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Is Pacific white shrimp (*Penaeus vannamei*) farming in India is technically efficient? — A comprehensive study

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ABSTRACT

Technical efficiency (TE) measures the ability of the farmer to obtain maximum outputs from a given combination of inputs. Stochastic frontier production function analysis (SFA) was employed to assess the technical efficiencies of Pacific white shrimp (*Penaeus* (*Litopenaeus*) *vannamei*) farming in India. The findings of this comprehensive study shown that the mean technical efficiency of *P. vannamei* farms in the country was 0.9013, indicating that the farms achieved 90% of the maximum possible output from a given set of inputs. Maximum likelihood estimates of production function indicated that shrimp stocking density, feed quantity and its management, access to technical consultancy, adoption of zero water exchange, cropping intensity and duration of the culture were the major determinants of TE. The ANOVA and student 't' analyses have shown significant differences in the TE of *P. vannamei* farming across salinity of culture systems ($p < 0.05$), geographical distribution of farms ($p < 0.01$), sources of rearing water ($p < 0.05$), nature of pond bottom (lined and earthen ponds) ($p < 0.01$), stocking methods ($p < 0.01$) and cropping intensity ($p < 0.01$). It is suggested that the aquaculture extension agencies need to educate the farmers on selection of quality seed, adopting suitable stocking densities, optimization of inputs, energy use and better management practices to sustain the technical efficiencies. It is important to refine the farming practices of *P. vannamei* farming in tune with the scale and systems of operation being adopted. Ensuring disease free seed supply, cost effective feed and provision of electricity to aquaculture farms in the rates applicable to agriculture farms and promoting energy efficient automatic feed dispensers, aerators, generators, and popularising HDPE (high-density polyethylene) lining of ponds bottom would aid in sustaining the efficiencies of production systems and sustainability of *P. vannamei* farming in India.

Statement of relevance: Pacific white shrimp (*Penaeus vannamei*) has been farmed extensively in the coastal states of India. It is imperative to optimize usage of critical inputs and technology in *P. vannamei* shrimp farming to enhance the efficiency and profitability of production systems. Assessing the technical efficiency (TE) of the production systems points out the aspects to be paid attention by the farmers to optimize the inputs usage and enhance the profitability and sustainability of shrimp farming. Therefore, this study is timely and would aid in providing technical and policy inputs for the aquaculture researchers and planners for sustaining the shrimp farming in India.

1. Introduction

Shrimp is the lucrative crustacean species farmed across the world, and currently Pacific white shrimp (*Penaeus vannamei*) is the leading species farmed worldwide, and also in India. Having the potential of 1.2 million ha brackishwater area spread across nine maritime states, shrimp farming is a major fish production system contributing about 70% of India's total seafood in value (MPEDA, 2015). Farming area under *P. vannamei* is expanding (FAO, 2014) mainly because of the availability selectively bred, Specific Pathogen Free (SPF) seeds in the global market. Further, selectively bred *P. vannamei* is preferred over other species of shrimp for farming in view of its tolerance to a wide range of salinities (0 to 45 ppt), amenable for high stocking densities, rapid gain in weight up to 20 g, column feeding habit, feeding on natural biofloc, low dietary protein requirement (30–35%) and higher meat yield (65–70%) (Mathew Briggs et al., 2004; Ravichndran et al., 2009).

India has introduced SPF Pacific white shrimp in the year 2009 mainly to revive the regressing shrimp farming sector, which was struggling due to frequent crop failures of black tiger shrimp, caused by the fatal white spot disease. Since its introduction the farming area of *P. vannamei* has increased dramatically from 283 ha in 2009–10 to 50,241 ha in 2014–15 (Fig. 1) and the production has also grown from 1731 to 353,413 metric tonnes (MPEDA, 2015) during the same period.

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India has diverse range of shrimp farming systems ranging from traditional tide fed ponds to super intensive biofloc systems and from low saline to high saline culture systems with suitable amendments in the rearing medium. Unlike other Asian neighbours and Latin America where the shrimp production volumes drastically decreased during 2012–2013 mainly as a result of disease related problems such as Acute Hepatopancreatic Necrosis Disease (AHPND) popularly known as Early Mortality Syndrome (EMS), (FAO, 2016, 2014), Indian shrimp farming survived these situations and made a record in shrimp production, both in terms of volume (0.35 million MT) and value (US$3.7 billion). Probably technical efficiency (TE) of shrimp farms is the factor for such a efficient production.

