

# Variations in morphological traits, agronomic traits and traits related to drought tolerance in indigenous Thai rice varieties

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**ABSTRACT:** Indigenous rice is worth conserving as it possesses many important traits such as good table quality for consumers, resistance to biotic and abiotic stresses and, especially, quality of starch. The objectives of this study were to evaluate indigenous rice accessions collected in Northeast Thailand and select the superior accessions for further improvement of indigenous rice. Forty indigenous rice accessions were evaluated in a pot experiment in a split-plot design with completely randomized arrangement of the treatments and four replications for two years in 2014 and 2015. Main plots were two water regimes, including well-irrigated treatment and early season drought treatment; the subplots included 40 indigenous rice accessions. Well-irrigated treatment was higher than early season drought condition in terms of plant height, number of tiller per plants, number of ears per plant, number of unfilled grains per ear, grain weight per plant, straw weight per plant and shoot dry weight per plant; drought treatment was higher than irrigated treatment in terms of the number of filled grains per plant, 1000-grain weight and root dry weight; whereas these two types of treatment showed no differences in terms of the number of tillers/plant at 30 days after emergence and harvest index. The superior genotypes for each trait and the genotypes with better drought tolerance index were identified.

**KEYWORDS:** drought tolerance index, early season drought, water regimes, well-irrigated treatment

## INTRODUCTION

Rice is a staple food crop in Asia. In Thailand, the land area used for planting rice has been estimated at 10 397 920 ha with the country producing 21 424 000 t of rice in 2018<sup>1</sup>. However, the country's productivity has been recorded as being rather low, accounting for only 2.7 t ha<sup>-1</sup>. The low productivity of rain-fed rice is mainly due to droughts occurring each stage of rice growth, especially in the growing areas in Northeast Thailand which was estimated to comprise 60% of the country's overall rice growing area.

Drought at seedling stage could cause a yield loss of 25%<sup>2</sup>, while drought at flowering and grain filling stages could cause severe yield losses (29–40%)<sup>3</sup>. It is very difficult to irrigate the crop in the rain-fed areas, thus the use of drought-resistant varieties is a promising option to improve the sustainability of crop productivity under drought con-

ditions.

Screening of germplasm sources for drought resistance is used as an initial step to develop drought-resistant varieties. Indigenous rice is interesting for use as a germplasm source for drought resistance as this type of rice has long been cultivated in harsh environments and has good adaptation to environments. In China, traditional upland rice is used to transfer drought resistance to commercial lowland rice<sup>4</sup>. In a study in Thailand, 60 accessions of rice landraces were classified into three groups, including tolerant genotypes, intermediate genotypes and susceptible genotypes based on the drought resistance index<sup>5</sup>. In a study for salt tolerance of rice landraces in Northeast Thailand, nine out of a total of 30 landraces were found to be salt-tolerant at seedling stage<sup>6</sup>.

Some traits of indigenous rice varieties are unique, such as aromatic trait, salt tolerance,

drought tolerance, disease and pest-resistance, high nutrition, antioxidant and stickiness<sup>7</sup>. In India, the majority of indigenous rice varieties are disease and pest-resistant varieties suitable for lowland cultivation and some varieties are also resistant to waterlogging and flooding<sup>8</sup>.

Although most indigenous rice varieties have good agronomic traits and are unique for growing areas, these varieties are gradually disappearing from cultivation, especially in irrigated areas. It is important to collect, conserve and evaluate indigenous rice varieties for further use as germplasm sources for rice breeding. The assumption underlying this study project is that indigenous rice should possess some extent of variations in grain yield, agronomic traits and traits related to drought resistance. The objectives of this study were to evaluate indigenous rice accessions collected in Northeast Thailand and select the superior accessions for the further improvement of indigenous rice. The information obtained in this study is useful for the advanced evaluation of these indigenous accessions for possible release and selection of superior genotypes for use as parents in indigenous rice breeding.

## MATERIALS AND METHODS

### Plant materials and experiment design

Forty indigenous rice accessions were collected in Northeastern Thai provinces, including Mahasarakham, Roi Et, Kalasin, Khon Kaen, Sakon Nakhon, Nakhon Phanom, Nong Khai, Yasothon, Ubon Ratchathani and other nearby provinces from November 2014 to April 2015. The details of the collection sites are given in Table 1. These accessions were evaluated in terms of drought resistance in a split-plot design with treatment arrangement in a completely randomized design with four replications for two years in 2014 and 2015. Water regimes with well-irrigated treatment and early season drought treatment were assigned in the main plots, and 40 indigenous rice accessions were assigned in subplots.

### Crop management

The soil in the experiment was first collected from the rice field, then air-dried and sieved through 80-mesh screen. The soil samples were also taken from the bulk of soil for soil analysis according to standard laboratory protocols for soil's physical and chemical properties including sand, silt, clay, total nitrogen, available phosphorus, extractable potassium, extractable calcium, pH, cation exchange

**Table 1** The indigenous rice accessions kindly donated from six organizations, including Khon Kaen Rice Research Center (KKRRC), Surin Rice Research Center (SRRC), the groups of farmers for conservation of indigenous rice in Yasothon province (YP), Kalasin Province (KP), Maha Sarakham province (MSP), and Sakon Nakhon province (SNP).

Accession	Location	Accession	Location
Som Ma Lee	KP	Hom Dong	SRRC
Mali Dung Derm	YP	Sumpun Deang	MSP
Khao Yai	SRRC	Kaw Dor	MSP
Laum Phou	SNP	Kaen Doo	KP
Ku Larb Dum	KKRRC	Nang Mon	KKRRC
Wid Nee	KP	Hin Kong	KP
Pa Ka Amphuen	SRRC	San Pla Lard	YP
E-Noi	KP	Lueng Kaew	YP
Kum Ka Dum	KP	Lueng Yai	YP
Khao Park Mor	KP	Nang Hok	KP
Chao Deang	MSP	Kum Pay	MSP
Rark Phai	KP	Kore Deaw	KP
Hom Klong Luang	KKRRC	Kaw Muang	KKRRC
Leaung Kum Mad	YP	Hom Nang Nuan	KKRRC
Dore Khoa	MSP	Naew Deang	KP
Pa Ma	MSP	Lueng Boon Ma	YP
Num Sa Kouy 19	KP	Hom Sakon	KKRRC
Kun Dun Tia	KKRRC	Ku Muang Luang	KP
San Pa Thong	SRRC	KDML 105	KKRRC
Pha Daeng	SRRC	RD 6	KKRRC

(CEC) and organic matter. The data of soil properties were used for calculating the soil's water-holding capacity, water to be applied to the crop and fertilizer rates.

