水稻强再生力种质创制及遗传分析

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2020-07-13 收稿, 2020-07-30 修回, 2020-07-30 接受, 2020-07-31 网络版发表

国家重点研发计划(2017YFD0301602-01, 2016YFD0300508)、福建省科技厅-省属公益类科研院所科研专项(2018R1021-5)和福建省财政专项-福建省农业科学院创新团队项目(STIT2017-1-1)资助

摘要 当前直接选育的再生稻专用品种较少, 其制约的关键要素在于强再生力种质的缺乏. 选用8个生产上大面积应用的恢复系, 按4×4不完全双列杂交方式, 通过系谱法进行定向选择和种质创新, 以再生芽出鞘率为指标, 采用加性-显性遗传模型, 对恢复系再生力的遗传特性进行研究. 结果表明: (1) 再生力性状受控于加性效应基因和显性效应基因的共同作用, 同时易受环境条件与栽培技术的影响; (2) 再生力性状狭义遗传率(h^2N)和广义遗传率(h^2B)的估计值均达显著或极显著水平, 而且广义遗传率明显大于狭义遗传率; (3) 恢复系闽恢3301和亚恢627的再生力性状具有极显著或显著的正向加性效应和负向显性效应, 适合作为筛选强再生力的亲本材料; (4) 创制的新种质Ra201、Ra202、Ra212再生芽出鞘率较高, 再生力强, 其中Ra202低节位腋芽萌发优势明显, 可作为亲本用于粳型水稻再生力基因挖掘和利用; (5) 再生稻品种选育方法的研究进一步完善了传统育种技术, 具有间接鉴定和早期筛选的优点, 新种质创制和新品种选育取得了良好成效.

关键词 水稻, 恢复系, 再生力, 种质创制, 遗传效应

再生稻因其经济简约和高效多熟的特点, 在我国南方温光资源一季稻有余而双季稻不足或者双季改单季的地区形成一定的种植规模, 研究和推广再生稻对于我国提高复种指数、增加稻谷产量、确保粮食安全和战略技术储备具有重要意义^[1,2]. 当前再生稻品种主要从生产上推广的品种中筛选, 直接选育的专用品种较少^[3]. 强再生力种质缺乏, 尤其是适应于机械化和轻简化栽培的水稻品种缺少, 成为制约再生稻进一步应用发展的关键要素^[4]. 水稻再生力的遗传受微效多基

因控制, 环境、栽培措施等因素影响较大^[5-8], 再生稻品种要求头季、再生季两季都高产, 品种选育更加复杂, 难度大. 再生稻的育种技术尚处于不断完善之中, 前人对再生稻腋芽发育、产量形成的遗传特性作了大量研究. 郑景生等人^[9]、谭震波等人^[10]、杨川航等人^[11]、李兴星等人^[12]通过控制水稻再生力的不同QTL定位研究, 均发现其加性效应较小, 贡献率较低, 为微效基因. 晏月明等人^[13]通过水稻亚种间杂交, 分析F₁、F₂和F₃世代再生力的遗传特性, 指明再生力的选择具有

引用格式: 林强, 郑长林, 林芳, 等. 水稻强再生力种质创制及遗传分析. 科学通报, 2021, 66: 244–252

Lin Q, Zheng C L, Lin F, et al. Developing germplasms and genetic analysis of strong ratooning ability in *indica* rice (in Chinese). Chin Sci Bull, 2021, 66: 244–252, doi: 10.1360/TB-2020-0872

较好效果。李实蕢和陈廷文^[7]研究认为,再生力一般存在加性效应,可以选育出强再生力的新品种。任天举等人^[8]分析了水稻杂种F₁再生力特性的配合力和遗传力,认为再生力受加性基因效应和非加性基因效应的共同控制,加性基因效应占主导地位。上述研究具有较大的科学理论价值和育种指导作用。

水稻种质资源蕴藏大量高产、优质、抗病虫、抗逆等有利性状,可为育种提供优异的性状基因^[14]。水稻头季收割后腋芽萌发的数量与再生力直接相关,决定再生季的产量形成^[15],而且再生芽出鞘率可作为鉴定再生力的科学指标^[16]。因此,本试验在前期构建强再生力鉴定指标的基础上^[17],开展再生力遗传规律的应用研究及种质资源发掘和利用。主要通过种质创新,以再生芽出鞘率为指标,采用加性-显性遗传模型,研究再生力性状等位基因的显性互作效应和非等位基因的加性效应,估算遗传率和遗传效应值,进一步了解籼稻再生力特性的遗传规律,对当前再生稻育种具有实际应用价值和现实指导意义。

