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Consistency of Different Indices in Rapeseed (*Brassica napus*) may Predict the Waterlogging Tolerance

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Abstract

Different waterlogging tolerance indices between 15 rapeseed (*Brassica napus* L.) cultivar materials were investigated after seed germinating and field waterlogging, in order to research the consistency of different methods, as well as the effects of waterlogging on yields. The results showed significant variation between the 15 materials. Anoxic germination under room condition resulted in great differences in kinds of waterlogging tolerant indexes, such as vigor index, survival rate, relative seedling length, relative root length and fresh weight; in the fields, plant growths were repressed seriously under waterlogging stress: root fresh weight, root length, aerial parts fresh weight, plant height, plant fresh weight, aerial parts dry weight, root dry weight and root/shoot ratio were decreased by various degrees. Meanwhile, physiological indicators like contents of soluble sugar, soluble protein, malondialdehyde (MDA) and proline, as well as activity of superoxidase (SOD) increased; on the other hand, plant height, number of effective branches, number of pods per plant, number of seeds per pod, yield per plant decreased significantly. Especially, the number of effective branches decreased by 31.81%~78.02% compared with control. 1000-seed weights were increased in some materials. Waterlogging tolerance capabilities varied between materials, but generally, waterlogging tolerant plants showed less genotype reduction. Correlation analysis showed that waterlogging tolerant indices of germinating seed in the room were significantly correlative to those physiological and morphological data in the fields, as well as the final yield characters. Unit conductivity was found significantly negatively correlated with yield per plant, while the relative vigor index was significantly positively correlated with yield per plant. This consistency demonstrated that different methods of determining waterlogging tolerance in rapeseed have the same conclusion. Moreover, it helps predicting the waterlogging tolerance of rapeseed cultivars in the lab conditions so that the breeding of the waterlogging tolerant cultivars can be accelerated in the future.

Keywords: *Brassica napus* L.; Relative vigor index; Water-logging tolerance; Physiological index; Morphological index

Introduction

Rapeseed (*Brassica napus* L.) is one of the three most important oil crops in China. It is mainly grown in Yangtze River Basin, where the winter oilseed rape is often followed by a paddy rice crop which is flooded for several weeks during spring and summer (Zhang *et al*., 2008; Peluola *et al*., 2013) and it rains often in autumns (Fu *et al*., 2001). Therefore, the waterlogging stress happens during the seedling stage, bolting stage and flowering stage of rapeseed. In plants, Waterlogging stress usually Physiologically and biochemically resulted in: (1) toxication by the production and accumulation of ethyl alcohol and lactic acid in anaerobic respiration, (2) breaking the balance of reactive oxygen species (ROS) and the following consequent oxidative damage, (3) effecting the normal growth by regulating the contents of endogenous plant hormones such as ethylene (ET), abscisic acid (ABA), cytokinin (CTK) and so on, (4) disordering the absorption of nutrients (Dennis *et al*., 2000; Irfan *et al*, 2010) and (5) finally causes the decrease of yields (Song *et al*., 2009; Song *et al*., 2010; Li *et al*., 2011; Wang *et al*., 2012).

As to rapeseed, besides the necrosis of the root system, the reduction of root biomass, the morphological change in roots (Wang *et al*., 2012), the reduction of chlorophyll content (Li *et al*., 2011), the waterlogging also shortens the plant height and inflorescence length, decreases the numbers of effective branches and pods per plant and reduces the production by 26.80% at the most (Zhu *et al*., 2005; Song *et al*., 2009; Song *et al*., 2010). Therefore, in order to ensure the production of rapeseed seeds, it is extremely important to enhance its waterlogging tolerance and efficiently breed and screen out the tolerant cultivars (Zhou and Lin, 1995).

