India is blessed with a great diversity of rice germplasm accounting for about 20% of all the world rice production. Basmati rice cultivars of Indian sub-continent clinched a premium status in global market. Studies on characterization of quality attributes of basmati and non-basmati rice cultivars are mandatory for the improvement in rice quality and to meet the increasingly alternative demands of consumer’s everywhere. Furthermore, in basmati rice trade, the premium price, high quality traits and issues related to adulteration have evoked the need to assess the rice cultivars by effective and reliable methods. Hence, it is essential to assess the genetic diversity and finger printing of rice cultivars by using various tools like physico-chemical, biochemical and molecular. Systematic study and characterization of high quality germplasm is not only important for utilizing the appropriate attribute based donors, but also essential in the present era for protecting the unique rice. The development of DNA markers has opened up new pathways for detecting variations at the molecular level. Among all the DNA markers, simple sequence repeat (SSR) markers provides a rapid, reliable and an efficient approach to estimate the genetic diversity. Though, characterization of different rice cultivars by multivariate approaches is mandatory for the effective rice breeding and quality improvement, yet it is highly essential that these valuable parameters are to be collected, conserved, and properly documented in database to get a quick access about different parameters of any particular cultivar of rice at any time.

In the present investigation, eight indigenous rice cultivars (basmati and non-basmati) have been characterized from physico-chemical and molecular point of view. The thesis has been compiled into five chapters. Chapter one includes the introduction part, in which characteristics of different rice cultivars, their characterization methods
(physico-chemical and molecular), adulteration of basmati rice cultivars and need of database construction to assemble experimental data has been discussed along with the proposed objectives of the study. In the 2nd chapter, study begins with the literature review on indigenous rice cultivars, different physico-chemical methods adopted for characterization of paddy, milled rice grains, cooked rice and rice flour. Furthermore, characterization of rice cultivars by molecular markers has been discussed along with the importance of simple sequence repeat markers. Comparison of physico-chemical methods for genetic diversity assessment and detection of adulteration among basmati and non-basmati rice cultivars has also been discussed. In the last section of review, the importance of rice databases has been summarized.

Materials and methods used to fulfill the objectives of research work are presented with details in 3rd chapter. The seeds of different rice cultivars have been procured from Punjab Agricultural University (PAU), Ludhiana, (India) and Indian Agricultural Research Institute (IARI), Regional Center, Karnal (India) in the form of paddy. Out of these rice cultivars, P 44 and PR 118 were non-basmati and non-aromatic, PS 5 was non-basmati but aromatic, PB 1121, PB 1460, PB 1401 and PB 2 were evolved basmati varieties, whereas Bas 370 is traditional basmati rice variety.

Chapter four includes results and discussion related to physico-chemical, biochemical and molecular characterization of rice cultivars for assessment of genetic divergence among rice cultivars. The effectiveness of different characterization methods for adulteration detection among rice cultivars has also been discussed. In the first section of chapter four, the results related to physical characterization of paddy and milled rice grains have been given and discussed on basis of shape, size, husk percentage, milling turn over, brown rice yield, head rice recovery, 100 grain weight, bulk density and density. Length and breadth of paddy was found to be in the range of
8.87-11.91 mm and 2.41-2.01 mm, whereas milled grains showed the length and breadth in the range of 5.21-8.23 mm and 1.54-1.88 mm, respectively. The rice cultivars gave satisfactory results for hulding, brown yield, milling out and head rice recovery with a range of 22-24, 75-78, 67-69 and 47-54%, respectively. The weight of 100 grains found to be in the range of 2.03-2.25 g for milled rice grains. The bulk density has been observed to be maximum for short grains and minimum for longer ones. Density was found to be reciprocal of bulk density. The value of porosity was found to be in the range of 42-52%. Rice cultivars (P 44 and PR 118) having L/B ratio less than 3.0 have been categorized as medium grain variety. Bas 370 having L/B ratio greater than 3.0 and less than 4.0 has been categorized as long grain variety, whereas PB 1460, PB 1401, PB 2, PB 1121 and PS 5 having L/B more than 4.0 have been categorized as very long grain varieties. Similarly, cultivars having L/B ratio less than 3.0 have been categorized as medium in shape while other varieties has L/B more than 3.0 have been categorized as slender in shape.

