

Comparative Analysis of the 100 kb Region Containing the *Pi-k^h* Locus Between *indica* and *japonica* Rice Lines

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We have recently cloned a pathogen inducible blast resistance gene *Pi-k^h* from the *indica* rice line Tetep using a positional cloning approach. In this study, we carried out structural organization analysis of the *Pi-k^h* locus in both *indica* and *japonica* rice lines. A 100 kb region containing 50 kb upstream and 50 kb downstream sequences flanking to the *Pi-k^h* locus was selected for the investigation. A total of 16 genes in *indica* and 15 genes in *japonica* were predicted and annotated in this region. The average GC content of *indica* and *japonica* genes in this region was 53.15% and 49.3%, respectively. Both *indica* and *japonica* sequences were polymorphic for simple sequence repeats having mono-, di-, tri-, tetra-, and pentanucleotides. Sequence analysis of the specific blast resistant *Pi-k^h* allele of Tetep and the susceptible *Pi-k^h* allele of the *japonica* rice line Nipponbare showed differences in the number and distribution of motifs involved in phosphorylation, resulting in the resistance phenotype in Tetep.

Key words: comparative genomics, blast resistance gene, genome analysis, microcolinearity

Introduction

The genetic make-up and genome organization of related species is often sufficiently conserved, allowing alignments of the genomes. Genome alignment enables research communities to predict the presence of genes, build physical maps, and conduct comparative genome analysis among and between species. The recent genome sequencing of various organisms has enhanced the rate of new gene identification, annotation, and functional validation. Genome information available in the public domain has been used extensively in comparative genome studies with the help of bioinformatics tools.

Rice is considered as a model crop for genetic and molecular biology studies largely because of its small genome size (389 Mb) in cereals (1). The rice genome has been sequenced from two subspecies, *indica* cultivar 93-11 (2, 3) and *japonica* cultivar Nipponbare (1, 4). These two rice subspecies are thought to have diverged more than one million years ago (5). Sequence availability for each of the two rice subspecies has made comparative genomics an easy task. Genome alignment helps in carrying out comparative genome analysis, leading to the study of similarity

and variation between two genomes or gene sequences, which is useful for functional studies, genetics, and crop breeding.

Among various biotic stresses like bacterial leaf blight, sheath blight, and stem borer that limit rice productivity, the blast disease caused by *Magnaporthe grisea* (hebert) Barr is a serious constraint in rice production at the global level. In our previous study, we have tagged a durable blast resistance gene *Pi-k^h* from the *indica* rice line Tetep by using cleaved amplified polymorphic sequence (CAPS) and sequence tagged microsatellite site (STMS) markers at 1.6 cM and 1.1 cM distance, respectively (6). This gene was further fine mapped by using simple sequence repeat (SSR) markers at 0.7 cM and 0.5 cM distance, respectively, and its physical location was determined on the long arm of rice chromosome 11 (7). SSR markers identified in Tetep were used to locate the homologous region in the genomic sequence of the *japonica* rice line Nipponbare. Bioinformatics tools were used to identify candidate blast resistance genes from a physical map consisting of two overlapping chromosomes, namely bacterial artificial chromosome and P1 artificial chromosome, spanning a region of 143,537 bp on the long arm of rice chromosome 11. Consequently, a homologous sequence of 1.5 kb was cloned

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from Tetep. The cloned *Pi-k^h* gene has a single open reading frame (ORF) and belongs to the nucleotide binding site (NBS)-leucine-rich repeat (LRR) class of disease resistance genes (7). However, further molecular analysis of the *Pi-k^h* gene and its functional complementation has yet to be deduced.

Keeping in view the socio-economic importance of the blast resistance gene *Pi-k^h* in sustainable management of rice blast in the northwestern Himalayan region of India, we carried out the present investigation to analyze the structural organization of candidate blast resistance *Pi-k^h* locus and to perform microsynteny analysis of *indica-japonica* sequences on this specific locus.

Results and Discussion

Gene prediction and annotation

Sequence analysis was carried out to find the number and order of genes in a 100 kb region containing 50 kb upstream and 50 kb downstream sequences flanking to the *Pi-k^h* locus in both *indica* and *japonica* rice lines. A total of 16 genes in *indica* and 15 genes in *japonica* were predicted in this region (Tables 1 and 2). In the *indica* variety, 8 genes are present in the plus strand and another 8 are in the minus strand. The longest ORF is 4,722 bp in the minus strand, followed by ORFs of 2,820, 2,178, and 1,020 bp. The other 12 ORFs are less than 1,000 bp (Table 1). In the case of *japonica*, 6 genes are present in the plus strand and 9 are in the minus strand. Out of the 15 ORFs, the sizes of 4 ORFs are longer than 2,000 bp, in which the longest ORF is 2,808 bp in the minus strand; 3 ORFs are in the range of 1,000 to 2,000 bp; the remaining 8 ORFs are less than 1,000 bp (Table 2).

