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Research article

Impact of soil salinity on grain yield and aromatic compound in Thai Hom Mali rice cv. Khao Dawk Mali 105

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Abstract

The highest-priced aromatic Hom Mali rice is grown on saline soil in Northeast Thailand. The rice variety Khao Dawk Mali 105 (KDML 105), the main variety grown to produce Hom Mali rice was evaluated for yield, the aromatic compound 2-acetyl-1-pyrroline (2 AP) and softness texture at different levels of sodium chloride (NaCl) salt added to the soil. The rice was grown in wetland culture pots with soil made saline by adding 0 g NaCl/kg, 1.16 g NaCl/kg, 1.74 g NaCl/kg, 2.31 g NaCl/kg and 2.89 g NaCl/kg soil which had electrical conductivity (EC) values of 0.13 mS/cm, 0.62 mS/cm, 0.74 mS/cm, 0.95 mS/cm and 1.16 mS/cm, respectively. The addition of salt had different effects on the rice grain yield, yield component and aromatic compound, but did not affect the softness texture. Adding salt into the soil depressed the grain yield on average by 36.3% for all applications. The adverse effect of salt on the yield was correlated with the effect on the 1,000 grain weight (correlation coefficient (r) = -0.94, $p < 0.05$). The lowest level of salt application at 1.16 g NaCl /kg soil significantly raised the level of 2 AP, but not at the higher rates of salt application. Soil salinity did not affect the quality of grain softness texture at any application rate. These results suggested that while salinity may invariably depress the rice yield, at a certain level it may improve the grain quality by increasing the concentration of the main aromatic compound without impacting the softness texture. This needs to be confirmed using field trials in naturally occurring saline soils.

Introduction

Soil salinity is a major problem in global crop production as salt affected soils are reported to occupy about 20% of the world's cultivated land (Wu and Cheng, 2014) and 33% of the irrigated area (Jamil et al., 2011). Most of the affected areas are in the Africa and Asia, with 320 million ha of arable land in South and Southeast Asia facing salinity problems (Iqbal et al., 2010). In Thailand, soil salinity is widespread in the Northeast, affecting an estimated 29% of the region, or around 4.9 million hectares (Division of Mineral Resources Conservation and Management, 2015).

Rice is the major staple food crop in Asia, but its production has been limited by the extent of soil salinity in this region because rice is highly sensitive compared to other crops (Kao, 2018). Moderately saline soil with an electrical conductivity (EC) of 0.69 mS/cm when saturated has been reported to reduce grain yield by up to 50% (Van Genuchten and Gupta, 1993). Thailand is the world's leading rice exporting country, with a quarter of the global market share in the mid 2010 period (Office of Agricultural Economics, 2013). Thai Hom

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Mali or Thai jasmine rice, grown mainly from the cultivar KDML105, accounts for 37% of the wet season crop area and 29% of production (Office of Agricultural Economics, 2018). Most of Thailand's Hom Mali rice is grown in the Northeast, where soil salinity is widespread (Wongsomsak, 1986). The premium grade of Hom Mali rice is associated with saline soils, with the geographical indications (GI) designated Thung Kula Rong-Hai Thai Hom Mali Rice described as rice grown from the varieties KDML105 and RD15 on saline soils in a specific area in Northeast Thailand (Ngokkuen and Grote, 2012). The farmers who have been certified as producers of the GI rice have been identified in districts in northeastern provinces where soil salinity is prevalent (Ngokkuen and Grote, 2012). To date, there has been limited information on the effect of saline soil, particularly on the aromatic compound in rice. A study of three aromatic rice varieties in the temperate environment of the Camargue in France showed that soil salinity increased the concentration of the aromatic compound (2AP), while depressing yield (Gay et al., 2010). The Thai aromatic variety KDML105 is described in its release documents as tolerant to soil salinity (Bureau of Rice Research and Development, 2018). To the best if the current authors' knowledge, there is no definitive information on how its yield and aroma are affected by salinity. Therefore, this study aimed to determine the impact of the level of soil salinity on the grain yield, aromatic compound and softness texture of the rice variety KDML 105. This would be useful information for the management of premium grade rice quality production of Thai Hom Mali rice to improve the aroma and minimize yield lose.