In the second section, cooking and eating quality attributes have been studied on basis of cooked kernel length, elongation ratio, water uptake, solid loss, aroma, sensory evaluation and textural profile analysis. The cooking time varies from 14-16 min in different rice cultivars. Cooked kernel length and elongation ratio was higher in basmati cultivars, whereas non-basmati rice grains expand widthwise on cooking. The basmati cultivars showed more water uptake on cooking than non-basmati ones. The highest value for water uptake was found in PB 1121 and lowest in P 44. The solid loss in gruel was less in basmati varieties as compared to non-basmati ones and Bas 370 showed minimum loss in solid gruel. Aroma has been present in basmati and aromatic rice cultivar, while no aroma has been detected in two non-basmati rice cultivars. The sensory evaluation of cooked rice grains quality was estimated in 3 replicates on
account of appearance, stickiness, hardness, aroma and overall acceptability on basis of 9 point scale. The highest score (8.27) for appearance has been given to PB 1401, whereas lowest score was recorded for P 44 (3.45). The presence of rings on surface of cooked basmati rice grains have also been observed and found to be able to differentiate the outer appearance of cooked grains of basmati from non-basmati grains. The stickiness score for cooked basmati rice grains was observed to be lower as compared to non-basmati, which may be due to that long grains generally possess high amylose content and remain separate with a dry and fluffy consistency after cooking. Cooked grains of non-basmati rice cultivars were observed to be soft as compared to basmati rice cultivars by panelists. Basmati rice cultivars have been recorded with excellent overall acceptability in terms of cooking and eating qualities as compared to non-basmati. The values of major textural parameters of cooked rice grains have also been measured by texture analyzer. The values of hardness were observed to be higher in those cultivars having high amylose content and cooked kernel length. In contrast to hardness values, the adhesiveness values were observed to be higher in low amylose cultivars within the range of 829.441 to 989.441 g/sec, whereas basmati cultivars showed lower values in the range of 290.45 to 648.895 g/sec. Differences were also observed in the release of maltose during the in-vitro digestion of cooked rice grains of basmati and non-basmati rice cultivars. The highest release of maltose has been found in P 44 (14.21 mg/g), whereas PB 1401 (8.24 mg/g) showed lowest release of maltose during first 15 min. After 90 min, the highest release of maltose was again observed for P 44 (28.26 mg/g), but the lowest release was found in PB 1121 (23.12 mg/g). There was significant positive and negative correlation found between rice cultivars and their physical, chemical, cooking, textural and pasting parameters by Pearson correlation coefficient and Duncan multiple range test at 5% level of significance.
In the third section, different properties related to physico-chemical, pasting and thermal characteristics of rice flour showed significant variations among rice cultivars. The ash content was more in basmati varieties, whereas non-basmati varieties have higher fat content. Protein content was observed to be in the range of 7-9%, whereas starch content varied from 70-76% among different rice cultivars. There was significant difference found in the amylose content of different cultivars. Basmati cultivars showed intermediate amylose content (22-25%), whereas non-basmati rice grains have low amylose content (16-18%). Varietal distinctions among different rice cultivars has been observed based on alkali spreading value (ASV) test, which is taken as a useful indicator for gelatinization temperature. The ASV value (8) was highest for PB 1121 and lowest value (3.75) for P 44. The gel consistency test differentiated the rice flour into three categories i.e. very flaky with hard gel consistency (length of gel ≤ 40 mm), flaky with medium gel consistency (length of gel, 41- 60 mm), soft rice with soft gel consistency (length of gel, ≥ 61 mm). The values for iodine absorption spectra ($\lambda_{\text{max}}$) and blue value has been ranged between 599-607 nm and 0.16-0.12, respectively. Similarly, the values of swelling power and solubility values were 10.23-14.62 g/g and 8.86-11.23 g/g respectively.

The differences in rheological behavior of basmati and non-basmati have been analyzed by rapid visco analyzer (RVA). Pasting temperature and set back viscosities have been found to be lower in non-basmati. In contrast, peak, hot paste and breakdown viscosities have been found to be lower in basmati. The flour obtained from different rice cultivars showed the significant difference in thermal properties i.e. onset temperature ($T_o$), peak temperature ($T_p$), conclusion temperature ($T_c$) and enthalpy of gelatinization ($\Delta H_{gel}$) by differential scanning calorimeter.
In the **fourth section**, the sodium dodecyl sulphate - polyacrylamide gel electrophoresis (SDS-PAGE) of seed proteins in eight rice cultivars has been carried out to investigate the genetic diversity at total seed protein level. The protein profiling showed distinct polymorphism in electrophoretic banding patterns and led to the detection of polymorphic bands.