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Previous researches on waterlogging tolerance in rapeseed mainly focused on evaluating the effects on yields and quality characters (Wang *et al*., 1994; Leul and Zhou, 1999; Shi *et al*., 2001; Chen *et al*., 2006; Li *et al*., 2011; Wang *et al*., 2012; Chen *et al*., 2014) and could be cataloged by morphological, physiological and biochemical, as well as molecular levels. For example, (Chen *et al*., 2006) screened out the waterlogging tolerant rapeseed cultivars by germinating the seeds in room and treating the seedlings in fields under waterlogging; Zhang *et al*. (2011) and Li *et al*. (2013) evaluated the waterlogging tolerant traits of seedlings from 60 rapeseed cultivars after anoxic stress to germinated seeds by using the principle components (PCs) analysis and 2-dimensional scatter plot of the first three PC vectors, getting 18 tolerant cultivars; (Chen *et al*., 2014) treated a landrace "Chuan-you 36" under waterlogging stress in different period, finding that the yield reduced by 3.44% ~ 21.69% as waterlogging lasted 3~9 days. These researches investigated one or more physiological and biochemical indices in the lab and the effects on morphology and yield in the fields, respectively, making positively contribution to the waterlogging tolerance studies (Li *et al*., 2010; Lu *et al*., 2013).

However, it was still not very clear whether there were some potential indices could be used to predict the finally production in fields. In other words, to identify or screen out the waterlogging tolerant cultivars could be realized only when the relevancy and consistency of different waterlogging tolerance indices were established. So in this study, different waterlogging tolerance indices between 15 rapeseed cultivar materials were investigated after seed germinating and field waterlogging, respectively. The results showed significant variation between the 15 materials, but generally, tolerant plants showed less genotype decaying. Correlation analysis showed that the two data obtained in the lab, definitely, the unit conductivity and relative vigor index were significantly correlative to those physiological and morphological data in the fields, as well as the final yield characters. This consistency not only demonstrated that different methods came to the same conclusion, it also provides a possibility to screen out or predict the waterlogging tolerant rapeseed cultivars in the lab conditions, making it possible to breed the waterlogging tolerant cultivars quickly and efficiently in the future.

Materials and Methods

Plant Materials

According to the previous researches, 15 rapeseed materials of different waterlogging tolerances were chosen to study. They were: 2012DTZ, 2012DFJSQ, 2012DMZ91-9, 2012DCYHY, 2012DCY11-21, 2012DCS, 2012DGJ89-1, 2012DWY11, 2012DMZ90-9, 2012DGJ1, 2012FDS3, 2012DCY2, 2012DCY20, 2012DCY2 and 2012DCYⅢ-24. All the seeds were kept by Crop Research Institute, Sichuan Academy of Agricultural Sciences.

Anoxic Germination in Room Conditions to Determine the Waterlogging Tolerance

Full and plump seeds of the 15 cultivars were selected and weighed, then plated into culture dishes with 4 pieces of sterile wet filter paper at 25°C, respectively. 24 h after germination, they were transported into climate incubator at 4°C for another 36 h. Fifty seedlings of each cultivars with the length of 0.2 ~ 0.5 cm were selected. After washed at 3 times with distilled water, they were transported into 10 mL centrifuge tubes full of distilled water, respectively for 14 h. After the waterlogging treatment, digital conductivity meter (Type DDS-309+) was used to determine the conductivity of the water, while the treated seeds were washed 3 times with fresh distilled water and then plated in culture pots to grow with 4 pieces of sterile wet filter paper. Seeds for control were directly plated in culture pots with 4 pieces of sterile wet filter paper to grow, without any waterlogging treatment. 6 days later, 10 seedlings of each material were selected randomly and indices were determined. Three parallel repeats were done. The indices were: unit conductivity (UC), relative seedlings rate (RSR), relative root length (RRL), relative seedling length (RSL), relative fresh weight (RFW) and relative vigor index (RVI). The calculating methods were modified from Chen *et al*. (2006):

$$\text{unit conductivity } (\text{mS}/(\text{cm}\cdot\text{g})) = \frac{\text{electrical conductivity}}{\text{weight of seeds}}$$

$$\text{relative survival rate } (\%) = \frac{\text{survival rate of treated seeds}}{\text{survival rate of control seeds}} \times 100\%$$

$$\text{relative root length } (\%) = \frac{\text{root length of treated seeds}}{\text{root length of control seeds}} \times 100\%$$

$$\text{relative seedling length } (\%) = \frac{\text{seedling length of treated seeds}}{\text{seedling length of control seeds}} \times 100\%$$

$$\text{relative fresh weight } (\%) = \frac{\text{fresh weight of treated seeds}}{\text{fresh weight of control seeds}} \times 100\%$$

$$\text{relative vigor index } = \frac{\text{survival rate of treated seeds} \times \text{seedling length of treated seeds}}{\text{survival rate of control seeds} \times \text{seedling length of control seeds}}$$