Materials and Methods

Plants culture

A pot experiment was conducted at Kalasin University, Kalasin province, Thailand in the wet season from July to December 2017. The experiment was arranged in a completely randomized design with four independent replications. The seed of KDML 105 was obtained from the Kalasin Rice Seed Center, Kalasin province, Thailand. The soil series of Si Thon (coarse-loamy) was used in this experiment. Five different levels of soil salinity were tested by applying salt at 0 g NaCl/kg soil, 1.16 g NaCl/kg soil, 1.74 g NaCl/kg soil, 2.31 g NaCl/kg soil and 2.89 g NaCl/kg soil. At 2 wk after soil had been incubated in the pot, the EC was measured using a portable EC meter (model EZ-1, China) in each salt application to determine the soil salinity class after one week of soil incubation (Wolf, 1999). Seedlings aged 2 wk were transferred into the prepared 5 L plastic pots containing 9.5 kg of soil (9% moisture content), with two plants per pot. The water level in each pot was maintained at 2–5 cm above the soil surface until harvest. At 10 d after transplanting, N and K fertilizer were applied at 16.50 mg/kg soil and 12.67 mg/kg soil, respectively. At 22 d after transplanting, 11.71 mg N/kg soil was applied. Finally, N P and K at 3.82 mg/kg soil, 1.67 mg/kg soil and 3.17 mg/kg soil, respectively, were applied at 57 d after transplanting. At maturity, the yield and yield components were evaluated consisting of tillers per hill, panicles per hill, number of seeds per panicle and 1,000 seed weight. Seeds samples were kept in the cold room at 18°C before being subjected to chemical analysis.

Aromatic compound and alkaline spreading value analysis

About 10 g of each paddy rice sample was de-husked to yield brown rice grain. A key aroma compound, 2-acetyl-1-pyrroline (2AP), was evaluated based on the fresh extract of uncooked brown rice using capillary gas chromatography-mass spectrometry as in the published method of Mahatheeranont (2001).

The alkali spreading value was tested following the protocol of the National Bureau of Agricultural Commodity and Food Standards (2018) with a small adjustment for brown rice. Twenty brown rice grains from each saline treatment and replicate were placed into Petri dishes, 30 mL of 1.7% KOH solution was added and left at room temperature. Four brown rice grains of KDML105 (low gelatinization temperature) and RD4 (high gelatinization temperature) were used as checks for the precision and accuracy of the method. The degree of spreading was assessed at 25 hr, using a seven-point integer scale, where a lower score indicated a higher gelatinization temperature and vice versa for a higher score.

Data analysis

Data were analyzed using one-way analysis of variance. The differences among treatment means were compared using least significant difference at $p < 0.05$. Correlations between datasets were determined using coefficient correlation analysis.

Results

The EC of the incubated soil increased linearly with an increasing rate of the salt added (Table 1). Based on the EC (Wolf, 1999), the soil in the experiment was non-saline without added salt, slightly saline with 1.16 and 1.74 g NaCl/kg soil, moderately saline with 2.31 g NaCl/kg soil, and strongly saline with 2.89 g NaCl/kg soil with EC values of 0.13 mS/cm, 0.62 mS/cm, 0.74 mS/cm, 0.95 mS/cm and 1.16 mS/cm, respectively.

Adding salt to the soil depressed the rice grain yield and 1,000 seed weight, but there was no effect on the plant height, number of tillers per hill, number of panicles per hill and number of seeds per panicle as shown in Table 2. The yield was depressed on average by 36.3% when salt was applied at all rates compared with no salt application. Similar to the grain yield, the 1,000 seed weight was reduced by 8.4% when salt was added at all rates compared to the control treatment. The effect of increasing salinity on yield depression was evident in the significant, negative, linear relationship between electrical conductivity and yield (correlation coefficient (r) = -0.94) and between electrical conductivity and 1,000 seed weight (r = -0.82). The grain yield was positively correlated with the number of seeds per panicle (r = 0.89) and the 1,000 seed weight (r = 0.93), while the 1,000 seed weight was positively correlated with the number of tillers per hill (r = 0.89) as shown in Table 3.

Table 1 Electrical conductivity and salinity classes of soil at five different rates of salt concentration

Salt (NaCl) application rate (mg/kg dry soil)	Electrical conductivity 1:5 soil:water (mS/cm)	Soil salinity class[1]
0	0.13	Non saline
1.16	0.62	Slightly saline
1.74	0.74	Slightly saline
2.31	0.95	Moderately saline
2.89	1.16	Strongly saline

[1] Source: Wolf (1999)

Table 3 Correlation coefficients between electrical conductivity, yield, 2-acetyl-1-pyrroline (2AP) concentration and other yield component characters

	Yield	1,000 seed weight	2AP concentration
Electrical conductivity	-0.94^{*}	-0.82^{*}	-0.35^{ns}
Yield			0.13^{ns}
Plant height	-0.57^{ns}	0.26^{ns}	
Number of tillers/hill	0.73^{ns}	0.89^{*}	
Number of panicles/hill	0.29^{ns}	0.31^{ns}	
Number of seeds/panicle	0.89^{*}	0.69^{ns}	
1,000 seed weight	0.93^{*}		0.28^{ns}