Technical efficiency (TE) measures the ability of the farmer to obtain maximum outputs from a combination of given set of inputs. The concept of technical efficiency was first introduced by Ferrell (1957) and it is measured as a ratio of actual to potential production. The level of TE is measured by the distance a particular farm is from the production frontier. Thus, a farm that fits on the production frontier is said to be technically efficient. Estimation of TE helps in identification of critical inputs and optimizing the inputs which result in cost effectiveness. Assessment of the efficiency of biological production sectors pave the way for important policy implications, provided such assessment takes into account the effects of input use on output variance (production risk), as this is vital for development planning (Jaenicke et al., 2003; Villano and Fleming, 2006). Several studies have reported the technical efficiency of fish farming and other aquaculture systems (Anetekhai et al., 2004; Adeokun et al., 2006; Kareem et al., 2008; Singh et al., 2009; Sesabo and Tol, 2007; Ogundari and Akinbogun, 2009; Muralidhar et al., 2012; Ajao, 2012). The stochastic frontier approach has been widely adopted method in analysing farm level data where measurement errors are substantial and weather is likely to have a significant effect (Coelli, 1996). Several studies in fisheries and aquaculture adopted stochastic frontier production function to estimate the TE (Ogundari and Akinbogun, 2010; Ajao, 2011; Begum et al., 2013; Bhattacharya, 2008; Chiang et al., 2004; Den and Ancev, 2007; Dey et al., 2005; Ghee-Thean et al., 2016; Kareem et al., 2008; Singh et al., 2009; Nguyen Thi Hoai, 2012; Ogundari and Akinbogun, 2009). The technical efficiency of shrimp farming particularly of tiger shrimp (*Penaeus monodon*) in India was studied earlier by Kumar et al. (2004) and Uma and Prasad (2004) and Muralidhar et al. (2012). However, TE of Pacific white shrimp (*Penaeus vannamei*) farms in India has not been studied so far and this is the first its kind. We expect that, this study will elucidate the ways and means of optimizing the inputs and out put (productivity) of *P. vannamei* farming systems in Indian agroclimatic conditions. This study assumes importance because of the increased investment on variable inputs with increased stocking densities with SPF shrimp seed. The TE analysis will also help in suggesting farmers to optimize their inputs and rationalize their production cost on shrimp, *P. vannamei*. Further, this study could identify the farming practices which are to be revalidated by the researchers and practices on which the farmers need special training from the extension agencies.

2. Hypotheses formulated

The following hypotheses were postulated for the study to assess and interpret the findings scientifically. These hypotheses were arrived based on logical expectations as SPF seeds, feed and management protocols are made available across the country by the planners.

H1. There is a significance of difference in the technical efficiencies of *P. vannamei* farms across the salinity regimes.

H2. There is a significant difference in the technical efficiencies of *P. vannamei* farms of different states.

H3. There is a significant difference in the technical efficiencies of *P. vannamei* farms using different sources of water.

H4. There is a significant difference in the technical efficiencies of *P. vannamei* farms according to the cropping intensity.

H5. There is a significant difference in the technical efficiencies of *P. vannamei* farms having lined and earthen ponds.

H6. There is a significant difference in the technical efficiencies of *P. vannamei* farms adopting different stocking methods.

3. Research methodology

3.1. Data source and sampling design

Farmers practicing Pacific white shrimp *P. vannamei* farming were the population of this investigation. State and district wise list of *P. vannamei* farmers was obtained from the Coastal Aquaculture Authority (CAA), the country's regulatory agency for coastal aquaculture. A sample of 604 shrimp farmers was personally surveyed and interviewed following proportionate random sampling design in eight coastal states of India (Fig. 2) to collect primary data for the study. As *P. vannamei* shrimp farming was practiced extensively in brackishwater as well as

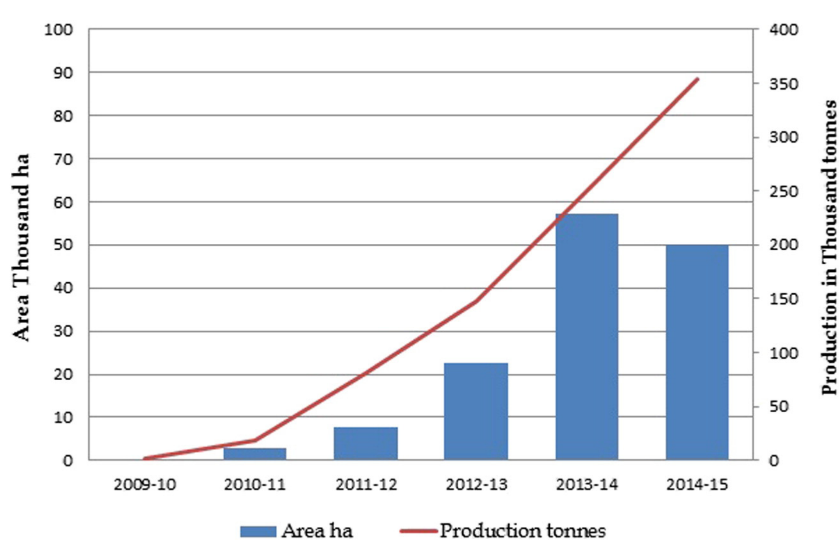

Fig. 1. Area and production of *Penaeus vannamei* in India 2009 to 2015.