To know the functions of these predicted genes, BLASTX was performed with the NCBI nr protein database (Tables 1 and 2). Nine genes in *indica* and seven in *japonica* were predicted as hypothetical proteins, while two genes in *indica* and three in *japonica* were annotated as expressed proteins. Two genes (*osi10* and *osi12*) in *indica* were annotated as encoding the putative L-zip+NBS+LRR domain, compared with one (*osj10*) in *japonica*. Similarly, two genes (*osi09* and *osi11*) in *indica* were annotated as encoding the putative Phyb1 protein, compared with one (*osj09*) in *japonica*. The gene *osi15* in *indica* was found similar to *osj13* in *japonica* for encoding the putative NB-ARC domain [nucleotide-binding adaptor shared by APAF-1 (apoptotic peptidase activat-

ing factor), resistance (R) proteins, and CED-4]. The genes *osj01* and *osj15* in *japonica* were annotated as the putative GTP-binding protein and the putative LRR domain, respectively. However, their counterparts were not found in *indica*.

Our analysis supports the evidence that there exists conservation of gene order across regions spanning many megabases (macrocolinearity) (8), but the colinearity of gene order and content at the level of local genome structure (microcolinearity) has also been observed (9). The LRR domain is implicated in interactions between proteins, ligands, and carbohydrates (10, 11). Its role as a major determinant of recognition specificity is supported by studies on domain swaps among alleles of *L* and *P* genes in flax (12, 13). In addition to recognition, LRR has the tendency to form horse-shoe-shaped molecules with β -sheet on the concave side. A central “xxLxLxx” motif, where “x” represents any amino acid, forms the β -sheet with leucine buried in the center of the protein and the adjacent residue, which is a hypervariable region exposed to solvents (10). Each R protein contains a conserved NBS that probably binds ATP or dATP (14). The NBS region, which is around 320 amino acids long, has several R proteins, including kinase 1a, 2, and 3a domains, as well as short motifs known as NB-ARC domains. The NB-ARC domain, which generally controls cell death, might be involved in ATP-dependent oligomerization or histidine aspartic acid phosphotransfer without nucleotide bindings.

Analysis of the 100 kb target region revealed that the gene density in this region is one gene per 6.25 kb in *indica* and one gene per 6.67 kb in *japonica*, while the overall gene density of rice is one gene per 5.7 kb (15). The International Rice Genome Sequencing Project (IRGSP) detected a total of 37,544 non-transposable-element-related protein-coding sequences in rice, with a lower gene density of one gene per 9.9 kb (1). To further investigate the relationship among similar predicted gene functions of *indica* and *japonica*, multiple sequence alignments were performed using the ClustalW program (www.align.genome.jp) and a phylogenetic dendrogram was constructed. All the 16 predicted genes of *indica* and 15 genes of *japonica* were classified into three large groups (Figure 1). Groups I and II have two subgroups for each, while Group III has three subgroups, which is the largest group containing 51.6% of the predicted genes. The dendrogram shows that the predicted genes with similar functions between both cultivars are grouped together. This was expected

Table 1 Predicted genes and their annotations in the 100 kb region of the *indica* rice line

Gene ID	Start (bp)	End (bp)	cDNA size (bp)	DNA strand	BLAST hit	Gene function
<i>osi01</i>	548	2,251	762	+	ABA94924.1	expressed protein
<i>osi02</i>	3,637	3,897	261	+	ABA94925	hypothetical protein LOC_Os11g41930
<i>osi03</i>	6,691	7,218	528	+	ABA94926.1	hypothetical protein LOC_Os11g41940
<i>osi04</i>	8,799	9,110	312	+	OSJNBa0041A02.28	hypothetical protein
<i>osi05</i>	10,079	10,666	588	-	ABA94927.1	hypothetical protein LOC_Os11g41950
<i>osi06</i>	12,127	12,441	315	+	ABA94928.1	hypothetical protein LOC_Os11g41960
<i>osi07</i>	13,653	15,123	525	-	ABA94924.1	hypothetical protein
<i>osi08</i>	15,991	30,983	4,722	-	ABA94930.1	hypothetical protein LOC_Os11g41980
<i>osi09</i>	36,253	38,219	324	+	ABA94971.1	Phyb1, putative
<i>osi10</i>	39,515	40,644	1,020	-	BAA75541.1	L-zip+NBS+LRR
<i>osi11</i>	45,161	49,476	699	+	ABA94971.1	Phyb1, putative
<i>osi12</i>	50,252	51,649	630	-	ABA94972.1	L-zip+NBS+LRR, putative
<i>osi13</i>	54,698	55,033	336	-	ABA94973.1	hypothetical protein LOC_Os11g42020
<i>osi14</i>	58,932	61,109	2,178	+	ABA94974.1	expressed protein
<i>osi15</i>	75,984	78,803	2,820	-	ABA94975.1	NB-ARC domain, putative
<i>osi16</i>	82,010	82,495	486	-	NP_910833.1	hypothetical protein