The **fifth section** includes the effectiveness of molecular markers (SSR) for assessment of genetic divergence among rice. The 50 SSR markers covering all the rice chromosomes have been selected. Out of 50 SSR markers, 42 markers have been found to be polymorphic in nature. The polymorphism percentage of SSR marker has been found to be 84%. A total of 127 alleles were scored from all the analyzed Indigenous rice cultivars with a range of 1-4. The size of alleles has been recorded in the range of 90-320 (bp). Polymorphism information content value was ranged from 0.195-0.703 with an average of 0.37. Six SSR markers (RM 19, RM 121, RM 133, RM 282, RM 465 and RM 560) showed their potential in differentiating two medium grained non-basmati and non-aromatic rice cultivars. Ten SSR markers (RM 44, RM 84, RM 121, RM 124, RM 128, RM 220, RM 302, RM 310, RM 447, RM 528) have been found to be competent in differentiating basmati and non-basmati rice cultivars. Similarly, ten SSR markers (RM 44, RM 166, RM 210, RM 216, RM 223, RM 253, RM 321, RM 495, RM 506 and RM 522) were found to be able to differentiate between aromatic and non-aromatic rice cultivars. Nineteen SSR markers (RM 16, RM 18, RM 162, RM 174, RM 210, RM 282, RM 310, RM 431, RM 447, RM 465, RM 490, RM 502, RM 506, RM 220, RM 304, RM 516, RM 570, RM 549 and RM 593) showed their potential contribution to estimate genetic divergence within basmati rice cultivars. Six SSR markers (RM 81, RM 84, RM 133, RM 281, RM 441 and RM 560) have been observed
to be efficient in discriminating traditional basmati rice cultivar (Bas 370) from evolved or cross-bed rice cultivars (PB 1121, PB 1460, PB 1401 and PB 2).

Some markers produced rare alleles, which were found to be variety specific i.e. their allele position is different from all the other genotypes for specific SSR marker. These specific markers have been further used for detection of adulteration among rice cultivars. SSR marker i.e. RM 81 has been observed to be specific for PB 2 whereas RM 441 and RM 84 were specific for Bas 370. Similarly, RM 447, RM 16, RM 225 and RM 133 were found to be specific for PB 1460, PB 1121, PS 5 and P 44, respectively.

The sixth section includes the comparative studies on physico-chemical and molecular approaches for detection of adulteration among rice cultivars. The authentication and effectiveness of variety specific SSR markers have been tested by mixing the paddy of two different rice genotypes randomly. It has been revealed that only single allele has been observed in pure sample, whereas two alleles at different positions (based on their specificity for specific marker) have been observed in case of adulterated sample. The important parameters related to quality attributes of rice cultivars i.e. grain length, cooked kernel length, amylose content, gelatinization temperature etc. have been selected to detect adulteration among rice cultivars by physico-chemical approach. It has been observed that physico-chemical attributes are not efficient indicator to detect adulteration among closely related rice cultivars as compared to molecular approach.

In the seventh section, experimental data derived from multivariate (physico-chemical, biochemical and molecular) characterization has been also analyzed by statistical tools for cluster and principal component analysis. The maximum genetic distance has been observed between P 44 and PB 1401, whereas minimum genetic
distance has been observed between Bas 370 and PB 2 on basis of physico-chemical attributes. The maximum similarity has been observed between PB 1401 and PS 5, where minimum similarity has been recorded for PB 2 and P 44 based on cooking, textural and pasting properties. In case of protein polymorphism, the maximum similarity was between PS 5 and PB 2, whereas minimum similarity has been recorded with P 44 and PS 5. In contrast to this, the maximum similarity has been observed in PB 1460 and PB 1401 on basis of molecular characterization. Bas 370 showed maximum diversity from both non-basmati rice cultivars as compared to other basmati cultivars. The correlation derived from physico-chemical and molecular dissimilarity matrix by Mantel’s test has been found to be significant but not very high (r=0.46; p=0.99).

During principal component analysis, all the rice cultivars have been loaded into one component when the principal component analysis has been done on basis of physico-chemical attributes. In contrast to this, the cultivars have been loaded into two components based on molecular characterization.

The last section of chapter 4 includes the designing of an offline database (RicePCMC), which has been constructed for all the experimental data derived from physico-chemical and molecular characterization of different rice cultivars by using Visual Basic 6 software. This database includes the information about various physico-chemical attributes related to paddy seed, milled rice grain and rice flour. The user can derive information about various physico-chemical traits by selecting any keyword from ‘contents of database’ tab and then select any variety from ‘select variety’ tab to get complete information about characteristics of that particular keyword. Similarly, information related to molecular data can also be derived from ‘Molecular Characterization’ tab. Some images, graphs, tables and protocols have been also provided for the easy access of data.
Based on above findings, the results have been summarized and conclusions have been drawn in 5th chapter. Multivariate analysis of rice cultivars gave satisfactory results to compare basmati and non-basmati rice cultivars on basis of physico-chemical and molecular approach. The physico-chemical characterization could be useful indicator of grain quality assessment, whereas, molecular characterization could be useful to confirm classical, morphological and genetic relationship among different cultivars of rice. Moreover, molecular markers are more useful to detect polymorphism among closely related rice genotypes, which are otherwise morphological undistinguishable. Furthermore, adulteration can be better perceived by molecular markers as compared to physico-chemical approach. DNA fingerprinting by novel SSR markers can be helpful to develop protocol to detect the adulteration of Basmati with non-basmati rice. Designing of database (RicePCMC) based on experimental work would be very helpful to get quick access about physico-chemical and molecular attributes of studied rice cultivars in a single click. Moreover, rice based industrial products can be developed on basis of cultivar and consumer choice. Therefore, findings of the present investigation have shown importance both in food and agriculture sector.