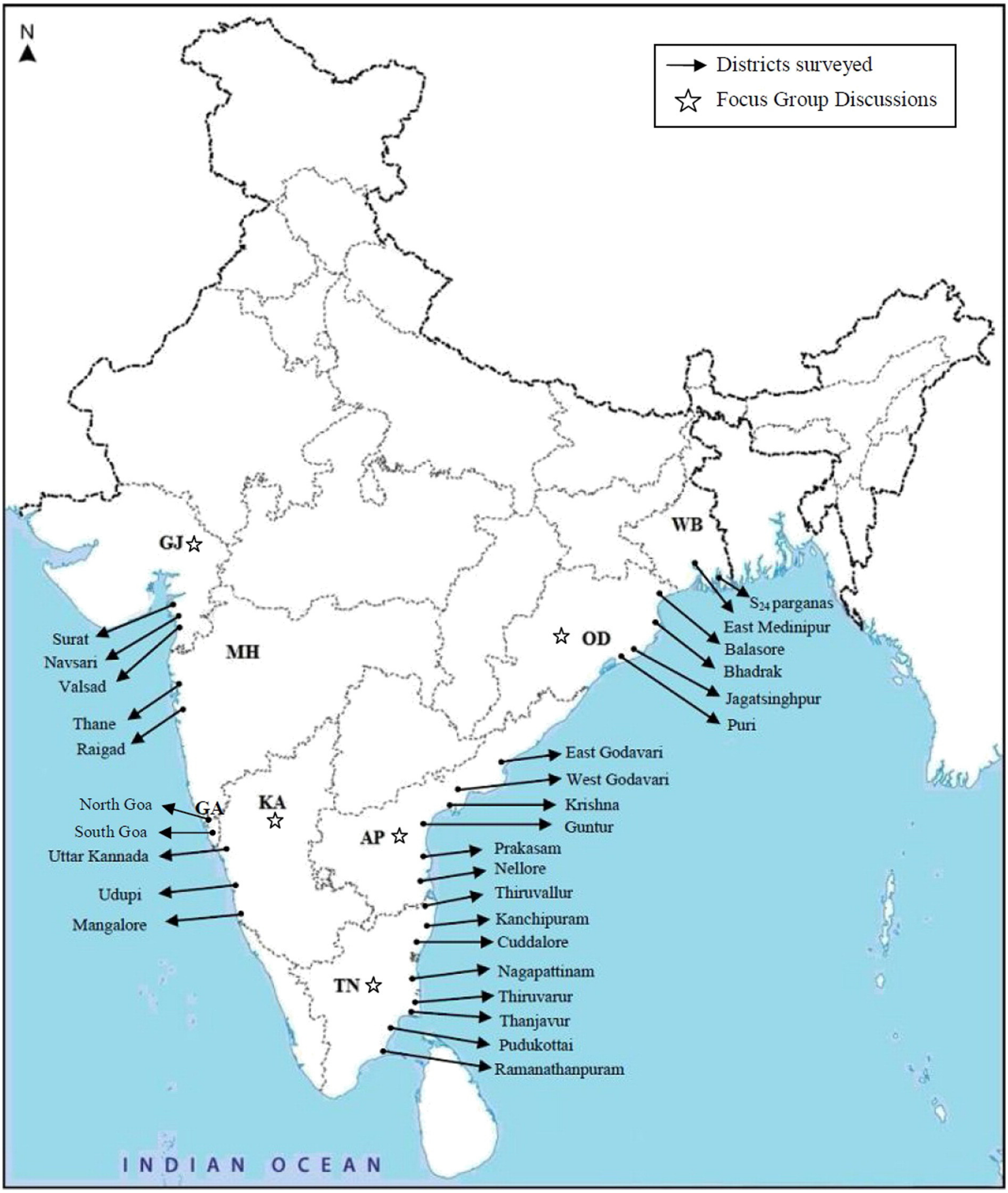

Fig. 2. Map showing the sampling area from where data was collected for this study.

in low saline waters the samples were taken from both the systems. Proportionately 71% of the sample respondents were chosen from brackishwaters and the remaining 29% were from the low saline waters. The primary data were collected using a structured questionnaire which was pre-tested for its reliability and validity in a non-sampling area.

3.2. Estimation of technical efficiency

The concept of TE was introduced by Farell (1957). Aigner et al. (1977) and Meeusen and Van den Broeck (1977) propounded stochastic frontier model with composite error term in order to estimate the technical efficiency. In the context of Asian aquaculture, studies by Dey et al. (2000), Begum et al. (2013), Ghee-Thean et al. (2016), Sharma (1999) and Sharma and Leung (1998), have adopted stochastic frontier production function analysis (SFA) to measure technical efficiencies of different aquaculture species like carps, tilapia, tiger shrimp and Pacific white shrimp respectively. In the present study, similar stochastic frontier production function model was used to assess the technical efficiency of *P. vannamei* culture systems. The theoretical explanation of the SFA is presented below.

Let us assume that each farm uses m inputs (vector x) and produces a single output y, in our study, yield of shrimp in kg. Following Aigner et al. (1977) and Meeusen and Van den Broeck (1977), we assume that the production technology of the ith farm is specified by the stochastic frontier production function

$$y_i = f(x_i;\beta)\exp(\varepsilon_i) \quad 1$$

where i = 1,2, … n refers to farms, β is a vector of parameters and ε_i is an error term and the function $f(x;\beta)$is called the 'deterministic kernel'. The frontier is also called as 'composed error' model because the error term ε_I is assumed to be the difference of two independent elements,

$$\varepsilon_i = v_i - u_i \quad 2$$

where v_i is a two sided error term representing statistical noise such as weather, strikes, luck etc. which are beyond the control of the farm and $u_i \geq 0$ is the difference between maximum possible stochastic output (frontier) $f(x_i;\beta)\exp(v_i)$ and actual output y_i. Thus, u_i represents output oriented technical inefficiency. Thus the error term ε_i has an asymmetric distribution. From Eqs. (1) and (2), the farm-specific output-oriented technical efficiency is given by

$$TE_i^o = \exp(-u_i) = y_i/\{f(x_i;\beta)\exp(v_i)\} \quad 3$$

Since $u_i \geq 0$, $0 \leq \exp(-u_i) \leq 1$ and hence$0 \leq TE_i^o \leq 1$. When $u_i = 0$ the farm's output lies on the frontier and it is 100% efficient. Thus, the output oriented technical efficiency tells how much maximum output is possible with the existing usage levels of inputs.