1 材料与方法

(i) 试验材料。选用籼型三系杂交稻育种中大面积应用的恢复系品种:4个籼型恢复系(闽恢3301、福恢2736、绵恢725、蜀恢527)作母本和4个籼型恢复系(明恢86、亚恢627、宜恢1577、N175)作父本,按照4×4不完全双列杂交方式,配制成16个F₁杂交种,通过系谱法以产量及相关性状为目标进行定向选择,至F₁₀代株系群体稳定整齐,每对杂交后代按恢复系的性状标准决选出1个优良株系,与8个籼型恢复系亲本构成一套遗传试验材料。

(ii) 试验方法。2012年开始杂交配组,经多年多地穿梭育种完成恢复系新种质材料的选择和创制。连续2年进行田间再生力遗传试验,2019年在福建省三明市沙县,试验田块肥力较为均匀,地力中等偏上,5月14日播种,6月10日插秧,10月14日成熟,采用机械方式收割。在海南省三亚市海棠湾区藤桥,田块肥力中等,2019年12月6日播种,2020年1月4日插秧,4月25日成熟,采用手工模拟机割方式收获。2年田间试验均按随机区组设计,3次重复,单本栽植,株行距规格为20 cm×20 cm,每小区种植56株,头季稻收割的留桩高度为20 cm左右。施肥管理基本一致,头季稻总氮肥150 kg hm⁻²,以水稻专用复合肥为主,秧苗移栽前2 d深施基肥,返青后撒施分蘖肥,促芽肥于头季齐穗后15 d一次性施尿素50 kg

hm⁻²,头季稻收割后不再施肥,水分管理上采取利于根系活力干湿交替灌溉的措施,其他病虫害防治与一般再生稻稻田相同。

(iii) 再生力测定和分级。参照徐富贤等人^[16]再生力测定和分级方法并进行优化,用1周再生芽出鞘率和2周再生芽出鞘率作为衡量再生力指标。测定方法:头季收割后第7天和第14天每小区连续调查10株再生芽萌发苗数及母茎数,再生芽出鞘率=再生芽萌发苗数/母茎数。1周再生芽出鞘率<60%时,再生力为3级;60%≤1周再生芽出鞘率≤80%时,再生力为2级;1周再生芽出鞘率>80%时,再生力为1级。

(iv) 统计方法。应用禾本科植物数量性状的加性-显性遗传模型(AD模型)和统计分析方法^[18-22],分别对2年恢复系亲本和杂交后代再生力性状的平均数进行估算和分析。以MINQUE(1)法估算再生力性状的加性方差(V_A)和显性方差(V_D):

$$\begin{aligned} \hat{V}_A &= 2\hat{\sigma}_A^2; \\ \hat{V}_D &= \hat{\sigma}_D^2. \end{aligned} \quad (1)$$

方差分量的估计值向量 $[\hat{\sigma}_u^2]$ 由MINQUE(1)等式计算获得:

$$[\hat{\sigma}_u^2] = H^{-1} \{y^T Q U_u U_u^T Q y\} \quad (2)$$

其中, $H = [\text{tr}(U_u^T Q U_v U_v^T Q U_u)]$; $Q = V^{-1} - V^{-1} I (I^T V^{-1} I)^{-1} \times I^T V^{-1}$; $V = \sum_{u=1}^m \sigma_u^2 U_u U_u^T$; $U = [U_1 : U_2 : \dots : U_{m-1} : U_m]$; $y = Iu + \sum_{u=1}^m U_u e_u$; u, v 为亲本数量($u, v=1, 2, \dots, m$), tr 是矩阵对角线元素的总和, y^T 是观察值向量 y 的转置向量, I 是向量, e^u 是第 u 项独立随机变量的向量。