Waterlogging in the Fields and the Determination of the Morphological and Physiological Indexes

Experiments in the fields were designed according to random groups and managed by traditional methods. Waterlogging was operated on December 10, 2011 (at seedling stage), by flooding the fields. The surface of water was kept 2 cm higher than the soil. 10 days later, the water was drained away, while the plants for control were without any waterlogging treatment. Then the functional leaves were severed to determine kinds of morphological and physiological indexes.

Eighteen plants of each cultivar were randomly selected and the morphological indices were measured. These indices included plant height (PH), root length (RL), root fresh weight (RFW) and plant shoot fresh weight (PSFW). After the plants were dried, the Root dry weight (RDW) and Plant shoot dry weight (PSDW) were determined. Then the root/shoot ratio (R/S) was got. As to the physiological indexes, contents of chlorophyll, water, soluble protein, malondialdehyde (MDA), proline, soluble sugar, as well as activity of superoxidase (SOD) were determined.

Three parallel repeats were done. The waterlogging tolerances were judged by waterlogging tolerance coefficient (WTC). R/S and WTC were calculated by the following formula:

$$\text{root/shoot ratio (R/S)} = \frac{\text{root fresh weight}}{\text{aerial parts fresh weight}}$$

$$\text{waterlogging tolerance coefficient (WTC)} = \frac{\text{measured value from treated plant}}{\text{measured value from control plant}}$$

The values of subordinate functions were calculated by the following formula (Zhou *et al*., 2001):

$$X(u) = \frac{X - Xmin}{Xmax - Xmin}$$

Or, if it was negatively correlative, the following formula was used:

$$X(u)neg = 1 - \frac{X - Xmin}{Xmax - Xmin}$$

Determination of Yield Traits at Mature Stage

5 plants of each cultivar were picked to investigate when rapeseed were mature. The plant height, number of effective branches, number of effective pods, number of seeds per pod, 1000-seed weight and yield per plant were determined. Waterlogging tolerance index (α) for each character was calculated according to the following formula (Zhou and Zhu, 2002):

$$\text{waterlogging tolerance index of corresponding trait (\%)} = \frac{\text{measured value from treated plant}}{\text{measured value from control plant}} \times 100\%$$

Data Analysis

All the experiments were operated at least 3 times. Analytical software SPSS 17.0 and DPS 6.55 were used to analyze the data. A difference was considered statistically significant when P<0.05 or very significant when P<0.01.

Results

Determination of Waterlogging Tolerance at Seedling Stage

It was showed in Table 1 that the 15 cultivars had different waterlogging tolerances. 3 of them, precisely, 2012DTZ, 2012DFJSQ and 2012DMZ91-9 showed relatively stronger tolerance. They had higher relative survival rates (RSR, 84.52~89.53%), relative root lengths (RRL, 59.77~66.84%), relative seedling lengths (RSL, 81.30~96.18%), relative fresh weights (RFW, 95.87~98.48%) and therefore higher vigor index (VI, 0.73~0.83, 0.79 at average). Meanwhile, they had the lower unit electrical conductivity (UE, 0.49~0.53 $mS \cdot cm^{-1} \cdot g^{-1}$). On the other hand, 6 cultivars, 2012DGJ1, 2012FDS3, 2012DCY2, 2012DCY20, 2012DCY2 and 2012DCYⅢ-24 were relatively less tolerant. They had lower RSR (53.40~60.19%), RRL (24.07~30.78%), RSL (40.10~67.04%), RFW (57.02~71.00%) and therefore higher VI (0.23~0.38, 0.285 at average). Meanwhile, they had the higher unit electrical conductivity (UE, 0.49~0.53 $mS \cdot cm^{-1} \cdot g^{-1}$).