Table 2 Predicted genes and their annotations in the 100 kb region of the *japonica* rice line

Gene ID	Start (bp)	End (bp)	cDNA size (bp)	DNA strand	BLAST hit	Gene function
<i>osj01</i>	33	3,693	1,257	+	ABA94923.1	GTP-PI-KH-binding protein, putative
<i>osj02</i>	5,596	9,614	1,623	+	ABA94924.1	expressed protein
<i>osj03</i>	12,488	14,583	588	+	ABA94926.1	hypothetical protein LOC_Os11g41940
<i>osj04</i>	17,626	18,180	555	-	ABA94927.1	hypothetical protein LOC_Os11g41950
<i>osj05</i>	19,549	19,986	438	+	ABA94928.1	hypothetical protein LOC_Os11g41960
<i>osj06</i>	21,998	22,448	204	-	ABA94929.1	expressed protein
<i>osj07</i>	23,438	26,842	2,301	-	ABA94930.1	hypothetical protein LOC_Os11g41980
<i>osj08</i>	31,077	39,956	2,415	-	ABA94931.1	hypothetical protein LOC_Os11g41990
<i>osj09</i>	45,208	49,523	699	+	ABA94971.1	Phyb1, putative
<i>osj10</i>	50,513	51,533	810	-	ABA94972.1	L-zip+NBS+LRR, putative
<i>osj11</i>	54,624	54,959	336	-	ABA94973.1	hypothetical protein LOC_Os11g42020
<i>osj12</i>	63,371	65,551	2,181	+	ABA94974.1	expressed protein
<i>osj13</i>	76,976	79,783	2,808	-	ABA94975.1	NB-ARC domain, putative
<i>osj14</i>	83,579	84,077	339	-	ABA94976.1	hypothetical protein LOC_Os11g42050
<i>osj15</i>	103,360	105,306	1,947	-	ABA94977.1	Leucine-rich repeat, putative

since *indica* and *japonica* subspecies have a common ancestor and there is a high degree of gene conservation between both subspecies (16). In Group I, the genes encoding the putative Phyb1 protein, the L-zip+NBS+LRR domain, and the NB-ARC domain are clustered together, respectively. However, the gene *osi10* in *indica* encoding for the L-zip+NBS+LRR domain did not cluster with the functionally similar predicted genes *osi12* and *osj10*. This might be due to the long cDNA sequence (1,020 bp) of

gene *osi10* compared with *osi12* (630 bp) and *osj10* (816 bp). As a result, the alignment score between *osi10* and *osi12* as well as that between *osi10* and *osj10* was 8.64 and 11.11, respectively, whereas the alignment score between *osi12* and *osj10* was 32.85, indicating a better alignment. Groups II and III contain clusters of genes similar to the hypothetical proteins and expressed proteins from both *indica* and *japonica* rice lines.

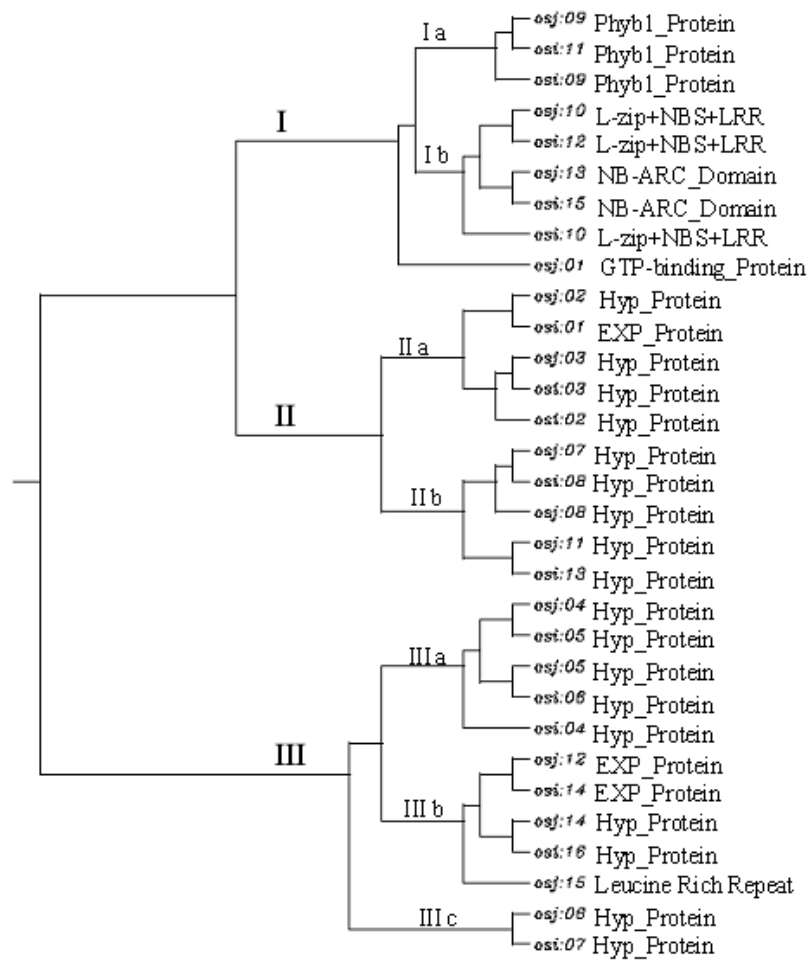


Fig. 1 Phylogenetic analysis of the predicted genes of *indica* and *japonica* rice lines.