Two-stage estimation procedure is widely used to explain the efficiency differentials between farms. In the first stage the parameters of the stochastic model and technical efficiencies are computed. Then the estimated technical efficiencies are regressed with the socio-economic attributes like farmer education, experience, training etc. Many authors have criticized this two-stage procedure, because it violates the assumption of identically distributed inefficiency effects in the stochastic frontier, which is necessary in the maximum likelihood estimation (Battese and Coelli, 1995; Reifschneider and Stevenson, 1991). The model developed by Battese and Coelli's (1995) overcomes this deficiency and technical efficiencies are estimated by employing a single estimation procedure. In their model, the one-sided error tem is specified as

$$u_i = g(z_i;\delta) + \omega_{i,} \quad 4$$

where z is a vector of variables used to explain efficiency differentials among farmers, δ is a vector of parameters to be estimated (including an intercept term) and ω_i is a independent and identically distributed random variable with zero mean and variance defined by the truncation of the normal distribution such that $\omega_i \geq -[f(z_i;\delta)]$. The models (1) and (4) for specific forms of $f(x_i, w_i;\beta)$ and $g(z_i;\delta)$ can be estimated econometrically in a single stage using maximum likelihood techniques. The variance parameters of the likelihood function are estimated in terms of $\sigma^2 \equiv \sigma_v^2 + \sigma_u^2$ and $\gamma \equiv \sigma_u^2/\sigma^2$,where the γ has a value between zero and one.

In the present study the single stage method of Battese and Coelli (1995) above has been used to estimate the parameters. The 'Cobb-Douglas' function in log form used in the present study is stated as follows:

$$\ln(y_i) = X_i\beta + v_i - u_i, i = 1, 2, \ldots n \quad 5$$

where X_i is a vector consisting of the logarithms of the following inputs were used.

i) Stocking density per ha
ii) Feed quantity (tonnes per ha)
iii) Labour (man days)
iv) Electricity/fuel cost (Rs. per ha)

In addition to the above variables, techno-socio-economic variables viz., education, occupation, experience (in years), farm size (ha), farming infrastructure, training in farming of *P. vannamei*, adoption of zero-water exchange technology, adoption of automatic feeder, manuring, duration of the crop (days), social participation, farm ownership, consultant-availability, ploughing, filtrations (score), disinfection of pond water, application of fermented juice, water source and cropping intensity were included to explain the efficiency differentials in the light of techno-socio-economic variables. Maximum likelihood estimation procedure was followed to estimate the frontier production function, for this purpose Frontier 4.1 developed by Coelli (1996) was employed. Descriptive statistics like mean, standard deviation, range, percentage analysis, and co-efficient of variation were used to consolidate and interpret the data contextually. One-way analysis of variance (ANOVA) and Student '*t*' test were used to interpret the results and test the hypotheses formulated.

4. Results and discussions

4.1. Production parameters

The production parameters of *P. vannamei* shrimp farming are presented in the Table 1. Based on the results of the study the average productivity of *P. vannamei* farms was 5.9 t/ha and the mean stocking density was 38 shrimp post larvae (PL) per square meter. The average Feed Conversion Ratio (FCR) was worked out to be 1.4. The mean labour requirement to manage 1 ha farm was 281 man-days per crop, which mean that on an average two persons, are required to manage the day to day operations of one hectare farm. The energy (electricity/fuel) cost to produce *P. vannamei* shrimp was Rs.17 per kg (approximately 0.4 USD). The average culture duration was 112 (111.87 ± 19.36) days, however, the duration in the brackishwater area was more as the farmers preferred to produce relatively bigger size (25–30 g) shrimp, which took 120–140 days. About 70% of the respondent farmers had two crops in a year and the remaining 30% of the respondent farmers had only one crop per year.

4.2. Technical efficiencies (TE) of Penaeus vannamei farms characterized based on different farming variables

Data on technical efficiencies (TE) of *P. vannamei* farms characterized based on different farming variables identified in this study is presented in the Table 2. Different salinity regimes, stocking method, pond type, cropping intensity and source water were used to delineate the production systems in this study. However, within each system there were several technology based variations which include stocking density, feeding protocols, water quality management and aeration systems adopted. The findings show that the mean technical efficiency of *P. vannamei* farms in the country was 0.9013 indicating that a farmer was able to produce 90% of the maximum possible production with the given inputs. Further, it was found that brackishwater culture systems, sea water based systems, single cropping systems, lined ponds and nursery stocking systems had exhibited higher technical efficiencies than their respective counterparts. Kumar et al. (2004), Muralidhar et al. (2012) and Uma and Prasad (2004) reported that the mean technical efficiency of tiger shrimp (*Peneaus monodon*) farming in India was in the range of 59 to 87%. In a similar study Malaysian white shrimp farmers have achieved an average technical efficiency of 81.2% (Ghee-Thean et al., 2016) and Bangladesh shrimp farms secured a mean technical efficiency of 82% (Begum et al., 2013). In the present study, majority of the shrimp farms (60%) had a TE of 90% and above (Fig. 3), about 35% of the farms exhibited a TE of 80–90% and hardly 5% of the farms had a TE of <80%. This findings indicate that, majority of the farms had the production levels commensurate with the inputs and management protocols adopted. Further it may be noted that shrimp farms need to operate with higher technical efficiencies otherwise the farmer would incur loss considering the investments and resources involved in production.

Table 1
Summary of production parameters of *Penaeus vannamei* farming (N = 604).