以Jackknife数值抽样技术对各世代平均数进行抽样,计算各项遗传参数的估计值和标准误,采用 t 检验对遗传参数进行显著性检验。采用朱军教授公开的Quantitative Genetics Analysis Software(QGASStation v2.0)软件进行运算和分析,利用Microsoft excel 2019进行数据整理和系谱作图。

2 结果与讨论

2.1 恢复系新种质创制

2012年晚季在福州将强恢恢复系闽恢3301、福恢2736、绵恢725、蜀恢527稻穗温汤去雄后作母本,分

别授以亲本明恢86、亚恢627、宜恢1577、N175花粉,共杂交16对,后代通过系谱法选择株型理想、熟期转色好的大穗型株系,经福州仓山(东经119°21',北纬26°00',海拔5 m,亚热带季风气候)、三亚滕桥(东经109°44',北纬18°23',海拔4 m,热带海洋性季风气候)、三明沙县(东经117°39',北纬26°34',海拔183 m,中亚热带季风性湿润气候)3地多年穿梭选育和抗性筛选,主要以产量为选择目标进行定向培育和反复加代,至F₁₀代群体农艺性状已整齐一致.对选留株系逐个进行恢复力和杂种优势测定,每对杂交后代最终决选出1个产量高、农艺性状协调、米质优、抗稻瘟病、花粉量大、花期长、恢复力强、生育期较为一致的代表性优良株系作为再生力遗传效应试验材料,相关株系依次暂定名为Ra201、Ra202、Ra203、Ra204、Ra205、Ra206、Ra207、Ra208、Ra209、Ra210、Ra211、Ra212、Ra201、Ra213、Ra214、Ra215、Ra216,其系谱关系见图1.

2.2 恢复系亲本的再生力

从表1可见,8个恢复系亲本再生芽出鞘率的表型值存在较大差异,2年的品种间变化较为一致.闽恢3301和亚恢627的1周再生芽出鞘率和2周再生芽出鞘率较高,2019年分别为80.5%和97.8%、82.4%和

102.5%,2020年分别为71.2%和109.0%、72.2%和110.1%,恢复系宜恢1577再生力表现最弱,2年分别为41.4%和50.7%、44.0%和65.2%.8个恢复系1周再生芽出鞘率按2年平均计算,恢复系闽恢3301、亚恢627、绵恢725、蜀恢527再生力达2级,宜恢1577、福恢2736、明恢86、N175再生力为3级(图1).

2.3 恢复系亲本遗传方差和遗传率

分析估算了恢复系亲本和杂交后代再生力性状各项遗传方差分量及占表现型方差比率(表2),遗传方差分量的估计值表明,籼稻恢复系再生芽出鞘率的 V_A 和 V_D 均达到显著($P<0.05$)或极显著水平($P<0.01$),表明1周再生芽出鞘率和2周再生芽出鞘率这2个性状共同受加性效应基因和显性效应基因的控制.再生力性状的 V_D/V_P 均大于 V_A/V_P ,表明籼稻恢复系的再生芽出鞘率性状受显性效应基因的作用更大.此外,剩余方差(V_E)比率在8.6%~31.1%之间,1周再生芽出鞘率和2周再生芽出鞘率均达显著水平,表明该类遗传群体再生力性状的表现还受到环境条件或抽样误差等其他因素影响,但总体上以加性效应或显性效应为主.

遗传率的大小可以衡量数量性状从亲代传递给子代的能力,狭义遗传率表示真实遗传的部分,较高狭义遗传率的性状适宜在育种中作早代选择.籼稻恢复系

图1 16个恢复系新种质系谱图.紫色、黄色和绿色分别表示再生力1级、2级和3级

Figure 1 Pedigree chart of 16 new restorers. The first, second and third grade of ratooning ability were marked in purple, yellow and green respectively

表 1 2019和2020年8个恢复系的再生力性状比较^{a)}

Table 1 Comparison of ratooning ability of 8 restorer lines between 2019 and 2020