^{ns} = non-significant different at $p < 0.05$; * = significant different at $p < 0.05$

Table 2 Yield (14% moisture content) and yield components of KDML 105 rice grown at different levels of salt application

Salt application (g NaCl/kg soil)	Yield (g/pot)	Plant height (cm)	Number of tillers/hill	Number of panicles/hill	Number of seeds/panicle	1,000 seed weight (g)
0	39.5^{a}	112.6	10.3	8.3	114.9	24.8^{a}
1.16	28.8^{b}	111.2	10.5	9.0	93.6	23.8^{ab}
1.74	24.4^{b}	109.6	9.5	8.5	79.1	22.3^{b}
2.31	23.9^{b}	113.1	9.0	8.1	106.5	22.0^{b}
2.89	23.5^{b}	107.6	9.4	7.5	86.8	22.8^{b}
F-test	**	ns	ns	ns	ns	*
SD	7.3	3.9	1.7	1.0	21.5	1.6
CV (%)	15.9	9.8	17.9	11	19.7	5.5

CV = coefficient of variation; ns = non-significant difference at $p < 0.05$; * = significant difference at $p < 0.05$; ** = highly significant difference at $p < 0.01$. Different lowercase superscript letters within each column indicate a significant difference ($p < 0.05$).

The effect of soil salinity on the aromatic compound 2AP was different from the yield effect ($p < 0.05$) (Fig. 1). The 2AP concentration increased by about 15% with increasing soil application at 1.16 g NaCl/kg soil from no salt application, but no effect was found at the higher salt application rates of 1.74–2.31 g NaCl/kg soil, while applying at the even higher rate of salt at 2.89 g NaCl/kg soil slightly decreased the concentration of 2 AP compared to the control treatment. The 2AP concentration did not show any significant correlation with the electrical conductivity (r = -0.35), grain yield (r = 0.13) and 1,000 grain weight (r = 0.28) as shown in Table 3. These results indicated that the gelatinization temperature of rice grain was not affected by applying salt in the soil and did not affect the alkali spreading value at any of the concentration rates as shown in Fig. 2.

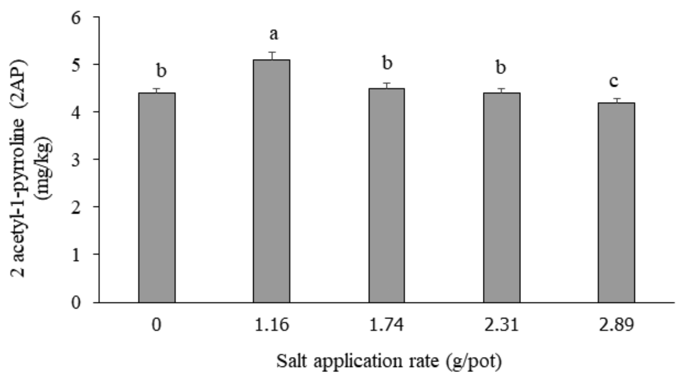

Fig. 1 Effect of soil salinity on the aromatic compound 2-acetyl-1-pyrroline intensity of KDML 105, where different lowercase letters above bars indicate significant difference at $p < 0.05$.

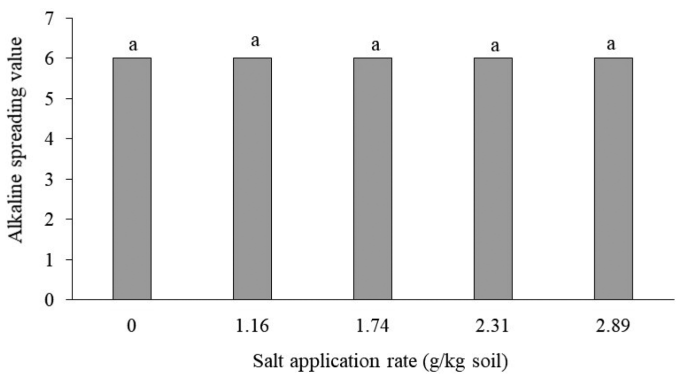

Fig. 2 Effect of soil salinity on alkaline spreading value of KDML 105, where the same letter above bars indicates no significant difference ($p > 0.05$) and the standard checking for alkaline spreading value for KDML105 (low gelatinized temperature check) = 6–7 and for RD4 (high gelatinized temperature check) = 2.