Sl. No	Variables	Mean	Mini	Max	Std. Dev.	CV (%)
1.	Yield (tones/ha/crop)	5.90	1	22	2.69	45.7
2.	Seed stocking density (post larvae/m^2)	38	10	100	13.0	36.3
3.	Feed consumption (tones/ha/crop)	8.43	1	36	4.19	49.7
4.	Labour (man days/ha)	281.28	0.25	360	51.21	18.2
5.	Electricity and/or fuel cost (Rs./crop/ha)	99,298	30,000	430,000	42,445.00	42.7
6.	Duration of the crop (days)	111.87	12	160	19.36	17.3

The maximum likelihood estimates of Stochastic Cobb-Douglas frontier production function for the *P. vannamei* shrimp farming is given the Table 3, which shows that seed stocking density and feed quantity were the major determinants of the technical efficiency in *P. vannamei* farms ($p < 0.01$) and both were highly significant at 1% level of probability. While adoption of zero-water exchange and practicing of a single cropping pattern per year had significant positive relationship with TE, duration of the crop and availability of consultant had significant negative influence towards TE. While some variables show positive coefficients, several variables viz. education, occupation, experience, farm size, farming infrastructure, adoption of periphyton, adoption of biofloc technology, duration of the crop, farm ownership, disinfection of pond water and application of fermented carbon source indicate negative co-efficients. The negative co-efficients point out that these variables are having insignificant influence over the TE. The significant negative coefficients indicate that there is an inverse relation between the variable and technical efficiency. For example as the duration of the crop decreases technical efficiency increases. However non-significant variables irrespective of positive or negative does not influence the technical efficiency. Ghee-Thean et al. (2016) and Islam et al. (2014) reported similar results in the TE analysis of Pacific white shrimp farming in Malaysia.

Optimum stocking density of quality seed in tune with the infrastructure and carrying capacity of the pond were the critical factors determine the success of shrimp farming. Stocking density and duration of culture determine the production and shrimp size at production (Suresh babu et al., 2014). Stocking at higher densities than the pond carrying capacity would certainly lead to production risks in vannamei shrimp farming. Therefore, it is must that farmers should procure only SPF shrimp seed from a registered hatchery after due disease screening for the presence of World Organization for Animal Health (OIE) listed pathogens and adopt other quality checking measures like age of the post larvae, gradual acclimatization, development of hepatopancreas, without fouling organisms etc. for the successful culture and better TE. As the economics of shrimp farming mainly depends on the operational costs such as seed and feed, Singh et al. (2009) reported that seed quality was found as an important determinant of TE and Ghee-Thean et al. (2016) reported that shrimp seed size was the significant factor for TE. Analysis of data and discussions with farmers have revealed that optimal age of the PL should be 12 days (PL12) and above for stocking in brackishwater ponds, whereas in low saline culture, PL15 and above is the optimum. Further, gradual acclimatization of PL to pond water salinity at the rate of 3 to 4 ppt per day at the hatchery is critical in avoiding the initial survival loss due to transfer stress. The age of the PL was found to directly influence the tolerance of larvae to the salinity. Rate of salinity reduction, salinity end point, temperature and age of the post larvae are important factors in acclimatization as indicated by earlier studies (Davis et al., 2004; McGraw and Scarpa, 2004). PL15 and above aged

Table 2
Technical efficiencies (TE) of *Penaeus vannamei* farms characterized based on different farming variables.

States	TE of *P. vannamei* farms in %					Mean TE	Significance
TE of *P. vannamei* farms across different coastal states	50–60	60–70	70–80	80–90	90–100		
TE of *P. vannamei* farms in relation to the different coastal states							
Andhra Pradesh (n = 239)	0.0	0.0	0.5	28.1	71.4	0.92	F = 40.51806**
West Bengal (n = 52)	7.7	3.8	17.3	61.5	9.6	0.81	($p < 0.01$)
Maharashtra/Goa (n = 74)	0.0	0.0	3.1	68.8	28.1	0.87	
Gujarat (n = 33)	0.0	0.0	0.0	6.1	93.9	0.94	
Karnataka (n = 45)	0.0	0.0	13.0	43.5	43.5	0.89	
Odisha (n = 41)	0.0	0.0	0.0	17.1	82.9	0.93	
Tamil Nadu (n = 120)	0.0	0.0	4.2	40.3	55.5	0.90	
TE of *P. vannamei* farms in relation to the water conditions							
Water condition							
Brackishwater	0.6	0.0	3.8	32.8	62.8	0.91	t = 1.808*
Low Saline	1.2	1.2	3.5	39.9	54.3	0.89	($p < 0.05$)
TE of *P. vannamei* farms in relation to different water source							
Source of water							
Creek (n = 398)	0.8	0.0	4.3	37.0	57.9	0.8982	F = 3.074696*
Bore-well water (n = 174)	0.8	1.5	2.3	32.8	62.6	0.9067	($p < 0.05$)
Direct Sea water (n = 32)	0.0	0.0	0.0	7.7	92.3	0.9369	
TE of *P. vannamei* farms in relation to number of crop cycles/annum							
One crop/year	1.3	0.0	1.3	28.2	69.1	0.9099	F = 9.602559**
Two crops/year	0.6	0.6	4.7	38.8	55.4	0.8961	($p < 0.01$)
TE of *P. vannamei* farms in relation to the stocking and rearing of post larvae							
Nursery rearing of post larvae before stocking in grow out pond	0.00	0.00	0.00	0.00	100.00	0.985 ± 0.009	30.83**
Direct stocking of post larvae in grow out pond	0.77	0.39	3.68	35.20	59.96	0.901 ± 0.062	($p < 0.01$)
TE of *P. vannamei* farms in relation to the nature of the pond bottom							
Earthen ponds	0.77	0.39	3.68	35.20	59.96	0.900 ± 0.062	2.81**
Lined ponds	0.00	0.00	0.00	20.00	80.00	0.952 ± 0.039	($p < 0.01$)