恢复系亲本	2019年福建三明		2020年海南三亚	
	1周再生芽出鞘率(%)	2周再生芽出鞘率(%)	1周再生芽出鞘率(%)	2周再生芽出鞘率(%)
闽恢3301	80.5±4.0ab ^{b)}	97.8±0.9ab	71.2±1.2a	109.0±2.6a
福恢2736	56.1±3.2c	77.7±6.6e	48.2±3.4cd	80.5±1.9c
绵恢725	67.1±9.0bc	90.2±2.9bcd	61.4±5.1b	96.8±3.6b
蜀恢527	80.0±3.5ab	94.1±8.2abc	63.9±3.4ab	98.5±2.6b
明恢86	63.3±9.4c	86.6±2.3cde	54.8±3.7bc	96.1±3.3b
亚恢627	82.4±5.6a	102.5±5.4a	72.2±7.1a	110.1±1.8a
宜恢1577	41.4±10.7d	50.7±6.1f	44.0±4.2d	65.2±3.9d
N175	59.0±2.6c	83.3±0.4de	60.4±5.0b	76.2±4.7c
平均值	66.2	85.4	59.5	91.6
变异系数(%)	23.13	18.96	17.87	17.11

a) 同列后跟相同字母表示差异未达0.05显著水平(最小显著差法), 样本数量 $n=3$; b) 平均值±标准误差, 余同

表 2 恢复系再生力性状遗传方差的估计值^{a)}

Table 2 Genetic variance estimates of ratooning ability traits of restorer lines

遗传参数	2019年三明		2020年三亚	
	1周再生芽出鞘率	2周再生芽出鞘率	1周再生芽出鞘率	2周再生芽出鞘率
V_A	50.670**	58.505*	26.381*	61.974*
V_D	147.057*	278.234**	26.638*	263.082**
V_E	60.002*	52.206*	23.912*	30.689*
V_P	257.729**	388.944**	76.931*	355.745**
V_A/V_P	0.197**	0.150*	0.343*	0.174*
V_D/V_P	0.571**	0.715**	0.346*	0.740**
V_E/V_P	0.233*	0.134*	0.311*	0.086**
h^2N	0.197**	0.150*	0.343*	0.174*
h^2B	0.767**	0.866**	0.689**	0.914**

a) *, **分别表示差异达0.05、0.01显著水平; V_A 为加性方差, V_D 为显性方差, V_P 为表型方差, V_E 为机误方差, h^2N 为狭义遗传率, h^2B 为广义遗传率

亲本再生芽出鞘率的狭义遗传率(h^2N)均达显著或极显著水平, 2年材料1周再生芽出鞘率分别为19.7%和15.0%, 2周再生芽出鞘率分别为34.3%和17.4%。该结果表明, 早代对再生力性状的选择是有效的, 但受到显性效应的影响较大。再生力性状广义遗传率的变幅在68.9%~91.4%之间, 均达极显著水平, 表明在选种时, 应利用系谱法对有利变异加以固定。

2.4 恢复系亲本遗传效应预测值

为了预测各恢复系亲本的育种价值, 以便在强再生力种质创制和杂交组配中加以应用, 对亲本再生力性状

的遗传效应作进一步分析。恢复系亲本的遗传效应预测值(表3)表明, 恢复系闽恢3301和亚恢627的再生力性状多数具有显著或极显著的正向加性效应和负向显性效, 说明这2个恢复系能明显增加后代再生腋芽萌发的数量, 容易获得再生力强的后代。蜀恢527多数具有正向加性效应和负向显性效应, 2年表现基本一致, 表明通过加大选择压力可以筛选获得再生力强的后代; 明恢86、绵恢725再生力性状不同年份间加性效应和显性效应多数为负向, 且多数未达显著水平, 说明这两个亲本不会明显降低后代再生能力; 恢复系宜恢1577、N175、福恢2736再生力性状多数具有显著或极显著的负向加性效

表3 恢复系亲本遗传效应预测值^{a)}

Table 3 Predicted values of genetic effects of ratooning ability of parents for restorer lines