Subordinate Function Value of Morphological and Physiological Waterlogging Tolerance Indices (α) in the Fields

in fields, waterlogging stress affected the aerial parts dry weight, root dry weight, root fresh weight most (Table 2), indicating that it repressed the development of root, as well as the accumulation of dry matter and the absorption of water. Meanwhile, waterlogging stress affected root length, plant height and root/shoot ratio (R/S) less. 8 morphological tolerance indices (α) varied extensively and the variation coefficients ranged from 8.43% to 30.94% (Table 2). The values of these morphological tolerance indices (α) from high to lower in order were: root fresh weight (RFW)> aerial parts fresh weight (APFW)> aerial parts dry weight (APDW)> whole plant fresh weight (WPFW)> relative plant height (RPH)> relative root dry weigh (RDW)> relative root/shoot ratio (R/S)> relative root length (RRL, Table 2).

Moreover, physiologically, contents of soluble sugar, soluble protein, malondialdehyde (MDA) and proline, as well as activity of superoxidase (SOD) increased, and these increasing degrees differed from one cultivar to another greatly. The content of chlorophyll and water decreased significantly. Water content got the lowest variation range value, while the MDA content got the highest one (Table 3). The values of these physiological tolerance indices (α) from high to lower in order were: MDA content>proline content>Soluble sugar content>Soluble protein content>Chlorophyll content>SOD activity>Water content (Table 3).

Average reflected properties of the indices (Zhang *et al*., 2011; Li *et al*., 2013), so they were used to comprehensively estimate the waterlogging tolerance of rapeseed in this study. Waterlogging tolerance indices in room, morphological and physiological indices (α) in fields were calculated (Table 4). The subordinate function values showed that waterlogging tolerances between cultivars varied greatly. But the cultivars which were tolerant under anoxic stress germinating stage also showed strong tolerance to waterlogging stress correspondingly in the

Table 1: waterlogging relative traits of germinating seed

Cultivar	UC ($mS\cdot cm^{-1}\cdot g^{-1}$)	RSR (%)	RRL (%)	RSL (%)	RFW (%)	VI
2012DTZ	0.49	89.19	66.84	92.52	98.48	0.83
2012DFJSQ	0.53	84.52	60.55	96.18	97.83	0.81
2012DMZ91-9	0.53	89.53	59.77	81.30	95.87	0.73
2012DCYHY	0.79	82.99	31.40	77.92	80.54	0.65
2012DCY11-21	0.67	83.47	36.02	78.33	71.42	0.57
2012DCS	0.72	89.93	39.71	68.26	69.64	0.55
2012DGJ89-1	0.87	86.01	39.71	61.45	74.84	0.53
2012DWY11	0.78	71.17	33.86	61.59	88.30	0.50
2012DMZ90-9	0.64	60.38	33.82	70.73	88.08	0.47
2012DGJ1	1.30	60.19	30.78	67.04	64.68	0.38
2012FDS3	1.35	53.40	30.70	62.44	60.03	0.31
2012DCY2	1.89	56.63	29.75	57.52	61.54	0.30
2012DCY20	1.03	57.52	26.24	45.27	71.00	0.26
2012DCY2	1.24	57.55	24.07	40.10	57.02	0.23
2012DCYⅢ-24	1.24	57.55	26.70	40.10	57.02	0.23

UC: unit conductivity; RSR: relative seedlings rate; RRL: relative root length; RSL: relative seedling length; RFW: relative fresh weight; VI: vigor index

fields, indicating an obvious consistency between different test methods. Generally, cultivar 2012DTZ, 2012DFJSQ and 2012DMZ91-9 were more waterlogging tolerant than other materials, while 2012DCY2 was the least tolerant one.