**, * Significant at 1%, and 5% levels respectively.

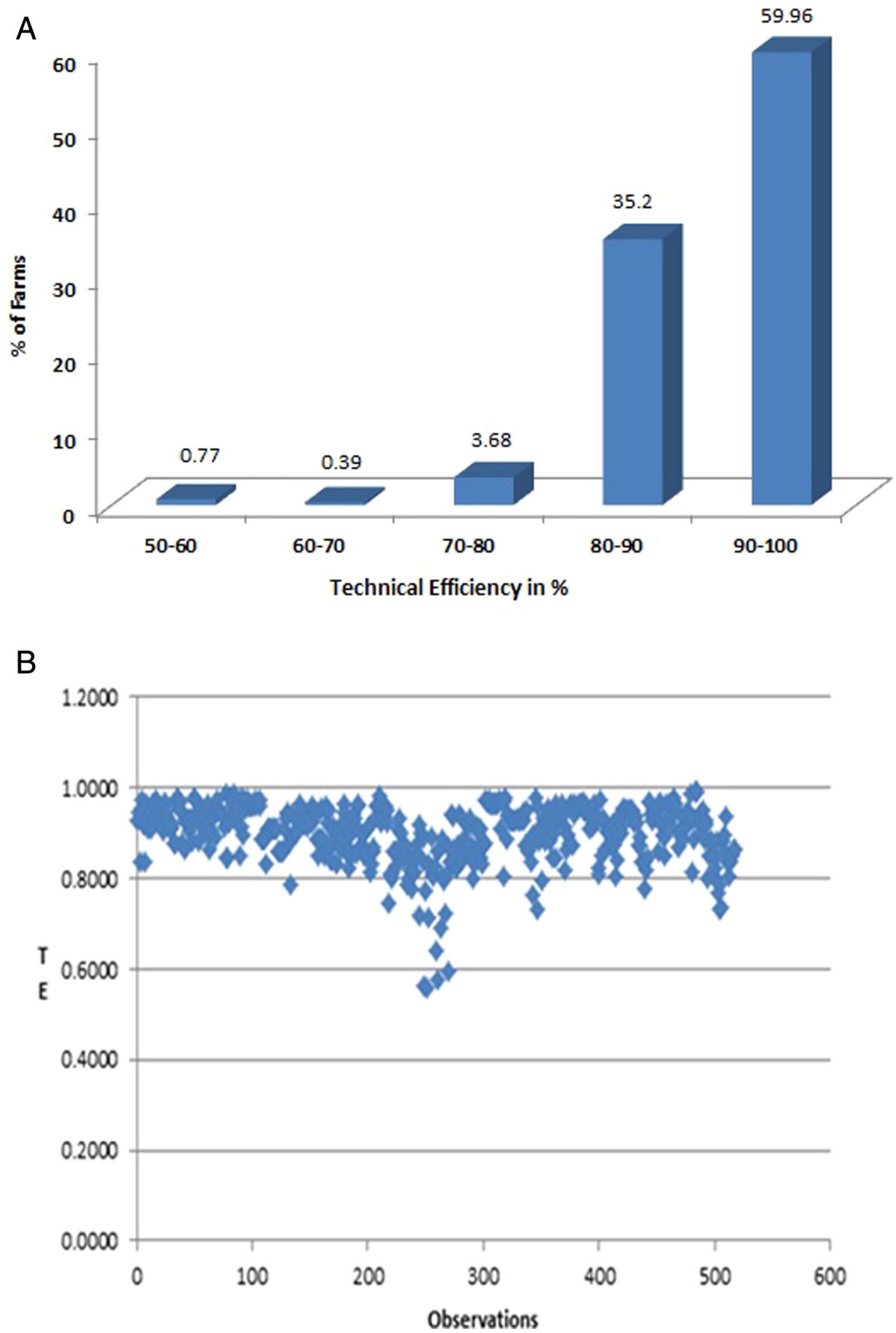

Fig. 3. Technical efficiency (TE) of *Penaeus vannamei* farms in India (N = 604).

vannamei seed tolerated the low-salinity waters better than PL10 (Alvarez et al., 2004; Laramore et al., 2001; McGraw et al., 2002; Olin et al., 1992). Extended acclimation duration with gradual decrease in salinity was observed to help in increasing the survival even in 1 ppt salinity (Kumlu and Jones, 1995; McGraw and Scarpa, 2004; Vidyajayasankar et al., 2009).

Most of the farmers interviewed in this study witnessed that adoption of farm level nursery rearing (for 30 days) was found to be successful in ensuring survival >95% and attaining faster growth to a size of 1.5 to 2 g. In another 60 days of culture in the grow-out pond the shrimp has attained a marketable size of 18–20 g with good survival. In such two tiered farming model, altogether 90 days was sufficient for completion of one successful crop, and in this way the farmers were able to have three crops in a year. It is wise to stock lesser than the optimum stocking density keeping in mind the infrastructure availability, carrying capacity of the pond, season, history of pond performance over the period of time and farmer's experience. Higher stocking density is the major cause for many problems associated with pond miss management. Seed quality and carrying capacity based stocking density are the two critical indicators of sustainable *P. vannamei* shrimp farming. The optimum stocking density of seeds in a pond is to be determined in accordance with the production capacity of the pond and the culture system, which included the soil and water quality, food availability and seasonal variations, target production and farmers experience (Gunalan et al., 2011; Karuppasamy et al., 2013; Margabandu and Ramamurthy, 2015; Shailender et al., 2013).

Feed quantity and its efficiency was the second important determinant of TE. Studies have reported that feed is not only a significant

Table 3
Maximum likelihood estimates of Stochastic Cobb-Douglas frontier production function.