年份	恢复系	1周再生芽出鞘率		2周再生芽出鞘率	
		V_A	V_D	V_A	V_D
2019	闽恢3301	6.498 [*]	-11.145 [*]	7.339 [*]	-21.505 ^{**}
	福恢2736	-2.041 ⁺	-16.117 ^{**}	-1.738	-17.362 [*]
	绵恢725	-1.781	-4.560	-0.781	-5.841 [*]
	蜀恢527	3.361 ⁺	-3.485 ⁺	0.440	-4.988
	明恢86	-2.977	-5.646	-1.471 [*]	-7.911 ⁺
	亚恢627	6.582 ^{**}	-9.212	6.783 [*]	-14.376 [*]
	宜恢1577	-7.806 [*]	-17.465	-9.925 [*]	-23.772 [*]
	N175	-1.835 [*]	-13.427 [*]	-0.646	-14.198 ^{**}
2020	闽恢3301	4.765 [*]	-0.943	6.867 [*]	-15.250 ^{**}
	福恢2736	-3.056	-8.745 [*]	-2.189	-21.952 [*]
	绵恢725	0.231	-1.842	-0.400	-8.171
	蜀恢527	0.612	-0.038	1.293	-11.149 ⁺
	明恢86	-0.867	-6.417 [*]	-0.517 ⁺	-8.720
	亚恢627	4.247 [*]	1.105	7.582 [*]	-16.101 ^{**}
	宜恢1577	-6.392 ^{**}	-6.336 ⁺	-9.892 [*]	-17.246 [*]
	N175	0.460	-3.373	-2.744 [*]	-25.334 ^{**}

a) +、*、**分别表示差异达0.1、0.05、0.01显著水平; V_A 为加性方差, V_D 为显性方差

应和显性效应,在两种效应共同作用下,容易削弱后代的再生能力.在育种实践中,杂交亲本的选择应避免双亲同时具有明显的负向加性效应,或者与具有强再生优势的种质进行重组改良和轮回选择.

2.5 强再生力新种质的创制效果

创制的16个恢复系新种质再生芽出鞘率的表型值存在较大差异,变异范围较大(表4),2019年在福建三明1周再生芽出鞘率为55.0%~119.8%,均值为79.9%,2周再生芽出鞘率为84.0%~153.7%,均值为103.2%.2020年在海南三亚1周再生芽出鞘率为50.9%~80.4%,均值为63.7%,2周再生芽出鞘率为86.6%~155.8%,均值为110.9%.16个恢复系新种质1周再生芽出鞘率按2年平均计算,其中,Ra201、Ra202再生力达1级,Ra209、Ra207再生力为3级,其余Ra212等12个新种质再生力为2级.综合2年结果,Ra202、Ra201、Ra212再生芽出鞘率较高,再生力强.

据3个强再生力种质Ra202、Ra201、Ra212分蘖根茎形态的观察(图2),Ra202的腋芽萌发与Ra201、Ra212有所不同,Ra202具有低节位腋芽萌发优势(图2(b)),主要分蘖为倒4、倒5、倒6节位分蘖,着生于表土

层或贴近地表,基部茎节新长出较多的节根及多级侧根.而Ra212和Ra201具有高节位腋芽萌发优势,主要分蘖为倒2、倒3节位分蘖,新根系较少.在生产上,低节位腋芽萌发优势的品种头季适合低留桩机割,碾压轻,成熟期较为整齐一致,产量损失小.

3 讨论

本试验中,再生芽出鞘率的加性效应和显性效应均达到显著或极显著水平,同时环境效应也达到了显著水平,表明再生力受控于加性效应基因和显性效应基因的共同作用,且两套亲本互作产生的非加性遗传作用较为明显,即环境条件与栽培技术等影响较大.1周再生芽出鞘率和2周再生芽出鞘率的狭义遗传力估算结果,2次试验分别仅为19.7%和34.3%、15.0%和17.4%,与广义遗传力差距较大,同样表明再生力特性易受环境及栽培的影响.另外,再生力的加性效应显著,遗传率较高,说明早代选择再生力的性状是有效的.

优良亲本选育属于纯系育种,选择上以单株鉴定为依据,主要是利用加性效应^[23].评价恢复系亲本的遗传效应和再生潜力不仅有利于新种质的创制及利用,而且可为育种目标的制订提供参考.通过对亲本再生