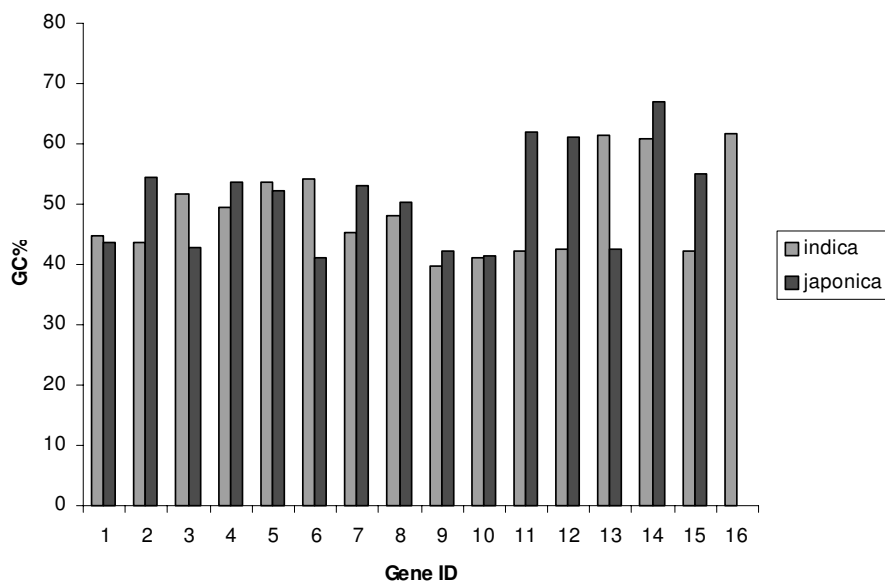


Fig. 2 Gene-wise distribution of GC content in *indica* and *japonica* rice lines.

The GC content of the 16 *indica* genes varies from 41.1% to 61.7%, while it is 41.2% to 67.0% for the 15 *japonica* genes (Figure 2). When performing gene to gene comparison, 10 genes predicted in the *japonica* rice line (excluding *osj01*, *osj03*, *osj05*, *osj06*, and *osj13*) have slightly higher GC content than those of *indica*. The average GC content of *indica* and *japonica* genes in the 100 kb region is 53.15% and 49.3%, respectively. The average GC percentage is higher in *indica* due to the presence of one extra gene (*osi16*) as compared with the 15 genes predicted in this region of *japonica*. The average GC content of the *indica* genes excluding *osi16* is 43.4%, compared with 49.3% of the *japonica* genes. The higher GC content in monocot genes than in eudicot genes has been reported before (17). In Gramineae genes, the gradients in GC content, codon usage, and amino acid usage have been reported along the direction of transcription (18). Our analysis showed that variations in GC content do exist between the genes of two subspecies of the genus *Oryza*.

Physical mapping of the predicted genes

Microsynteny analysis was performed on the *Pi-k^h* locus in both *indica* and *japonica* sequences (Tables 3 and 4). All the predicted genes from both subspecies showed 100% sequence similarity (except gene *osj01* in *japonica* that showed 99% homology) with respective chromosome database. Based on the above information, all the genes were classified and plotted with respect to their exact physical positions and directions on chromosome 11 of both *indica* and *japonica* rice lines (Figure 3). In both rice lines, the predicted *Pi-k^h* gene was flanked by the *Phyb1* gene at the left side in reverse orientation. This analysis further showed macrocolinearity as well as rearrangement and duplication since there are two genes encoding the putative *Phyb1* protein and two genes encoding the Lzip+NBS+LRR domain in *indica*. Therefore, on careful observation of the genome sequences, a narrower region of divergence can be found (19). This region relates to the area of divergence between two rice subspecies, and the alignment of the two rice subspecies may help in identifying regions of cereal genomes that are prone to rapid evolution. Similar results were obtained by Han and Xue (20), where they showed extensive conservation of microcolinearity in the gene order and gene content between *indica* and *japonica*, but they also discovered significant number of rearrangements and polymorphisms when comparing the

two genomes. Whole genome analysis of *indica* and *japonica* rice revealed 18 distinct pairs of duplicated segments that cover 65.7% of the genomes (5). It was concluded that ongoing individual gene duplications provide a continuous source of new material for the genesis of genes in rice (5). Song *et al* (19) identified orthologous regions from maize, sorghum, and the two rice subspecies. They found that gross macrocolinearity is maintained but microcolinearity is incomplete among these cereals. Deviation from gene colinearity is attributed to the changes such as gene insertion, deletion, duplication, or inversion.