Variable	Coefficient	SE	t-Ratio
Farm inputs			
Constant	−1.1774	0.3120	−3.7735
Seed	0.1043***	0.0193	5.4101
Feed	0.8404***	0.0151	55.6058
Labour	−0.0105	0.0127	−0.8302
Electricity/fuel cost	−0.0012	0.0140	−0.0832
Socio-economic variables			
Constant	−0.3724	0.4840	−0.7694
Education	−0.0066	0.0106	−0.6242
Occupation	−0.1267	0.0863	−1.4692
Experience (in years)	−0.0023	0.0126	−0.1808
Farm size (ha)	−0.0010	0.0013	−0.7331
Farming infrastructure (total score)	−0.0074	0.0058	−1.2842
Training in *P. vannamei*	0.0103	0.0340	0.3025
Adoption of periphyton technology (DV)	−0.0575	0.1243	−0.4626
Adoption of bio-floc technology	−0.0398	0.1152	−0.3451
Adoption of zero-water exchange technology (DV)	0.1075*	0.0594	1.8096
Adoption of automatic feeder	−0.1016	0.0666	−1.5264
Manuring	0.0268	0.0302	0.8889
Duration of the crop (days)	−0.0015*	0.0008	−1.8209
Social participation	0.0446	0.0311	1.4338
Farm ownership (1 = owned/2 = leased)	−0.0403	0.0280	−1.4417
Consultant-availability	−0.0620**	0.0262	−2.3708
Plough before liming	0.0452	0.0424	1.0648
Filtrations (score)	0.0082	0.0146	0.5585
Disinfection before water culture	−0.0315	0.0758	−0.4151
Application of fermented carbon source (DV)	−0.0648	0.0557	−1.1636
Water source - creek	0.1097	0.0846	1.2967
Water source - agricultural drain agricultural rrrdrain (DV)	0.0669	0.0876	0.7643
No. of crops - one	0.8340*	0.4990	1.6713
No. of crops - two	0.7772	0.4922	1.5790
Sigma-squared	0.0168***r	0.0031	5.3302
Gamma	0.6621***	0.0640	10.3406
Log-liklihood	450.67		

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

contributor to shrimp yield (Ogundari and Akinbogun, 2009; Muralidhar et al., 2012; Kareem et al., 2008) but also a key factor which determines the cost of production (Gunalan et al., 2011; Ramakrishna, 2000). Therefore provision of quality feed in appropriate quantity is essential as 60–65% of the production cost is controlled by feed. Farmers reported that white leg shrimps are voracious feeders if they have access to fresh feed offered at frequent intervals and therefore, feeding daily ration equally splitted at more frequent intervals is preferred over bulk feeding at a longer time intervals. By this way of feeding they witnessed better FCR and pond water quality. Multiple feedings helps in the breakdown of organic wastes by beneficial bacteria and reduce ammonia and avoids water quality problems. Growth and feed conversion increases with feeding frequency (Robertson et al., 1993; Tacon et al., 2004; Yeoh et al., 2010). Feeding efficiency was found to be better during the day time and it is always advisable to complete the feeding by 7.00 PM. Robertson et al. (1993) evaluated the effects of feeding time and frequency, found that instantaneous growth rates were improved significantly by daytime feeding and switching frequency from 1 to 4 times per day. Optimization of feeding regime by careful monitoring of check trays, animal behaviour, climate and shrimp biomass appears to be more useful. Automatic feed dispensers could be used to increase the frequency of feeding and achieving better FCR. Automatic feeders saved time, man power and money (Craig and Helfrich, 2002).

Availability of technical consultant was found to have inversely significant relationship with TE at 5% ($p < 0.05$) level of probability. This may be because of the fact that many feed dealers themselves acted as consultants and suggested high stocking densities against low carrying capacities to get maximum feed sales. This might have caused failures at times and lead to technical inefficiencies. However, it was observed that technical counselling by qualified consultants was able to help the farmer in optimizing the inputs, sourcing best quality seed and other inputs and adoption of better management protocols. Similarly, duration of the culture system having inverse relationship with TE at 10% level of probability ($p < 0.1$). Longer the cropping duration lesser the TE. Duration of the crop and TE are inversely related because longer durations increase the inputs usage, energy costs, disease risks and increase the cost of production (Ruiz-Velazco et al., 2010). Sookying et al. (2011) reported that longer rearing periods and higher stocking densities were the variables with the most significant influence on disease incidence and lead to crop failures. However, adoption of zero water exchange system was positively contributing for the TE of farms at 10% level of probability ($p < 0.1$). Several studies reported that zero water exchange condition assures the biosecurity of the system and decrease the probability of pathogen introduction, increase biosecurity while producing cost-effective margins of shrimp production (Becerra-Do'rame et al., 2012; Browdy and Moss, 2005; Lei et al., 2012; Onanong et al., 2006; Wasielesky et al., 2006). It was observed that many farmers practiced partial harvest of the standing stock at an appropriate time that would decrease competition for feed and other nutrients, increase individual growth rates and total production. Partial harvesting helps in maintaining the carrying capacity of the pond and minimizes other risks. A well-managed, discrete partial harvesting can outperform single-batch harvesting and thus enhance profitability (Yu and Leung, 2006).