表 4 恢复系新种质的再生力比较^{a)}

Table 4 Comparison of ratooning ability of new restorer lines

恢复系	2019年三明		2020年三亚	
	1周再生芽出鞘率(%)	2周再生芽出鞘率(%)	1周再生芽出鞘率(%)	2周再生芽出鞘率(%)
Ra201	86.4±4.2b ^{b)}	131.0±3.1b	75.2±2.9ab	128.0±3.1b
Ra202	119.8±2.2a	153.7±4.7a	80.4±2.7a	155.8±5.8a
Ra203	78.5±3.2bcd	95.5±3.1def	60.4±2.4def	102.3±2.7def
Ra204	70.0±2.2cde	90.6±4.0ef	59.2±3.7defg	98.6±1.7efg
Ra205	80.0±1.9bcd	99.8±1.9cde	63.9±5.0cde	107.4±4.3de
Ra206	82.1±3.0bc	105.8±7.6cd	64.7±1.1cde	122.6±2.6b
Ra207	64.8±3.7ef	84.7±7.5f	52.9±1.2fg	86.6±1.5h
Ra208	83.6±3.7b	109.9±4.8c	67.8±2.0bcd	118.8±2.1bc
Ra209	55.0±4.3f	84.0±4.3f	50.9±2.2g	88.8±3.8gh
Ra210	81.7±1.9bc	103.9±6.1cd	63.4±4.2cde	107.8±4.8de
Ra211	68.7±6.4de	88.8±3.8ef	57.8±3.3efg	93.1±4.5fgh
Ra212	85.9±0.9b	110.2±3.4c	71.0±5.2abc	124.0±2.2b
Ra213	78.5±6.6bcd	84.7±3.3f	61.3±5.5def	103.8±2.9de
Ra214	82.3±8.9b	104.8±2.7cd	65.0±1.2cde	118.7±3.1bc
Ra215	79.1±1.5bcd	99.0±1.6cde	61.1±2.9def	107.7±5.5de
Ra216	81.5±4.2bc	105.4±3.9cd	64.3±2.2cde	110.1±2.1cd
平均值	79.9	103.2	64.3	111.5
变异系数(%)	18.29	18.25	12.59	15.19

a) 同列后跟相同字母表示差异未达0.05显著水平(最小显著差法), 样本数量 $n=3$; b) 平均值±标准误差, 余同

图 2 3个强再生力新种质的根茎性状比较. (a) 单株根茎; (b) 单个根茎

Figure 2 Comparison of rhizome characters of 3 new germplasms with strong ratooning ability. (a) Single plant rhizome; (b) single shoot rhizome

力性状遗传效应的预测, 了解恢复系亲本的育种价值, 对亲本的再生潜力做出实用性评价, 及时淘汰不良后代或者重新寻优组配. 闽恢3301和亚恢627正向加性效

应较大, 提高后代再生力的效应强. 宜恢1577、N175、福恢2736加性效应不明显, 应避免选择双亲都具有负向加性效应明显的亲本. 绵恢725、蜀恢527和明恢86

加性效应和显性效应多数不显著, 加大压力下结合其他性状共同选择可以达到头季高产与再生特性相统一的育种目标. 在实践中, 蜀恢527和N175的杂交后代, 经生态压力选择, 创制恢复系福恢2736, 之后与谷丰A不育系组配产生的杂交稻品种谷优2736^[24]表现头季丰产, 并且具有一定的再生能力, 在生产上头季产量7770 kg/hm²左右, 再生季产量2816 kg/hm²以上, 通过福建省品种审定, 说明加大压力下再生力性状的选择有效. 另外, 本试验采用不完全双列杂交设计, 可以降低杂交样本容量, 减少试验工作量, 同时能够较好表达完全双列的内容. 选用的8个恢复系亲本均是生产上大面积推广应用的材料, 再生力遗传差异较大, 具代表性, 该样本容量方差分量的估值对群体参数的估值有一定的参考作用和意义.

系统的育种理论和方法、优异的种质资源和基因是水稻品种选育的基础^[14], 选育强再生力的水稻品种, 首先必须筛选、鉴定和创制再生能力强的种质资源. 籼稻高节位腋芽先萌发, 抑制低节位腋芽的萌发和生长, 属高节位再生型, 粳稻、糯稻高节位腋芽对低节位腋芽没有明显的抑制作用, 属低节位再生型^[2,25]. 朱永生等人^[26]的研究也表明, 籼稻品种的低节位腋芽萌发优势大多数低于粳稻. 轻简栽培通常头季采用低留桩来减少收割机对稻桩的碾压, 以低节位再生芽优势的

品种为佳, 机种机收更符合现代农业轻简化栽培的要求, 低留桩机收再生稻的低节位腋芽萌发机制研究成为未来再生稻发展的主要方向^[27,28]. 本试验创制的籼稻材料Ra202, 经连续2年异地鉴定, 均表现低节位萌发优势明显, 可作为亲本进一步用于籼稻再生力基因挖掘和再生杂交稻的配组利用.