The forty accessions of indigenous rice were evaluated for yield, yield components, agronomic traits and the traits related to drought resistance in a pot experiment under well-irrigated and drought conditions in the field at the Faculty of Agricultural Technology, Mahasarakham Rajabhat University for two years from May to November in both 2014 and 2015. The crop was planted in plastic containers 30 cm in diameter and 30 cm in height and each container accommodated one plant. Two containers were considered to be one plot in a replication and there were eight containers for each accession in four replications. Hence the experiment in each year had 640 containers in total, which were divided into two groups consisting of 320 containers for well-irrigated treatment and 320 containers for early season drought treatment.

Three to five seeds were planted in each container. After planting, water was applied to the crop

at field capacity for good seed germination and good crop establishment. The seedlings were thinned to obtain one plant per container at seven days after emergence (DAE). Chemical fertilizer formula 16-16-8 of N-P-K was applied to the crop at the rate of 187.5 kg ha<sup>-1</sup> at 15 DAE, and nitrogen fertilizer in the form of urea (46-0-0) was applied to the crop at the rate of 62.5 kg ha<sup>-1</sup> at 60 DAE. Manual weeding was carried out regularly to control weeds. For well-irrigated treatment, flood water was applied to the crop at 10–15 cm above the soil surface at tillering stage until physiological maturity.

For drought treatment, water at field capacity level was stopped at 30 DAE in order to commence the drought for a period of 28 days. The soil was gradually dried until it reached the driest level at 28 days after water withholding. This practice was done to mimic drought conditions at the early growth stage. After a drought period of 28 days, water was applied to the crop at field capacity until physiological maturity. Amounts of water that were applied to the crop for both well-irrigated and drought treatments were calculated according to Doorenbos et al<sup>9</sup>.

### Data collection

The data were recorded for number of tillers, plant height days to flowering, grain yield and yield components. Number of tillers was recorded at flowering and harvest stages. Plant height was measured at 30, 60, and 90 days after emergence and at harvest. Before flowering, plant height was measured from the soil surface to the highest point of the leaves, and, after flowering, plant height was measured from the soil surface to the highest point of the ear. Plant height was averaged from all plants in the plot. The number of days to flowering was recorded from the first day of blooming to the day when 50% of the plants in the plot had shed pollen.

At harvest, the data were recorded for grain weight per plant, 1000-grain weight, number of ears per plant, number of grains per ear, number of filled grains, number of unfilled grains, total dry weight and harvest index, which was calculated as grain weight/total dry weight.

### Traits related to drought resistance

Traits related to drought resistance, including leaf rolling score, drought scoring and drought recovery were recorded at appropriate times and these traits were evaluated under drought treatment only. Leaf rolling score indicates the response of plants to drought by rolling the leaves for five levels, and

this trait was evaluated according to the method suggested by De Datta et al<sup>10</sup> as follows: (1) normal leaf without rolling, (2) leaf margins bend inward slightly, (3) leaf margins bend inward greatly, (4) leaf margins bend and are close to each other, and (5) leaf margins bend and make contact with each other.

Drought scoring is a symptom of leaves in response to drought occurring after leaf rolling. Ten levels of drought scoring rating were recorded, and the traits were evaluated according to the method described by De Datta et al<sup>10</sup> as follows: (0) normal leaf, (1) slightly dry at the end of leaf, (2) dry at the end of leaf for 25%, (3) dry at the end of leaf for 50%, (4) dry at the end of leaf for more than 50% and leaf necrosis for 25%, (5) whole leaf dry 50%, (6) whole leaf dry more than 50% but less than 70%, (7) whole leaf dry 70%, (8) whole leaf dry more than 70%, and (9) whole leaf dry 100%.

Drought recovery is the ability of plant to recover from drought after the end of a drought period. The traits were evaluated at 10 days after re-watering by using a scoring system with five levels of drought recovering scores according to the method described by IRR<sup>11</sup> as follows: (1) recover 90–100%, (3) recover 70–89%, (5) recover 40–69%, (7) recover 20–39%, and (9) recover 0–19%.

Drought tolerance index (DTI) was also calculated for all traits. The indexes indicated the degree of drought tolerance for these traits as suggested by Nautiyal et al<sup>12</sup>. The genotypes with higher drought tolerance index had better adaptation to drought than the genotypes with lower drought tolerance index. The calculation for DTI is stress treatment/non-stress treatment.

### Data analysis

Data were analysed according to a split-plot design with treatment arrangement in a completely randomized design and four replications. At the first step of data analysis, the data for each year were analysed individually, and the error variances for each trait were compared for variance homogeneity according to Gomez<sup>13</sup>, and the difference of error variances lower than three folds was considered homogeneous. At the second step, the data with variance homogeneity were combined with an ANOVA of the data for two years. The data for traits that related to drought resistance were analysed separately according to a completely randomized design because these traits could not be evaluated under well-watered condition. Mean differences were separated by Duncan's multiple range test

(DMRT) at a probability level of 0.05. All calculations as part of the ANOVA were performed by using MSTAT-C software<sup>14</sup>. Cluster analysis based on all characters under the study was performed using Ward's method and squared Euclidean distance method. All calculations were performed using JMP Pro software (version 10.0, SAS institute Inc., Chicago, USA).

## RESULTS

### Year

Years were significantly different ( $p \leq 0.05$ ) for plant height, number of tillers per plant and number of ears per plant (Table 2). Years were also significantly different ( $p \leq 0.05$ ) for the number of filled grains/ear, number of unfilled grains/ear, 1000-grain weight, grain weight/plant, straw weight/plant, root dry weight/plant, shoot dry weight/plant and harvest index (Table 3).