Identification of SSRs in the *Pi-k^h* locus

The frequency of SSRs in the 100 kb region was calculated on both *japonica* and *indica* rice lines (Figure 4). In this region, there are more monomers (A, C, and T repeats) in *japonica* than in *indica*, whereas dimers are equal in both sequences (Figure 4A). The number of trimers in *japonica* and *indica* sequences is 10 and 7, respectively. C repeat and pentamer are absent in *japonica*, whereas tetramer is absent in *indica* (Figure 4A and B). All together *japonica* and *indica* has 46 and 36 SSRs in this region, respectively. In the 100 kb region of both rice lines, the first 70 kb region is rich in SSRs compared with the rest of the region (Figure 4C). The *Pi-k^h* locus is flanked by monomer T and A repeats in both rice lines at the left and the right side, respectively. We found that 76.0% and 91.0% of the repeats were present in the intergenic region of *japonica* and *indica*, respectively, whereas 23.9% and 8.6% repeats were also detected within the genes encoding for hypothetical and expressed proteins.

Repeat elements play a major role in gene duplication and amplification for generating new alleles in the population. IRGSP has identified and annotated a total of 18,828 Class I di-, tri-, and tetranucleotide SSRs, representing 47 distinctive motif families (1). They reported an average of 51 hypervariable SSRs per Mb, with the highest density occurring on chromosome 3 (55.8 SSR/Mb) and the lowest occurring on chromosome 4 (41.0 SSR/Mb). These repeat elements also act as SSR markers for specific regions of the genome. Thousands of such SSRs have already been shown to amplify well and are polymorphic in a panel of diverse cultivars, and thus are of immediate use for genetic analysis (1). Both of the sequences from *japonica* and *indica* are polymorphic for SSRs. The results on the SSR distribution in the 100 kb region showed that these SSRs are mono-, di-, tri-,

tetra-, and pentanucleotides. Similar results were obtained on the SSR distribution in rice and *Arabidopsis* genomes, which also reported that the majority of the SSRs were mono-, di-, tri-, tetra-, and pentanucleotides, accounting for up to approximately 80% of all the SSRs found in various regions of the genomes (21). As described above, there are more SSRs in intergenic regions than in intragenic regions. This might be the reason that the sequences of rice chromosomes 11 and 12 are rich in disease resistance genes and recent gene duplications (22). Therefore, the resistance and defense response genes, enriched

on these chromosomes relative to the whole genome, have evolved due to duplication, amplification, and reduplication. SSRs play a major role in this process of evolution. Within the gene, only trimer repeats were found to be present in both *japonica* and *indica* sequences. This is consistent with the study of Zhang *et al* (23) in which a more comprehensive survey of SSRs was performed in *Arabidopsis* and showed that SSRs in general are more favored in upstream regions of the genes and trinucleotide repeats are the most common repeats found in the coding regions.

Table 3 Microsynteny analysis of the predicted genes in the 100 kb region of the *indica* rice line

Gene ID	BLAST hit	Bit score	E-value	Homology	Start (bp)	End (bp)
<i>osi01</i>	Chr11 2003-08-01 BGI	808	0.0	420/420 (100%)	20,399,132	20,399,551
<i>osi02</i>	Chr11 2003-08-01 BGI	502	E-142	261/261 (100%)	20,400,937	20,401,197
<i>osi03</i>	Chr11 2003-08-01 BGI	1,015	0.0	528/528 (100%)	20,403,991	20,404,518
<i>osi04</i>	Chr11 2003-08-01 BGI	600	E-171	312/312 (100%)	20,406,099	20,406,410
<i>osi05</i>	Chr11 2003-08-01 BGI	1,131	0.0	588/588 (100%)	20,407,966	20,407,379
<i>osi06</i>	Chr11 2003-08-01 BGI	606	E-173	315/315 (100%)	20,409,427	20,409,741
<i>osi07</i>	Chr11 2003-08-01 BGI	604	E-172	314/314 (100%)	20,412,423	20,412,110
<i>osi08</i>	Chr11 2003-08-01 BGI	4,224	0.0	2,197/2,197 (100%)	20,416,754	20,414,558
<i>osi09</i>	Chr11 2003-08-01 BGI	202	7E-52	105/105 (100%)	20,434,981	20,435,085
<i>osi10</i>	Chr11 2003-08-01 BGI	1,017	0.0	529/529 (100%)	20,437,343	20,436,815
<i>osi11</i>	Chr11 2003-08-01 BGI	217	4E-56	113/113 (100%)	20,446,229	20,446,341
<i>osi12</i>	Chr11 2003-08-01 BGI	706	0.0	367/367 (100%)	20,448,209	20,447,843
<i>osi13</i>	Chr11 2003-08-01 BGI	646	0.0	336/336 (100%)	20,452,333	20,451,998
<i>osi14</i>	Chr11 2003-08-01 BGI	4,188	0.0	2,178/2,178 (100%)	20,456,232	20,458,409
<i>osi15</i>	Chr11 2003-08-01 BGI	5,422	0.0	2,820/2,820 (100%)	20,476,103	20,473,284
<i>osi16</i>	Chr11 2003-08-01 BGI	935	0.0	486/486 (100%)	20,479,795	20,479,310