Yield Characters after Waterlogging Treatment

Waterlogging stress decreased the plant height, number of effective branches, and number of seeds per pod, 1000-seed weight and yield per plant, among which numbers of effective pods decreased by 31.81% ~ 78.02% (Table 5) compared with control. On the contrary, 1000-seed weights of most cultivars were increased. Index (α) for yield per plant in cultivar 2012DTZ was 75%, and the reduction degree was significantly lower than other cultivars. Although the numbers of seeds in each pod show no obvious difference (α value was 93%) from Control, the number of effective pods per plant was higher than other cultivars (α value was 65.37%) and moreover, the 1000-seed weight (α value was 123.99%) was even higher than Control, cultivar 2012DTZ showed very strong waterlogging tolerance. On the other hand, cultivars 2012DCY20, 2012DCY2 and 2012DCY Ⅲ -24 were decreased in yield per plant (α value ranged from 26.30% to 36.30%).

Correlation Analysis of Indices of Germinating Seeds, Morphological and Physiological Indices in Fields and Yield Indices (α)

Correlation analysis of indices (α) showed that relative vigor index (RVI), relative root length (RRL), relative seedling length (RSL) and relative fresh weight (RFW) from the experiments in the lab were significantly or even extremely significantly positively correlated with plant height, number of effective branches, number of pods per plant, 1000-seed weight and yield per plant from the experiments in the fields (Table 6). The electronic conductivity (UE) was significantly negatively correlated with plant height, number of effective branches and yield per plant, but not obviously correlated with number of effective pods, number of pods per plant or 1000-seed weight. Relative survival rate was correlated with indices except number of effective pods and 1000-seed weight (Table 6). The results showed that vigor index, Relative root length, Relative seedling length, Relative fresh weight and UE were potential to predict the waterlogging tolerance in the fields. Meanwhile, subordinate values of comprehensive indices based on morphological and physiological indices were significantly correlated with waterlogging tolerance indices of germinating seeds except relative survival rate. It indicated that the indices from the room were in accordance with those from the fields. Moreover, the UE and the RVI was

Table 2: Variation coefficients of morphological waterlogging tolerance indexes (α)

Traits	Average value	Variation Range	Range	Variation coefficients (α, %)
RFW	0.68	0.36-0.99	0.63	30.94
RRL	0.94	0.73-0.99	0.26	8.43
APFW	0.70	0.41-0.99	0.58	27.18
RPH	0.81	0.44-0.99	0.55	24.54
WPFW	0.69	0.41-0.99	0.58	26.16
APDW	0.66	0.41-0.99	0.58	26.97
RDW	0.68	0.42-0.98	0.56	23.16
R/S	0.86	0.36-0.99	0.63	22.73

RFW: root fresh weight; RRL: relative root length; APFW: aerial parts fresh weight; RPH: relative plant height; WPFW: whole plant fresh weight; APDW: aerial parts dry weight; RDW: relative root dry weigh; R/S: relative root/shoot ratio

Table 3: Variation analysis of physiological indexes

Traits	Average value	Variation Range	Range	Coefficient of variation (α, %)
Chlorophyll content	0.75	0.33-0.95	0.62	19.81
Water content	0.97	0.92-1.00	0.08	2.50
MDA content	2.08	1.03-7.42	6.39	69.96
Soluble protein content	1.18	1.00-2.37	1.37	25.99
Proline content	1.47	1.00-3.32	2.32	52.51
SOD activity	1.16	1.01-1.75	0.74	16.34
Soluble sugar content	1.73	1.01-2.98	1.97	36.85

Table 4: Subordinate value analysis of germinating seed anoxic stress and field waterlogging stress

Cultivars	Average subordinate value of morphological parameters	Average subordinate value of physiological indexes	Average subordinate value of comprehensive indexes	Average subordinate Value of germinating seed
2012DTZ	0.61	0.36	0.49	0.79
2012DFJSQ	0.98	0.37	0.68	0.83
2012DMZ91-9	0.92	0.31	0.62	0.75
2012DCYHY	0.66	0.26	0.46	0.68
2012DCY11-21	0.49	0.50	0.50	0.65
2012DCS	0.37	0.42	0.40	0.63
2012DGJ89-1	0.62	0.33	0.48	0.62
2012DWY11	0.56	0.47	0.52	0.63
2012DMZ90-9	0.84	0.38	0.61	0.61
2012DGJ1	0.59	0.30	0.45	0.6
2012FDS3	0.50	0.22	0.36	0.61
2012DCY2	0.29	0.44	0.37	0.42
2012DCY20	0.62	0.39	0.51	0.46
2012DCY2	0.44	0.20	0.32	0.23
2012DCYⅢ-24	0.43	0.38	0.41	0.42