The crop planted in 2014 was significantly higher ( $p \leq 0.05$ ) than the crop planted in 2015 for plant height at 30, 60, 90, and 120 days after emergence (DAE) (data not shown), and it was also significantly higher than the crop planted in 2015 for the number of tillers per plant at 30 DAE. However, the crop planted in 2014 was significantly lower ( $p \leq 0.05$ ) than the crop planted in 2015 in terms of the number of tillers per plant at 60 and 90 DAE and number of ears per plant. The crop planted in 2015 was significantly higher ( $p \leq 0.05$ ) than the crop planted in 2014 in terms of the number of filled grains/ear, number of unfilled grains/ear, 1000-grain weight, grain weight/plant, straw weight/plant, root dry weight/plant, shoot dry weight/plant, but it was significantly lower ( $p \leq 0.05$ ) than the crop planted in 2014 for the harvest index (data not shown).

### Water regime

Water regimes were significantly different ( $p \leq 0.05$ ) for most traits except for the number of tillers/plant at 30 DAE and harvest index (Tables 2 and 3). Numbers of tillers/plant at 30 DAE and the harvest index were not significantly different by water level. Well-irrigated crop was significantly higher ( $p \leq 0.05$ ) than the crop subjected to early season drought for plant height at 90 and 120 DAE, number of tillers per plant at 60 and 90 DAE, number of ears/plant, number of unfilled grains/ear, grain weight/plant, straw weight/plant and shoot dry weight/plant, but it was significantly lower ( $p \leq 0.05$ ) than the crop subjected to early

season drought for plant height at 30 and 60 DAE, number of filled grains/ear, 1000-grain weight and root dry weight (data not shown).

### Rice accession

As the error variances for all characters were homogeneous, the data of two years were combined and ANOVA and mean values of the two years of data were reported. Indigenous rice accessions were significantly different ( $p \leq 0.05$ ) for plant height at 30, 60, 90, and 120 DAE, number of tillers per plant at 30, 60, and 90 DAE and number of ears at harvest (Table 2). For all accessions, plant height increased with time from 30 DAE to 120 DAE. At 120 DAE, the lowest plant heights of 95.4 cm were recorded in Ku Larb Dum and Hom Klong Luang, whereas the highest plant height of 155 cm was recorded in Kum Ka Dum (data not shown). The other accessions were in the range of these accessions, and, therefore, the groups of accessions with tall plants or short plants could be clearly identified.

As with plant height, the number of tillers per plant also increased with time from 30 DAE to 90 DAE. The lowest tiller number of 14.03 tillers was recorded in Laum Phou, whereas the highest tiller number of 32.50 tillers was recorded in Chao Deang. Other indigenous rice accessions were within this range for the number of tillers per plant. The high group and the low group were identified for further use in breeding programs. In general, plant height was negatively correlated with the number of tillers per plant ( $r = 0.05, -0.43, \text{ and } -0.62$  for 30, 60, and 90 DAE, respectively). The number of panicles per plant at harvest (120 DAE) was also negatively correlated with plant height ( $r = -0.62$ ). (Data for correlations are available upon request).

The lowest ear number per plant of 10.6 ears was recorded in Kum Ka Dum, and this accession also had the shortest plant and lowest tiller number. The highest ear number per plant of 27.8 ears was recorded in Kun Dun Tia. The other accessions were intermediate between these extremes, and the accessions with low or high ear number per plant were identified.

The indigenous rice accessions were also significantly different ( $p \leq 0.05$ ) in terms of the number of filled grains/ear, number of unfilled grains/ear, 1000-grain weight, grain weight/plant, straw weight/plant, root dry weight/plant, shoot dry weight/plant and harvest index (Table 3). The numbers of filled grains ranging from 43.6 grains in Laum Phou to 123.1 grains in Kaw Muang were recorded among indigenous rice accessions,

**Table 2** Mean square values for plant height at 30, 60, 90, and 120 DAE, number of tillers per plant at 30, 60, and 90 DAE and number of ears/plant of 40 indigenous rice accessions planted under 2 water regimes of well-irrigated and early season drought conditions for two years in 2014 and 2015.

Source of variation	df	Plant height				Number of tillers/plant			Number of ears/plant
		30 DAE	60 DAE	90 DAE	120 DAE	30 DAE	60 DAE	90 DAE	
Season (S)	1	640.0**	160.0**	640.0**	111.4**	79.4**	12 509.5**	97 787.4**	20 748.0**
Within season	6	100.8**	370.0**	318.9**	1284.7**	87.2**	364.2**	221.6**	126.3**
Water level (W)	1	514.8**	748.2**	8806.1**	6033.2**	0.9	9139.3**	2636.6**	448.9**
SW	1	0.0	0.0	0.0	4.4	148.7**	5161.4**	909.6**	0.0
Variety (V)	39	532.8**	1764.1**	2435.0**	2960.6**	51.1**	94.9**	384.9**	290.4**
SV	39	0.0	0.0	0.0	2.2	17.6**	42.5**	223.3**	124.0**
WV	39	89.6**	389.8**	486.9**	151.1**	6.2	39.0**	85.6**	63.2**
SWV	39	0.0	0.0	0.0	2.2	6.7*	38.8**	89.8**	56.6**
Error	474	21.25	48.96	65.36	68.17	4.65	17.80	23.97	18.45
C.V. (%)	–	8.42	8.44	8.07	6.27	28.88	29.37	19.92	21.84

\*,\*\* Significant at  $p \leq 0.05$  and  $p \leq 0.01$ , respectively.

**Table 3** Mean square values for number of filled grains/ear, number of unfilled grains/ear, 1000-grain weight, grain weight/plant, straw weight/plant, root dry weight/plant, shoot dry weight/plant, and harvest index of 40 indigenous rice accessions planted under 2 water regimes of well-irrigated and early season drought conditions for two years in 2014 and 2015.