再生稻头季产量与再生季稻产量呈极显著负相关, 再生稻品种选育工作者应从追求单季高产转变为追求双季高产^[29]. 鉴于再生稻育种工作的复杂性, 可以借助现有的品种筛选方法, 从头季产量入手, 结合再生芽出鞘率的性状指标, 选择头季分蘖发生叶位数多, 再生季分蘖力强, 具有两季高产潜力的品种, 进一步完善强再生力品种的选育技术体系. 应用再生芽出鞘率(1周再生芽出鞘率和2周再生芽出鞘率)作为衡量再生力的指标, 可以早期对种质或品种的再生力作出判断, 减少工作量. 当在非再生稻生态区无法测产时, 也可作为间接鉴定和筛选的科学依据. 再生力遗传效应可以全面对亲本的再生特性进行分析, 有利于精确选择亲本和高效筛选后代. 当前生产上水稻品种更新换代较快, 授权品种的平均寿命仅为10.013年^[30], 在育成推广品种中筛选强再生力的品种显然不能满足再生稻发展的需求, 本研究进一步完善了再生稻品种的选育方法, 新种质创制和新品种选育取得了良好的成效.

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Summary for “水稻强再生力种质创制及遗传分析”

Developing germplasms and genetic analysis of strong ratooning ability in *indica* rice

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Ratooning rice can efficiently utilize temperature and heat resources from the sun to increase multiple cropping index and grain yield while benefiting from one sowing and two harvests. Therefore, it is very important to rice production and food security in China. The high-yield germplasms of ratoon rice are the material basis for breeding varieties with strong ratooning ability. The lack of rice varieties with robust ratooning ability is a key factor restricting the development of ratoon rice. At present, the germplasm with strong ratooning ability is lack, and ratoon rice varieties are mainly selected from the varieties popularized in production. Therefore, it is important to apply direct breeding strategies to select for varieties of ratoon rice.

The breeding technology of ratooning rice is continuously improving, and there are two methods to breed new varieties of ratoon rice. One approach is to employ combining ability to select for elite parents with strong ratooning ability and estimate the heritability of ratooning ability, which can be used to decide on selecting varieties or combinations with strong ratooning ability from its offspring. The second approach is to screen for characteristics closely related to ratooning ability of the 1st season rice. With the improvement of breeding technology, researching and solving the problem of rice ratooning ability from pedigree breeding and genetic effects will provide technical support and guarantee the direct breeding of new rice varieties with ratooning abilities.

Using eight restorers applied in a large area of production as materials, directional selection and germplasm innovation were carried out by the pedigree method. In order to study the genetic characteristics of ratooning ability, the ratio of stems of ratooning bud to total stems were analyzed in a 4×4 incomplete diallel design by using the additive-dominant model. The results showed the following: (1) Genetic expression of ratooning ability was mainly controlled by both additive and dominant effects, but they were easily influenced by environmental conditions and cultivation techniques. (2) Predicted value of heritability of the ratooning ability traits were significant or extremely significant, and broad heritability (h^2B) was significantly higher than broad heritability (h^2N). (3) The ratooning ability was significantly different among rice restoring lines, and the ratooning ability traits of the restoring lines, Minhui 3301 and Yahui 627 had significant positive additive effects and negative dominant effects, which were suitable for screening parents with strong regeneration ability. (4) The new germplasm resources of Ra201, Ra202 and Ra212 had a higher ratio of stems of ratooning buds to total stems and strong ratooning ability, among which Ra202 had obvious advantages of low-node germination and could be used as parents for the gene mining and utilization of the ratooning ability in *indica* rice. (5) The study on breeding methods of ratoon rice cultivars has further improved the classical breeding techniques, and has the advantages of indirect identification and early screening. The effect of new germplasm creations and new breeding varieties were useful and insightful.

rice, restoring lines, germination ability, creating germplasms, genetic effect

doi: [10.1360/TB-2020-0872](https://doi.org/10.1360/TB-2020-0872)