Table 5: Effects of yield characters after field waterlogging stress for 10 days (waterlogging tolerance index, α)

Cultivar	Plant height	Number of effective branches	Number of pods per plant	Number of seeds per pod	1000-seed weight	Yield per plant
2012DTZ	91.07	88.33	65.37	93.00	123.99	75.00
2012DFJSQ	95.68	81.36	44.86	91.45	122.39	52.00
2012DMZ91-9	95.15	77.56	54.43	88.61	111.43	55.74
2012DCYHY	87.75	73.13	55.25	90.11	106.83	55.30
2012DCY11-21	81.76	69.86	66.21	82.00	103.21	56.00
2012DCS	92.23	64.90	64.95	79.00	100.08	52.00
2012DGJ89-1	87.96	63.11	75.59	78.63	102.42	60.00
2012DWY11	83.01	62.16	76.22	74.00	101.63	57.50
2012DMZ90-9	89.8	51.83	63.51	80.00	100.84	50.00
2012DGJ1	82.59	39.53	68.94	78.46	104.33	53.00
2012FDS3	85.17	36.69	78.02	75.99	93.86	52.40
2012DCY2	83.38	37.25	42.48	90.00	114.93	43.35
2012DCY20	77.91	34.62	52.61	72.00	94.10	30.10
2012DCY2	76.36	38.83	55.13	74.11	96.56	36.30
2012DCYⅢ-24	79.84	34.00	31.81	73.95	105.05	21.30

Table 6: Coefficient of correlation between waterlogging tolerance relative characteristics

Item	Plant height	Number of effective branches	Number of pods per plant	Number of pods per plant	1000-seed weight	Yield per plant	Average subordinate value of comprehensive index
RVI	0.833**	0.979**	0.153	0.755**	0.696**	0.771**	0.660**
UE ($mS·cm^{-1}·g^{-1}$)	-0.625*	-0.833**	-0.236	-0.293	-0.274	-0.528*	-0.720**
RSR (%)	0.711**	0.928**	0.179	0.566**	0.490	0.667**	0.447
RRL (%)	0.815**	0.841**	0.034	0.709**	0.774**	0.654**	0.615*
RSL (%)	0.817**	0.868**	0.193	0.798**	0.692**	0.788**	0.636**
RFW (%)	0.745**	0.836**	0.126	0.589**	0.602**	0.635**	0.844**

RVI: relative vigor index; UC: unit conductivity; RSR: relative survival rate; RRL: relative root length; RSL: relative seedling length; RFW: relative fresh weight

significantly positively correlated with final yield (per plant).

Discussion

When suffered under waterlogging, plant cells got anaerobic signals and then regulated some relative gene expression, consequently causing physiological, biochemical and morphological changes to survive themselves by adapting to the environment. To some waterlogging susceptible, such as Barley (*Hordeum vulgare* L.), waterlogging was a main limiting factor affecting its production worldwide (Bertholdsson *et al*., 2015). As to rapeseed, besides kinds of physiological and morphological indices (Li *et al*., 2011; Wang *et al*., 2012), waterlogging stress also altered agronomic trait to worse and finally reduces the production by 26.80% at the most (Zhu *et al*., 2005; Song *et al*., 2009). To rapeseed, one of the most important oil crops in China, its development was repressed and finally the yield was reduced with the quality characters degraded (Leul and Zhou, 1999).

In our previous research, waterlogging tolerant traits of seedlings from 60 rapeseed cultivars were evaluated (Zhang *et al*., 2011; Li *et al*., 2013); one commercial rapeseed, “Chuan-you 36”, was treated under waterlogging stress in different period, turning out that its yield reduced by 21.69% if waterlogging lasted 9 days. But whether the data got from the lab experiments was relative to the final yield was still not clear.