Source of variation	df	Filled grains (no./ear)	Unfilled grains (no./ear)	1000-grain (g)	Grain (g/plant)	Straw (g/plant)	Root dry (g/plant)	Shoot dry (g/plant)	Harvest index
Season (S)	1	39 085.8**	6539.5**	8022.7**	19 430.2**	1 302 835.5**	191 081.5**	1 640 498.1**	0.771**
Within season	6	4407.4**	448.5**	150.8**	1347.0**	12 541.2**	2977.9**	19 730.1**	0.016**
Water level (W)	1	11 077.2**	15 826.2**	66.8**	4238.3**	38 747.7**	597.0*	68 619.5**	0.000
SW	1	14 816.8**	4189.3**	14.7	0.0	34.1	1029.7**	36.4	0.002
Variety (V)	39	5187.0**	2427.2**	331.2**	1072.1**	7838.2**	1171.0**	9409.3**	0.032**
SV	39	2569.3**	2314.6**	84.8**	845.9**	3706.2**	1129.7**	5889.0**	0.016**
WV	39	2176.7**	1413.2**	12.3	325.5**	1244.7**	129.6	1608.0**	0.007**
SWV	39	2333.1**	695.8**	24.0**	234.7**	1345.5**	103.9	1462.5**	0.007**
Error	474	1320.54	343.69	9.85	19.75	378.63	109.76	410.86	0.002
C.V. (%)	–	43.68	56.99	10.47	13.87	15.69	33.05	12.99	20.01

\*,\*\* Significant at  $p \leq 0.05$  and  $p \leq 0.01$ , respectively.

whereas the numbers of unfilled grains ranging from 14.4 grains in Hom Nang Nuan to 63.9 grains were observed in Pa Ka Amphuen (data not shown). The number of filled grains and number of unfilled grains were somewhat negatively correlated ( $r = -0.39$ ).

The highest 1000-grain weight (42.7 g) was observed in Nang Hok and the lowest 1000-grain weight (20.7 g) was observed in Sumpun Deang. San Pa Thong had the highest grain weight per plant (53.4 g), whereas Leaug Kum Mad had the poorest performance for this trait (18.0 g). Straw weights ranging from 73.5 g/plant in Laum Phou to 169.4 g/plant in Leaug Kum Mad were observed among indigenous rice accessions. Other accessions were intermediate between these extreme accessions.

Root dry weights among indigenous rice ac-

cessions ranged from 17.4 g/plant in KDML 105 to 48.3 g/plant in Mali Dung Derm, which was similar to 47.7 g/plant of Khao Park Mor. Shoot dry weights among indigenous rice accessions ranged from 92.4 g/plant in Laum Phou to 193.6 g/plant in Pha Daeng. The accessions with a high shoot dry weight included those in Khao Yai (192.5 g/plant) and Ku Muang Luang (192.8 g/plant). The variation in the harvest index among indigenous rice accessions was rather high, ranging from 0.10 in Leaug Kum Mad to 0.30 in Kaw Dor.

**Interaction effects**

The interaction effects for plant height at 30, 60, 90, and 120 DAE were significant ( $p \leq 0.01$ ) between water regime and rice variety but the effects were not significant between season and water regime; season and variety; and among season, wa-

ter regime and variety (Table 2). Most interaction effects for the number of tillers/plant at 30, 60, and 90 DAE were significant ( $p \leq 0.05$ ) or 0.01) except for the interaction effect between water regime and variety at 30 DAE. Most interaction effects for number of ears/plant were significant ( $p \leq 0.01$ ) except between season and water regime.

All interaction effects were significant ( $p \leq 0.01$ ) for number of filled grains/ear and number of unfilled grains/ear (Table 3). The interaction effects for 1000-grain weight were significant ( $p \leq 0.01$ ) between season and variety; and among season, water regime and variety; whereas other effects were not significant. Most interaction effects for grain weight/plant, straw weight/plant, shoot dry weight and harvest index were significant ( $p \leq 0.01$ ) except the interaction effects between season and water regime, whereas the interaction effects for root dry weight were significant ( $p \leq 0.01$ ) between season and water regime and between season and variety only.

#### Traits related to drought tolerance

Leaf rolling score and drought scoring were evaluated twice. Both evaluations found the leaf rolling score not to be significant, whereas drought scoring was significant ( $p \leq 0.05$ ) at the second time of evaluation only (Table 4). There was low variation for drought scoring in the evaluation at the second time, ranging from 4.75 in Wid Nee to 7.12 in Mali Dung Derm. Mali Dung Derm, Khao Yai, Leaug Kum Mad and Kaen Doo had high drought scoring, ranging from 6.87–7.12, which were significantly higher than 4.75 of Wid Nee. Other accessions were intermediate between these groups.

The rice accessions were significantly different ( $p \leq 0.05$ ) for drought recovery, ranging from 2.50 in Kum Ka Dum, Kun Dun Tia, Kum Pay and Lueng Boon Ma to 4.75 in Khao Yai, and these groups were significantly different ( $p \leq 0.05$ ), whereas other accessions were intermediate between these groups. When all drought-related traits are considered, Khao Yai might be a promising accession for drought resistance.

#### Drought tolerance index

Drought tolerance index (DTI) is the ratio of performance of any trait under drought and well-irrigated conditions. A high index score indicates good performance under drought and vice versa. The indigenous rice accessions were significantly different for drought tolerance index ( $p \leq 0.05$ ) for

**Table 4** Leaf rolling score (evaluated 2 times), drought scoring (evaluated 2 times) and drought recovery of 40 indigenous rice accessions grown under early season drought from June to December in 2014 and 2015.