4.2.1. TE of *P. vannamei* farming across the coastal states

A significant difference was found in technical efficiencies of the *P. vannamei* farms ($p < 0.01$) across the coastal states of the country. Gujarat state had the highest mean TE (94%), followed by Odisha (93%), Andhra Pradesh (92%), Tamil Nadu (90%), Karnataka (89%), Maharashtra/Goa (87%) and West Bengal (81%). The hypothesis of significant difference in the technical efficiencies of *P. vannamei* farms of different states is proved correct. It was observed that the farmers of Gujarat practiced only one crop in a year and they had adequate biosecurity systems, deep ponds, and adopted better management practices from pond preparation to harvest very carefully. Gujarat had the highest productivity per ha in *P. vannamei* shrimp farming in the country. Whereas, farms of West Bengal and Karnataka states shown relatively less TE which may be because of the traditional to extensive system of farming practiced. Hence, special efforts need to be undertaken to conduct capacity enhancement programmes for the farmers of these states to enhance the skills and optimize the input usage. Ghee-Thean et al. (2016) employed similar approach and assessed the TE of white shrimp farming across the coastal states of Malaysia.

4.2.2. TE of *P. vannamei* farming across the salinity regimes

Brackishwater farms had a mean TE of 0.91 and the low saline water farms had a mean TE of 0.89 and this is may be due to the relatively higher stocking density adopted by brackishwater farmers. Further, they had higher farming experiences and adopted better farming practices to have a maximum production. Farming of shrimps in low saline waters was taken up only in case of *P. vannamei* and hence the farmers in that area were relatively less experienced. The Student's '*t*' test indicated that there is a significant difference ($p < 0.05$) between the mean TE of brackishwater and low saline water culture systems. Accordingly the hypothesis of equal mean efficiencies between the salinity based production systems is accepted implying that the efficiencies are different between the two salinity based systems. This finding was contrary to the findings of Liao and Chien (2011) who reported that low saline water culture of *P. vannamei* had proven even more successful than brackishwater culture conditions.

4.2.3. TE of *P. vannamei* farming across the source water

Farms which drew water directly from the sea had better mean TE (0.94) followed by the groundwater (0.90) and creek waters (0.89).

This may be due to the water quality of the ocean water with optimal water quality parameters like salinity, pH and mineral composition required for normal growth of the Pacific white shrimp. One way ANOVA showed a significant difference ($p < 0.05$) between the efficiencies of farmers belonging to different water sources. Hence, the hypothesis of significant difference in the technical efficiencies of *P. vannamei* farms using different sources of water is valid.

4.2.4. TE of P. vannamei farming based on the cropping intensity

Farmers who have adopted single crop in a year had the highest mean technical efficiency of 0.91 than those who had two crops with a mean technical efficiency of 0.89. There is a significant difference between the efficiencies of farmers practiced number of crops per year ($p < 0.01$) and the hypothesis of significant difference in the technical efficiencies of *P. vannamei* farms according to the cropping intensity is tenable. It is obvious that the ponds were idle for about six months and get fully oxidized and naturally disinfected. Because of this the ponds were as good as virgin, management was relatively easy and productivity was high.

4.2.5. Technical efficiencies of P. vannamei farming as per the stocking method

Generally farmers' stocked shrimp seeds directly in the grow-out pond and rear it until harvest of required size driven by the market demand. However, 5% of the respondents adopted stocking of seeds in their on-farm nursery ponds, and witnessed increased survival, better growth, higher production and showed higher technical efficiencies. Farmers practiced it mainly to avoid peak season competition for quality seed and poor acclimatization of seeds at the hatchery level, which lead to poor survival. There is significant difference between the efficiencies of farmers practiced different stocking methods ($p < 0.01$). Hence the hypothesis of significant difference stands reasonable.

4.2.6. Technical efficiencies of P. vannamei farming in lined and earthen ponds

HDPE (high-density polyethylene) lined ponds had significantly higher technical efficiencies than the earthen ponds ($p < 0.01$). Accordingly the hypothesis in this regard is valid. Several studies reported that Pacific white shrimp (*P. vannamei*) reared in HDPE plastic lined ponds have been proved to be effective with minimum suspended solids (turbidity), low total ammonia nitrogen, disease prevention, bottom deterioration and acid soil problems (Anonymous, 2001; Pruder et al., 1992; López et al., 2002; Onanong et al., 2006) and amenable for higher production (McIntosh et al., 2002; Onanong et al., 2006). While Ajao (2011) reported higher TE for concrete ponds than earthen ponds, Kareem et al. (2008) reported the opposite. Considering the huge initial cost involved in the installation of lining, only few numbers of farmers (3%) adopted this infrastructure. HDPE lined ponds were found to be useful for intensive shrimp culture with high stocking densities with biofloc based rearing technologies. However, most of the farmers prefer to have earthen ponds and low stocking densities than going for a high density and HDPE lined ponds. But, farmers realize the benefits of lining the ponds. Considering the benefits the farmers need to be advised to adopt lining of dykes and ponds with HDPE liners.

5. Conclusion

This is the first comprehensive study on the TE of *P. vannamei* farms in India. It is apparent from the present findings that the introduction of Pacific white shrimp (*Penaeus vannamei*) has revived shrimp farming and resulted in exponential increase in the farmed shrimp production. As indicated by the study higher technical efficiencies of *P. vannamei* farms could also be the reason for the higher productions. Further, findings have shown that the TE can be enhanced and sustained by sourcing quality seed, adopting optimum stocking density, modified feeding protocols, access to qualified technical consultancy, adoption of zero water exchange, adoption of farm level nursery, partial harvesting and effectively adopting the better management practices at every stage of farming. It is essential to refine the package of practices in tune with the infrastructure available, production system and scale of farming being practiced at different regions. It is vital that extension agencies need to educate the farmers on parameters of quality seed and methods to be adopted during the selection of seed and motivate the farmers in adoption of better farm management practices. Similarly, it is imperative need to develop on-farm farmer friendly risk assessment tools and train the farmers to prevent production related risks and ensure sustainability.

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