Table 4 Microsynteny analysis of the predicted genes in the 100 kb region of the *japonica* rice line

Gene ID	BLAST hit	Bit score	E-value	Homology	Start (bp)	End (bp)
<i>osj01</i>	Chr11_pmol osa1	531	E-150	278/279 (99%)	24,671,510	24,671,788
<i>osj02</i>	Chr11_pmol osa1	1,269	0.0	660/660 (100%)	24,674,714	24,675,373
<i>osj03</i>	Chr11_pmol osa1	608	E-173	316/316 (100%)	24,682,968	24,683,283
<i>osj04</i>	Chr11_pmol osa1	1,067	0.0	555/555 (100%)	24,686,880	24,686,326
<i>osj05</i>	Chr11_pmol osa1	842	0.0	438/438 (100%)	24,688,249	24,688,686
<i>osj06</i>	Chr11_pmol osa1	367	E-102	191/191 (100%)	24,691,148	24,690,958
<i>osj07</i>	Chr11_pmol osa1	4,109	0.0	2,137/2,137 (100%)	24,695,542	24,693,406
<i>osj08</i>	Chr11_pmol osa1	1,396	0.0	726/726 (100%)	24,705,726	24,705,001
<i>osj09</i>	Chr11_pmol osa1	217	5E-56	113/113 (100%)	24,717,676	24,717,788
<i>osj10</i>	Chr11_pmol osa1	1,148	0.0	597/597 (100%)	24,719,809	24,719,213
<i>osj11</i>	Chr11_pmol osa1	646	0.0	336/336 (100%)	24,723,659	24,723,324
<i>osj12</i>	Chr11_pmol osa1	4,194	0.0	2,181/2,181 (100%)	24,732,071	24,734,251
<i>osj13</i>	Chr11_pmol osa1	5,399	0.0	2,808/2,808 (100%)	24,748,483	24,745,676
<i>osj14</i>	Chr11_pmol osa1	381	E-105	198/198 (100%)	24,752,777	24,752,580
<i>osj15</i>	Chr11_pmol osa1	3,744	0.0	1,947/1,947 (100%)	24,774,006	24,772,060

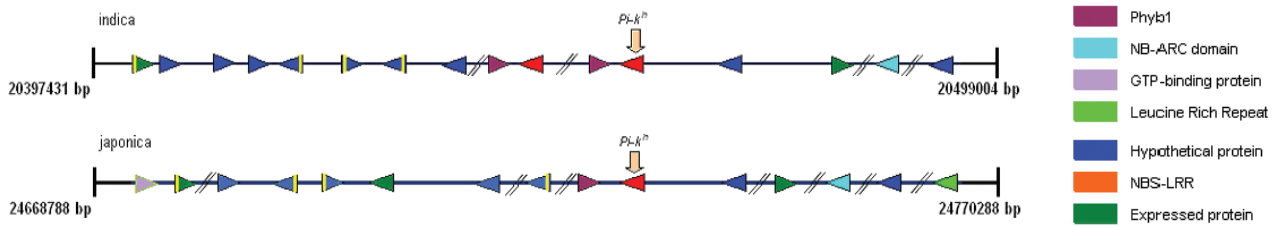


Fig. 3 Physical map of the genes predicted in the 100 kb region of chromosome 11 of both *indica* and *japonica* rice lines. The position of arrow head indicates the direction of the gene. Vertical yellow lines in the gene represent repeat elements present within the gene. The position of the *Pi-k^h* gene is shown with the vertical arrow.