Accession	Leaf rolling score		Drought scoring		Drought recovery
	1	2	1	2	
Som Ma Lee	3.37	4.87	2.12	5.37 <sup>ab</sup>	2.75 <sup>ab</sup>
Mali Dung Derm	3.87	4.75	4.12	7.12 <sup>a</sup>	3.75 <sup>ab</sup>
Khao Yai	3.50	4.50	4.50	7.00 <sup>a</sup>	4.75 <sup>a</sup>
Laum Phou	3.50	4.87	2.87	6.62 <sup>ab</sup>	3.00 <sup>ab</sup>
Ku Larb Dum	3.37	4.37	2.75	5.50 <sup>ab</sup>	3.00 <sup>ab</sup>
Wid Nee	3.12	4.12	2.50	4.75 <sup>b</sup>	3.00 <sup>ab</sup>
Pa Ka Amphuen	3.75	5.00	3.37	6.12 <sup>ab</sup>	3.50 <sup>ab</sup>
E-Noi	3.75	4.62	3.75	5.75 <sup>ab</sup>	3.00 <sup>ab</sup>
Kum Ka Dum	3.12	4.37	2.62	5.62 <sup>ab</sup>	2.50 <sup>b</sup>
Khao Park Mor	4.00	4.87	4.25	6.25 <sup>ab</sup>	4.00 <sup>ab</sup>
Chao Deang	3.37	4.37	3.25	5.25 <sup>ab</sup>	3.50 <sup>ab</sup>
Rark Phai	3.50	4.75	2.87	5.87 <sup>ab</sup>	2.75 <sup>ab</sup>
Hom Klong Luang	4.00	4.75	4.25	6.75 <sup>ab</sup>	3.75 <sup>ab</sup>
Leaug Kum Mad	3.87	5.00	4.25	7.00 <sup>a</sup>	4.25 <sup>ab</sup>
Dore Khoa	3.37	4.75	3.37	6.12 <sup>ab</sup>	3.75 <sup>ab</sup>
Pa Ma	3.25	4.25	3.12	5.12 <sup>ab</sup>	3.00 <sup>ab</sup>
Num Sa Kouy 19	3.50	4.87	3.62	6.62 <sup>ab</sup>	3.25 <sup>ab</sup>
Kun Dun Tia	3.37	4.62	3.50	6.25 <sup>ab</sup>	2.50 <sup>b</sup>
San Pa Thong	3.62	4.87	3.75	6.37 <sup>ab</sup>	2.75 <sup>ab</sup>
Pha Daeng	4.12	4.87	4.00	6.25 <sup>ab</sup>	3.25 <sup>ab</sup>
Hom Dong	3.62	4.75	3.37	5.87 <sup>ab</sup>	3.00 <sup>ab</sup>
Sumpun Deang	3.75	4.75	4.12	6.37 <sup>ab</sup>	3.75 <sup>ab</sup>
Kaw Dor	3.75	4.75	3.87	6.62 <sup>ab</sup>	3.00 <sup>ab</sup>
Kaen Doo	4.12	5.00	4.12	6.87 <sup>a</sup>	3.75 <sup>ab</sup>
Nang Mon	3.50	4.62	3.00	5.75 <sup>ab</sup>	3.75 <sup>ab</sup>
Hin Kong	3.25	4.50	2.87	5.37 <sup>ab</sup>	3.25 <sup>ab</sup>
San Pla Lard	3.62	4.87	3.87	6.37 <sup>ab</sup>	4.00 <sup>ab</sup>
Lueng Kaew	3.50	4.62	3.25	5.75 <sup>ab</sup>	3.00 <sup>ab</sup>
Lueng Yai	3.50	4.75	3.25	6.00 <sup>ab</sup>	2.75 <sup>ab</sup>
Nang Hok	3.75	5.00	3.37	6.62 <sup>ab</sup>	3.25 <sup>ab</sup>
Kum Pay	3.37	4.62	3.12	5.62 <sup>ab</sup>	2.50 <sup>b</sup>
Kore Deaw	3.62	4.62	3.87	6.12 <sup>ab</sup>	4.50 <sup>ab</sup>
Kaw Muang	3.50	4.37	3.37	5.87 <sup>ab</sup>	4.25 <sup>ab</sup>
Hom Nang Nuan	4.25	4.87	4.37	6.62 <sup>ab</sup>	3.25 <sup>ab</sup>
Naew Deang	3.62	4.75	3.50	6.00 <sup>ab</sup>	3.25 <sup>ab</sup>
Lueng Boon Ma	3.62	4.50	3.37	5.37 <sup>ab</sup>	2.50 <sup>b</sup>
Hom Sakon	3.87	4.87	4.12	6.62 <sup>ab</sup>	3.25 <sup>ab</sup>
Ku Muang Luang	3.75	4.50	4.00	5.50 <sup>ab</sup>	3.00 <sup>ab</sup>
KDML 105	3.75	4.75	3.75	6.00 <sup>ab</sup>	3.00 <sup>ab</sup>
RD 6	4.12	5.00	4.37	6.37 <sup>ab</sup>	3.25 <sup>ab</sup>

Mean values in the same column of the same group with the same letter(s) are not significantly different by Duncan's multiple range test ( $p \leq 0.05$ ).

grain dry weight, straw dry weight, root dry weight and shoot dry weight (Table 5).

Drought tolerance indexes for grain dry weight ranging from 0.39 in Som Ma Lee to 1.29 in Kaw Dor were observed among indigenous rice accessions, and there were 14 indigenous rice accessions having DTI for grain dry weight greater than 1. The range of DTI for straw dry weight was from 0.62 in Rark Phai to 1.10 in Kum Pay. Among these indigenous rice accessions, there were seven accessions with DTI for straw dry weight greater than 1.

DTI for root dry weight among the indigenous rice accession ranged from 0.80 in Hom Sakon to 1.36 in Lueng Boon Ma. It is interesting to note

**Table 5** DTI for grain dry, straw dry, root dry, and shoot dry weights of 40 indigenous rice accessions grown under early season drought from June to December in 2014 and 2015.

