CAR4	5.00	Kramoun Sar	1.41				Neang Om	2.00	
										CAR14	3.75	Leak Loek	1.90				CAR9	2.40	
										DSM	4.10	P. Romeat	2.40				Phka Malis	1.80	
										Sen Pidao	2.60	S. Kra Ob	2.08						
												Samb. Ankr.	1.40						

Notes:
vs. - versus; n.s. - not significantly different; ***,**,*-significantly different at a=0.001, 0.01, 0.05, respectively
PKR - Phka Rumduol; N. Khon - Neang Khon; N. Kong - Neang Kong; S. Kra Ob - Sen Kra Ob; P. Malis - Phka Malis; R. Chey - Riang Chey; P. Romeat - Phka Romeat; P. Doung - Phka Doung; P. Rumdeng - Phka Rumdeng; DSM - Damnoeb Sbai Mongkul; Samb. Ankr. - Sambok Angkrang