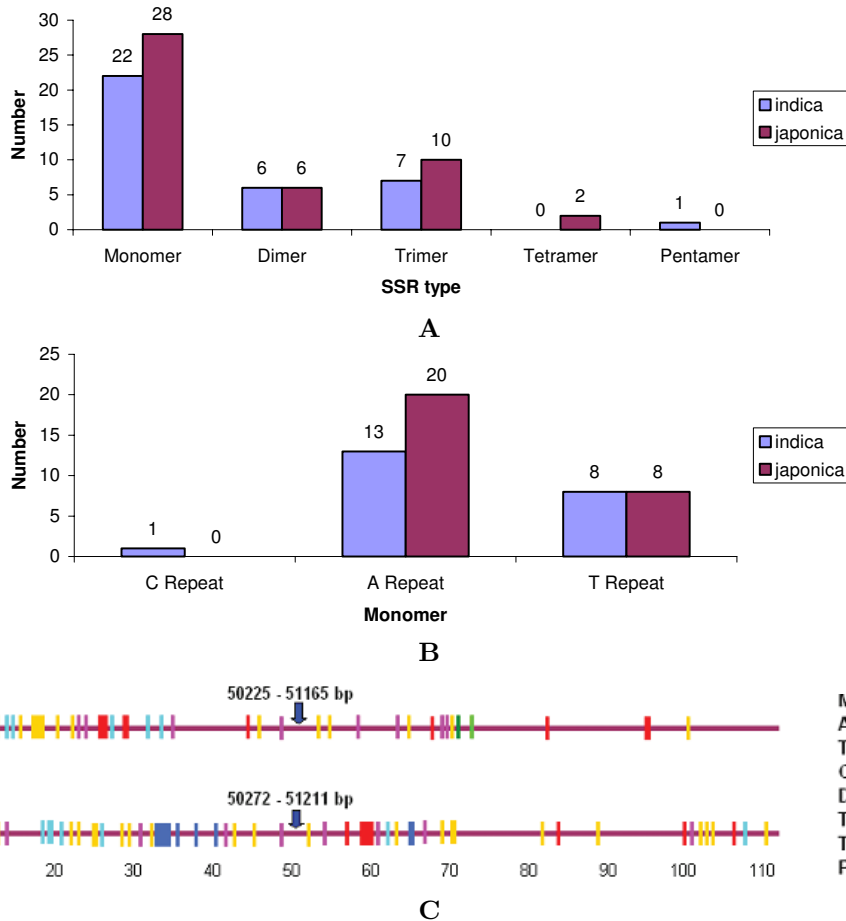


Fig. 4 Distribution of SSRs in the 100 kb region of chromosome 11 of *indica* and *japonica* rice lines. **A.** The number of SSR types present in both sequences. **B.** The number of monomer repeats present in this region. **C.** Physical mapping of SSRs in the 100 kb region of *indica* and *japonica* rice lines. The position of the *Pi-k^h* gene is indicated with the blue arrow. The types of repeats are shown in different colors.

Sequence analysis of *Pi-k^h* alleles isolated from Tetep and Nipponbare

For the analysis and characterization of *Pi-k^h* alleles in both *indica* (Tetep) and *japonica* (Nipponbare) rice lines, motif identification was performed using the motif search tool in EXPASY software (www.expasy.org). Eight types of common motifs were found in the *Pi-k^h* locus of both rice lines

with different number and spatial distribution (Figure 5). Four types of motifs, including tyrosine kinase phosphorylation site, EAR repeat profile, Na/K-ATPase β -chain, and LRR, are in the same number for each in Tetep and Nipponbare alleles, while others are variable in number (Figure 5A). There are 4 N-glycosylation sites and 4 N-myristoylation sites in Tetep allele compared with only 2 for each in Nipponbare allele. Similarly, Tetep allele has 12 casein kinase