Accession	Grain	Straw	Root	Shoot
Som Ma Lee	0.39 <sup>n</sup>	0.87 <sup>a-d</sup>	1.07 <sup>ab</sup>	0.76 <sup>b-f</sup>
Mali Dung Derm	0.60 <sup>k-n</sup>	0.99 <sup>bc</sup>	1.29 <sup>ab</sup>	0.88 <sup>a-f</sup>
Khao Yai	0.57 <sup>lmn</sup>	0.83 <sup>a-d</sup>	0.87 <sup>ab</sup>	0.79 <sup>b-f</sup>
Laum Phou	1.02 <sup>a-h</sup>	1.06 <sup>ab</sup>	1.10 <sup>ab</sup>	1.02 <sup>a-d</sup>
Ku Larb Dum	1.01 <sup>a-h</sup>	1.04 <sup>abc</sup>	1.18 <sup>ab</sup>	1.01 <sup>a-d</sup>
Wid Nee	0.80 <sup>f-m</sup>	0.79 <sup>a-d</sup>	0.83 <sup>b</sup>	0.79 <sup>b-f</sup>
Pa Ka Amphuen	0.91 <sup>c-j</sup>	0.88 <sup>a-d</sup>	1.06 <sup>ab</sup>	0.87 <sup>a-f</sup>
E-Noi	0.95 <sup>c-i</sup>	0.86 <sup>a-d</sup>	0.88 <sup>ab</sup>	0.86 <sup>a-f</sup>
Kum Ka Dum	0.74 <sup>h-m</sup>	1.06 <sup>ab</sup>	1.06 <sup>ab</sup>	0.99 <sup>a-e</sup>
Khao Park Mor	0.53 <sup>mn</sup>	0.97 <sup>a-d</sup>	1.14 <sup>ab</sup>	0.88 <sup>a-f</sup>
Chao Deang	0.57 <sup>lmn</sup>	0.87 <sup>a-d</sup>	0.89 <sup>ab</sup>	0.81 <sup>a-f</sup>
Rark Phai	0.96 <sup>b-i</sup>	0.62 <sup>d</sup>	0.97 <sup>ab</sup>	0.66 <sup>f</sup>
Hom Klong Luang	0.86 <sup>d-l</sup>	0.89 <sup>a-d</sup>	1.03 <sup>ab</sup>	0.87 <sup>a-f</sup>
Leaung Kum Mad	1.08 <sup>a-g</sup>	1.01 <sup>abc</sup>	1.05 <sup>ab</sup>	1.02 <sup>a-d</sup>
Dore Khoa	0.86 <sup>d-l</sup>	0.70 <sup>bcd</sup>	1.08 <sup>ab</sup>	0.72 <sup>def</sup>
Pa Ma	0.83 <sup>e-l</sup>	0.82 <sup>a-d</sup>	0.96 <sup>ab</sup>	0.83 <sup>a-f</sup>
Num Sa Kouy 19	0.79 <sup>g-m</sup>	0.78 <sup>a-d</sup>	0.85 <sup>ab</sup>	0.79 <sup>b-f</sup>
Kun Dun Tia	0.69 <sup>i-m</sup>	0.84 <sup>a-d</sup>	0.83 <sup>b</sup>	0.80 <sup>a-f</sup>
San Pa Thong	0.91 <sup>c-j</sup>	0.95 <sup>a-d</sup>	0.83 <sup>b</sup>	0.93 <sup>a-f</sup>
Pha Daeng	0.91 <sup>c-j</sup>	1.01 <sup>abc</sup>	1.26 <sup>ab</sup>	0.99 <sup>a-e</sup>
Hom Dong	1.18 <sup>abc</sup>	0.86 <sup>a-d</sup>	1.17 <sup>ab</sup>	0.92 <sup>a-f</sup>
Sumpun Deang	1.10 <sup>a-f</sup>	0.93 <sup>a-d</sup>	1.29 <sup>ab</sup>	0.95 <sup>a-f</sup>
Kaw Dor	1.29 <sup>a</sup>	0.97 <sup>a-d</sup>	1.11 <sup>ab</sup>	1.06 <sup>ab</sup>
Kaen Doo	1.04 <sup>a-h</sup>	1.03 <sup>abc</sup>	1.01 <sup>ab</sup>	1.03 <sup>abc</sup>
Nang Mon	1.11 <sup>a-f</sup>	0.90 <sup>a-d</sup>	1.27 <sup>ab</sup>	0.93 <sup>a-f</sup>
Hin Kong	0.73 <sup>h-m</sup>	0.98 <sup>a-d</sup>	1.15 <sup>ab</sup>	0.91 <sup>a-f</sup>
San Pla Lard	0.76 <sup>h-m</sup>	0.90 <sup>a-d</sup>	1.20 <sup>ab</sup>	0.87 <sup>a-f</sup>
Lueng Kaew	0.93 <sup>c-j</sup>	0.84 <sup>a-d</sup>	0.96 <sup>ab</sup>	0.84 <sup>a-f</sup>
Lueng Yai	1.18 <sup>abc</sup>	0.90 <sup>a-d</sup>	1.20 <sup>ab</sup>	0.93 <sup>a-f</sup>
Nang Hok	1.08 <sup>a-g</sup>	0.98 <sup>a-d</sup>	1.11 <sup>ab</sup>	1.00 <sup>a-d</sup>
Kum Pay	1.13 <sup>a-e</sup>	1.10 <sup>a</sup>	1.28 <sup>ab</sup>	1.09 <sup>a</sup>
Kore Deaw	0.84 <sup>d-l</sup>	0.77 <sup>a-d</sup>	1.07 <sup>ab</sup>	0.78 <sup>b-f</sup>
Kaw Muang	1.15 <sup>a-d</sup>	0.92 <sup>a-d</sup>	1.33 <sup>ab</sup>	0.96 <sup>a-f</sup>
Hom Nang Nuan	0.80 <sup>f-m</sup>	0.81 <sup>a-d</sup>	1.21 <sup>ab</sup>	0.80 <sup>a-f</sup>
Naew Deang	0.89 <sup>c-k</sup>	0.79 <sup>a-d</sup>	1.02 <sup>ab</sup>	0.80 <sup>a-f</sup>
Lueng Boon Ma	1.01 <sup>a-h</sup>	0.83 <sup>a-d</sup>	1.36 <sup>a</sup>	0.85 <sup>a-f</sup>
Hom Sakon	1.26 <sup>ab</sup>	0.85 <sup>a-d</sup>	0.80 <sup>b</sup>	0.91 <sup>a-f</sup>
Ku Muang Luang	0.89 <sup>c-k</sup>	0.67 <sup>cd</sup>	0.90 <sup>ab</sup>	0.70 <sup>a-f</sup>
KDML 105	0.99 <sup>a-i</sup>	0.86 <sup>ad</sup>	0.92 <sup>ab</sup>	0.85 <sup>a-f</sup>
RD 6	0.63 <sup>j-n</sup>	0.79 <sup>a-d</sup>	1.17 <sup>ab</sup>	0.75 <sup>c-f</sup>