In this study, all the 15 rapeseed cultivars suffered blocked development under waterlogging stress simultaneously. However, single phenotype or biochemical index varied significantly between the 15 cultivars; on the other hand, for one single cultivar material, different indices showed significantly diverse endurance capabilities in it. Take cultivar 2012DCS for example: under waterlogging stress in room, it showed the highest relative survival rate (89.93%); but other indices in 2012DCS looked mediocre, such as relative root length (39.71%), and it got the intermediate level relative seedling length (68.26%, Table 1) and mediocre yield (Table 5). That is to say, different indices behaved diversely in cultivar 2012DCS. But that did not mean the data had no regularity; it indicated that one single morphological index could hardly reflect the waterlogging tolerance.

When many indices were comprehensively analyzed and compared, the regularity emerged: 3 cultivars, 2012DTZ, 2012DFJSQ and 2012DMZ91-9 showed relatively stronger tolerance in kinds of morphological indices in room. They got higher RSR (84.52~89.53%), RRL (59.77~66.84%), RSL (81.30~96.18%), RFW (95.87~98.48%) and therefore VI (0.73~0.83, 0.79 at average, Table 1). Meanwhile, they had the lower UC (0.49~0.53 $mS\cdot cm^{-1}\cdot g^{-1}$). As to the field data, these 3 cultivars also showed better and got the higher yield than others (Table 5). Another 6 cultivars, 2012DGJ1, 2012FDS3, 2012DCY2, 2012DCY20, 2012DCY2 and 2012DCYⅢ-24, behaved worse either in room or in field. They got lower RSR (53.40~60.19%), RRL (24.07~30.78%), RSL (40.10~67.04%), RFW (57.02~71.00%), VI (0.23~0.38) and higher UC (0.49~0.53 $mS\cdot cm^{-1}\cdot g^{-1}$). They also performed worse in the field and got the lower yield than other cultivars (Table 5). So it was indicated that (1) data showed be analyzed comprehensively; (2) data obtained in room were associated with those in the field.

Therefore, it is necessary to screen out some typical indexes, by which the waterlogging tolerance and the stable production capacity could be predicted. Variation coefficients of morphological (Table 2) and physiological (Table 3) waterlogging tolerance indices (α) of the 15 cultivars were analyzed, followed by calculating of subordinate value analysis (Table 4) and coefficient of correlation between waterlogging tolerance relative characteristics (Table 6).

Finally two indices heaved in sight: UC and RVI. When suffered from waterlogging, membrane of plant cells was damaged, causing the exosmosis of cytoplasm and consequent increasing of conductivity. Changes of permeability would be used to reveal the structural and functional damage of cell membrane, and then reflected the tolerance of plants. UE reflected the damage of unit biomass, in this study, cultivar 2012DTZ showed the lowest UC (0.49 $mS\cdot cm^{-1}\cdot g^{-1}$, Table 1) and the highest final yield after waterlogging stress (Table 5), indicating a significantly negative correlation (Table 6). Waterlogging stress also affected the development of seedlings. Their relative survival rate, relative root length, relative seedling length and relative fresh weight decreased and it was considered due to the changing of redox states and the decreasing of photosynthesis (Liu *et al*., 2008); Combining two of these indexes, precisely relative survival rate and relative seedling length, the RVI could indicate the waterlogging tolerance not only in the seedling stage, but also the final yield (Table 5 and 6). UC or RVI, indicated the tolerance biochemically or morphologically, respectively. Using the two indices together could provide a better prediction of yield after waterlogging stress.

Studies on waterlogging tolerances in rapeseed so far mainly focused on tolerance judging, effects on physiology, yield and quality traits. Frequently-used methods insisted morphological identification, determination of physiology traits and molecular skills. Each had its advantages and contributed wonderfully to breeding.

Conclusion

There was a significant variation among the 15 materials; some were more tolerant to waterlogging than the others. After all the data was analyzed, it was found that unit conductivity was significantly negatively correlated with yield, while the relative vigor index was significantly positively correlated with yield per plant. Moreover, it provides a potential possibility to screen out or predict the waterlogging tolerant rapeseed cultivars in the lab conditions so that the breeding of the waterlogging tolerant cultivars can be accelerated in the future.

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