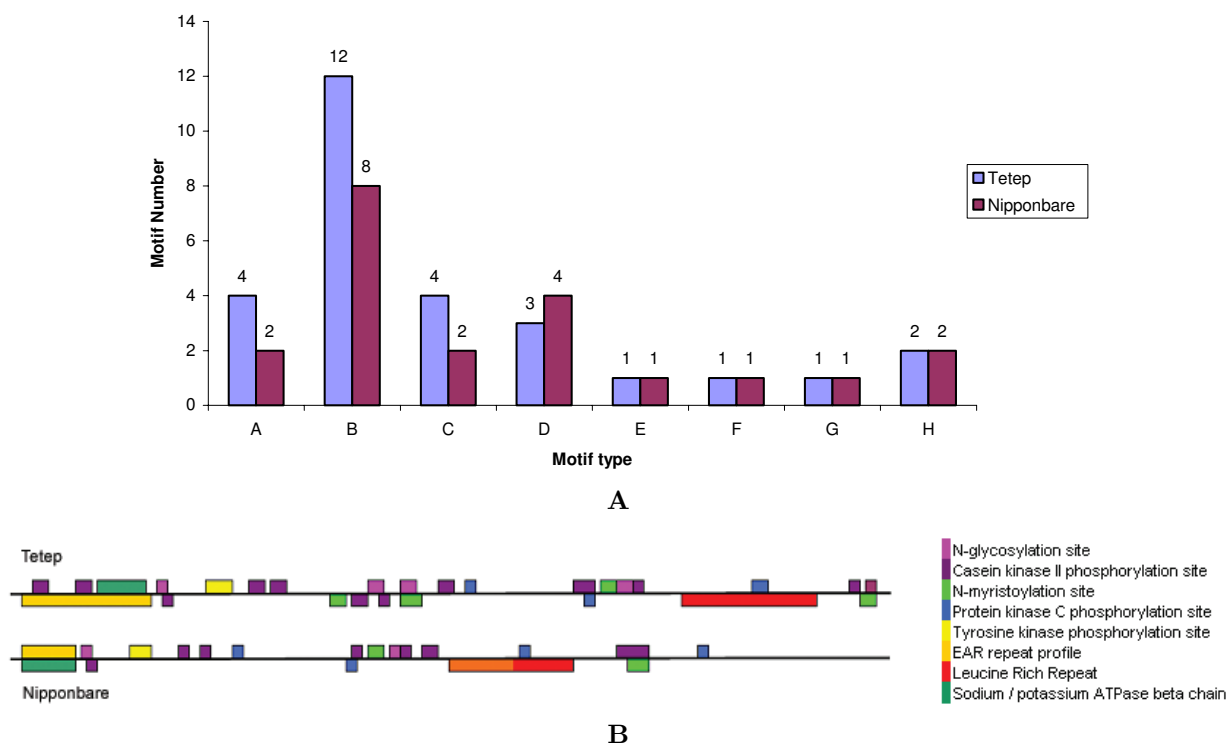


Fig. 5 Analysis of motifs and their physical positions in the *Pi-k^h* gene isolated from *indica* (Tetep) and *japonica* (Nipponbare) sequences. **A.** The number of motifs predicted in *Pi-k^h* alleles of *indica* and *japonica*. A: N-glycosylation site; B: casein kinase II phosphorylation site; C: N-myristoylation site; D: protein kinase C phosphorylation site; E: tyrosine kinase phosphorylation site; F: EAR repeat profile; G: Na/K-ATPase β -chain; H: leucine-rich repeat. **B.** Physical positions of motifs distributed in *Pi-k^h* alleles of *indica* and *japonica* sequences. The types of motifs are shown in different colors.

II phosphorylation sites while Nipponbare allele has only 8. The position of each motif is also different in both alleles as shown in Figure 5B.

Protein kinases and phosphatases are crucial for the activation of early defense responses in plants. As reported by de Vries *et al* (24), the tomato *Pto* gene encodes a functional N-myristoylation motif that is required for signal transduction in *Nicotiana benthamiana*. Similarly, the *Pto*, *Xa21*, and *Rpg1* R genes and several R-mediated signalling components encode kinases, suggesting a major role for phosphorylation in R-specified signalling (25). Phosphorylation-related events and protein kinases participate in the R-gene-mediated pathogen recognition and downstream signalling as established for *Arabidopsis* PBS1 and RIN4 proteins (26, 27). Thus, the difference in blast resistance and susceptibility of the two rice subspecies may be attributed to the different number of motifs and their spatial distribution.

From the present investigation, it can be concluded that in the comparison of structural organization of the *Pi-k^h* locus in both *indica* and *japonica* sequences, macrocolinearity is maintained but micro-

colinearity is incomplete. Both sequences from *indica* and *japonica* are polymorphic for SSRs. Sequence analysis of the specific blast resistant *Pi-k^h* allele of Tetep and the susceptible *Pi-k^h* allele of Nipponbare revealed the differences in the number and distribution of phosphorylation motifs that participate in the R-gene-mediated pathogen recognition and downstream signalling, thus causing the difference in blast resistance and susceptibility of the two subspecies.

Materials and Methods

The rice genome sequence database (www.ncbi.nlm.nih.gov) served as a basic resource during the present investigation. The 1.5 kb fragments of the *Pi-k^h* gene from Tetep and Nipponbare varieties were aligned using the local BLAST tool with *indica* and *japonica* sequences of chromosome 11 on local database (www.ncpcb.org), respectively. The target *Pi-k^h* locus was identified in both cultivars, and 50 kb upstream and 50 kb downstream sequences were extracted along with the desired locus from the se-

quences of both cultivars. Gene prediction in the 100 kb region of both cultivars was performed using the FGENESH tool (www.softbery.com) trained for monocot species. Then BLASTX with the NCBI nr protein database was performed to know the functions of these predicted genes. Multiple alignments of predicted genes were carried out using the ClustalW program (www.align.genome.jp). Gene-wise GC content was determined using the Accelrys gene software (Accelrys Software Inc., San Diego, USA). For the analysis of small variations at local genome level, we used the MISA tool (<http://www.ipk-gatersleben.de/en/>) to identify and recognize the distribution pattern of repeat elements in the 100 kb region of both *indica* and *japonica* subspecies.

The cDNA sequences were compared with the rice pseudomolecule chromosome 11 database (build 3) and the *indica* chromosome 11 database using the local mega BLASTN tool in order to know the physical position of predicted genes. Based on the above information, the number of genes was classified and plotted along a line with respect to their physical positions and directions on chromosome 11 of *indica* and *japonica* type, respectively.

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Authors' contributions

SPK carried out the sequence analysis, BLAST search, and drafted the manuscript. VD participated in the analysis and figure drawing. NKS participated in the design of the study. TRS conceived the study, participated in its design and coordination, and wrote the final manuscript. All authors read and approved the final manuscript.

Competing interests

The authors have declared that no competing interests exist.

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