Mean values in the same column of the same group with the same letter(s) are not significantly different by Duncan's multiple range test ( $p \leq 0.05$ ).

here that there were 27 accessions with DTI for root dry weight greater than 1, indicating that drought at early growth stage increased root growth in these indigenous rice accessions.

DTI for shoot dry weight ranging from 0.66

in Rark Phai to 1.09 in Kum Pay were observed among indigenous rice accessions. As with straw dry weight, there were seven accessions with DTI for shoot dry weight greater than 1, indicating that drought at early growth stage reduced shoot growth to some extent.

### Cluster analysis

A dendrogram based on grain yield, yield components and agronomic traits was used to divide the indigenous rice accessions into six distinct clusters (Fig. 1). Cluster A had 10 members, cluster B had nine accessions, cluster C consisted of six accessions, cluster D comprised four accessions, cluster E included eight accessions, and cluster F was formed of three accessions.

In cluster A, DTI for total dry weight, DTI for grain weight, and harvest index were low to intermediate, plant height was intermediate, total dry weight and root dry weight were intermediate to high, whereas straw weight and number of tillers/plant were high.

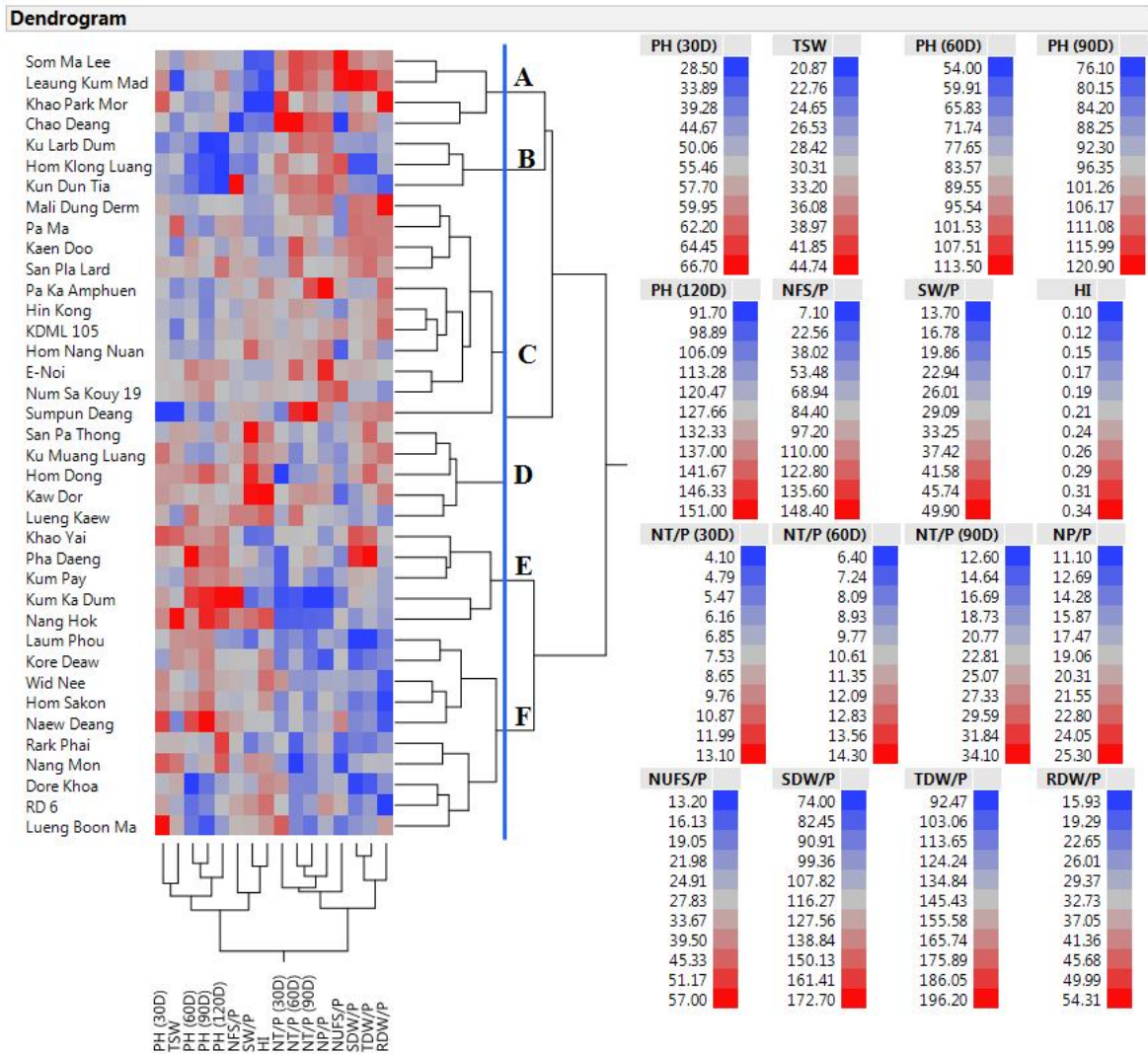
In cluster B, straw weight and DTI for straw weight were low to intermediate, total dry weight was intermediate, and grain weight, DTI for grain weight and DTI for total dry weight were intermediate to high.

The unique features of cluster C consisted of a low harvest index, low to intermediate grain weight, intermediate DTI for grain weight, intermediate DTI for root dry weight, intermediate to high number of tillers/plant, intermediate to high number of grain/panicle, and intermediate to high root dry weight.