Discussion

The results showed that soil salinity significantly depressed the grain yield of rice variety KDML 105 by reducing the individual seed weight as was reported by Van Genuchten and Gupta (1993). Saline soil has been shown to reduce grain yields in rice by disrupting fertilization resulting in a high percentage of undeveloped seeds (Patcharapreecha et al., 1990). The current study for the first time showed the effect of salt stress on yield and the the aromatic compound in Thai Hom Mali rice cv. KDML 105 which is a popular aromatic rice variety consumed globally. The current study did not produce any impact on the numbers of fertilized and undeveloped seed and the salinity level did not affect general plant growth characteristics as indicated by the lack of any significant differences for the plant height, tiller number per hill, panicle number per hill and number of seeds per panicle among the salt application rates (Table 2). On the other hand, the current study showed that the salt treatments affected the individual seed weight which consequently affected the grain yield as indicated by the correlation between grain yield and electrical conductivity and 1,000 seed weight which was reported by Gay et al. (2010). This phenomenon has been explained as perhaps being due the limited grain-filling process during grain development (Wei et al., 2017). Grain filling is the process of accumulating starch in rice which is an end product of photosynthesis and which saline soil was found to depress during processing (Chaves et al., 2009). Therefore, minimizing yield loss when rice is grown under salt stress conditions could be solved by reducing salt stress during the grain filling stage which could be conducted, for example, by applying gypsum into the soil (Basel, 2012), though no results from this have been reported recently. Thus, this should be the subject of future experiment to determine any yield loss based on the number of seeds per panicle and the 1,000 seed weight which should be major traits to indicate the effect of salt stress in rice.

The current study also showed that the concentration of the aromatic compound of 2AP in the indica Thai rice variety KMLD105 responded differently to salinity compared with the 2AP in the aromatic temperate japonica varieties grown in France (Gay et al., 2010). This latter variety showed highly significant correlations between electrical conductivity and the 2AP concentration and between the 2AP concentration and 1,000 grain weight. On the other hand, the variety KDML105 in the current study appeared to be more sensitive to salinity, with a stimulating effect on 2AP by very mild salinity at 1.16 g NaCl/kg soil (EC of 0.62 mS/cm). The 2AP compound disappeared at the higher levels of salt application with a significant lowering of the 2AP concentration at the strongest salinity treatment of 2.89 g NaCl/kg soil (EC of 1.16 mS/cm). The independence of the 2AP concentration from the 1,000 grain weight found here suggested that aroma expression in the Thai variety KDML105 may be influenced by salinity through a different process from that associated with smaller grain size as suggested for the French varieties (Gay et al., 2010). The absence of any relationship between electrical conductivity and the 2AP concentration confirmed previous reports on the adverse effect of soil salinity in decreasing rice yield and increasing the concentration of the aromatic compound 2AP (Van Genuchten and Gupta, 1993). While it depressed the grain yield in rice, it improved the aroma of the rice grains which have the secondary metabolite, 2AP as a key major compound (Poonlaphdecha et al., 2012). The 2AP compound increased when salt was applied at 1.16 g NaCl/kg soil (0.62 mS/cm soil EC (1:5, soil: water) from the control treatment (Tables 1 and Fig. 1). Secondary metabolites play an important role in defending plant tissues from adverse conditions, such as pathogens or environmental stress, including saline soil (Tiwari and Rana, 2015). Thus, rice grown under saline conditions may produce higher 2AP in an effort to increase its tolerance to the salinity, even in the low soil salinity condition. However, the 2AP compound was reduced at the higher rate of salt stress of 2.89 g NaCl/kg soil (1.16 mS/cm soil EC at 1:5 soil:water). In addition, the concentration of 2 AP compound did not have a dilution effect on the grain yield under saline soil growing conditions as no negative correlation between the grain yield and 2 AP concentration was observed in this study. Therefore, the proper management for growing rice under saline soil conditions is required when dealing with both the grain yield and aroma compound.

However, this study also showed that growing rice in saline soil did not affect the grain texture as indicated by no difference in the alkaline spreading value in the rice grain at all soil salinity levels. Northeast Thailand contains around 3.7 million ha of the slightly saline soil, almost 1 million ha of moderately saline soil and around 0.2 million ha of strongly saline soil (Division of Mineral Resources Conservation and Management, 2015). The current study showed that adequate grain yields of KDML 105 was produced even in moderately and strongly saline soils, even though the yield was slightly depressed. Therefore, it is possible to produce high-quality KDML 105 rice under saline soil growing conditions with the proper management.

The grain yield of the rice variety KDML 105 decreased when salt was applied at all applications from 1.16 g NaCl/kg soil to 2.89 g NaCl/kg soil, while the concentration of the 2AP aromatic compound increased under mildly saline conditions (1.16 g NaCl/kg soil) but was depressed under strongly saline conditions (2.89 g NaCl/kg soil) without any impact on grain softness texture. These results suggested that while mild salinity may depress the yield of Hom Mali rice, it can improve grain quality by increasing the concentration of the aromatic compound.

Conflict of Interest

The authors declare there is no conflict of interest.

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