The accessions in group D were unique for: short height, low total dry weight, low straw weight, low root dry weight, low to intermediate grain weight, low to intermediate DTI for grain weight, low to intermediate leaf rolling score, low to intermediate DTI for root dry weight, intermediate harvest index, intermediate 1000-grain weight, intermediate to high panicles/plant, and intermediate to high unfilled grains/panicle.

The accessions in group E were unique for: low tiller number, low panicles, low to intermediate root dry weight, low to intermediate straw dry weight, intermediate to high plant height, intermediate to high harvest index, and intermediate to high DTI for grain weight.

The accessions in group F were unique for: low panicles/plant, low number of unfilled grains/panicle, low leaf rolling score, low to intermediate root weight, low to intermediate harvest index, low to



**Fig. 1** A dendrogram classified indigenous rice accessions into six distinct groups based on plant height, number of tillers/plant, number of panicle/plant, number of filled seeds/panicle, number of unfilled seeds/panicle, 1000-grain weight, straw dry weight/plant, total dry weight/plant and harvest index.

intermediate leaf death score, intermediate 1000-grain weight, intermediate straw dry weight, intermediate total dry weight, intermediate to high DTI for root dry weight, high DTI for straw weight, high DTI for total dry weight, high number of filled grains, and tall plant heights.

As Kalasin province was the largest collection site (13 accessions), it dominated in clusters A, B, C, and E. KKRRC had nine accessions and it dominated in cluster D, Yasothn province dominated in cluster B and Maha Sarakham province dominated in cluster C together with Kalasin Province. SRRC did not dominate in any cluster but it distributed in

clusters A, B, C, and E.

**DISCUSSION**

**Year and water regime**

Although the experiment was undertaken in containers in an open-environment condition, crop performances for most characters differed between years. Environment is the important factor affecting growth and yield of many crops<sup>15</sup>. Furthermore, there were significant effects of genotype by environment interactions for most traits under investigation. In a previous study, one early season drought in rice, significant water regime × treat-



ment interactions ( $p \leq 0.001$ ) were observed for most morpho-physiological parameters<sup>16</sup>. Multi-environment traits might reveal the rice genotypes that are superior for yield and other agronomic traits<sup>17</sup>. The results indicated the importance of genotype by environment interactions, and extensive evaluation of the crop is necessary to identify the superior genotypes.

Crops respond to the early season differently. In general, drought at any growth stage is more or less detrimental to rice growth and yield<sup>18</sup>. However, the effect of drought on rice increased with plant growth and drought had larger detrimental influences during the reproductive phase (e.g., blooming stage, filling stage, and maturity)<sup>19</sup>. Drought stresses at different moisture levels reduced grain yield from 48.5–92% over control trials<sup>20</sup>. In this study, early season drought reduced grain weight/plant, straw weight/plant and shoot dry weight/plant of indigenous rice accessions but it increased plant height at 30 and 60 DAE, number of filled grains/ear, 1000-grain weight and root dry weight. However, water regime did not significantly affect the number of tillers/plant at 30 DAE or the harvest index. Some indigenous Thai varieties would be useful as parents for developing drought-tolerant and high-yield cultivars.

### Agronomic traits

Variations in agronomic traits are important for crop breeding both for selecting parents to generate segregating populations and selecting superior genotypes in segregating populations. In this study, the accessions with good agronomic traits were identified for further use in indigenous rice breeding programs.

Plant height is an important trait for rice. However, plant height should be suitable for cultivation. Very short plant height is associated with low yield potential and extremely tall plant height is associated with lodging. Variation in plant height was rather high and some accessions were selected for breeding purposes.

A high tiller number is preferable for rice as this trait is associated with high ear number and yield. Chao Deang was highest for this trait and Kun Dun Tia was highest for ear number. This study was able to identify other accessions with interesting traits, such as Kaw Muang for numbers of filled grains, Mali Dung Derm for root dry weight and Kaw Dor for harvest index.

### Traits related to drought resistance

In this study, indigenous rice accessions were evaluated for leaf rolling score and drought scoring and drought recovery to screen for drought tolerance in these rice accessions. The variation in leaf rolling in this study was low, indicating that leaf rolling was not a good trait for evaluating drought tolerance in this germplasm. However, significant variations in drought scoring and drought recovery were observed in these indigenous rice accessions, indicating the usefulness of these traits in screening drought tolerance in these rice accessions.

In rice and other crop species, drought tolerance index (DTI) has been used as a tool for selecting drought-tolerant genotypes<sup>21,22</sup>. In this study, drought tolerance indexes for grain dry weight, straw dry weight, root dry weight and shoot dry weight were used in identifying indigenous rice accessions with resistance to drought. Drought tolerance index greater than 1 indicated that the genotype should be resistant to drought for the trait under study. In this study, the results show that 14 accessions had high DTI for grain dry weight, seven accessions had high DTI for straw dry weight, 27 accessions had high root dry weight, and seven accessions had high DTI for shoot dry weight.

### Cluster analysis

In this study, the indigenous rice accessions were not collected primarily from the farmers but instead were collected from secondary sources. The rice accessions from the collection locations were distributed in all groups. The authors did not observe any clear pattern or relationships among the collection locations except for Maha Sarakham and Kalasin, which were somewhat closely related. However, the authors found the dominance of the collection locations in each group.

According to Promsomboon et al<sup>23</sup>, the distribution of indigenous rice in Thailand was related to agro-ecosystems, including lowland, upland and deep water ecosystems. As indigenous rice has long been cultivated in Thailand, rice accessions have been distributed across the different regions, which resulted in rice exchange and relocation of populations, who, in turn, generally carried rice with them to new settlements. In the upland rice variety grown by Karen people in different villages, the genetic diversity in the same variety was found due to geographic isolation of the variety<sup>24</sup>. The relationship observed between Maha Sarakham and Kalasin could possibly be due to the locations being

adjacent to one another. Molecular markers might reveal the genetic relationships among the indigenous rice accessions<sup>25</sup>, and further investigations are still required.

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