# Sedimentation rate in North Indian lakes estimated using $^{137}$Cs and $^{210}$Pb dating techniques

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**In the present study, recent sedimentation rates in Nainital, Bhimtal, Sattal and Naukuchiatal lakes, Uttarakhand; Mansar and Dal lakes, Jammu and Kashmir, and Sagar and Bhopal lakes, Madhya Pradesh have been determined employing $^{210}$Pb and $^{137}$Cs dating techniques. The results indicate comparatively higher sedimentation rates in certain western Himalayan lakes such as Dal, Nainital and Bhimtal than in Sattal, Naukuchiatal and Mansar. The Bhopal lake is getting silted at a higher rate than the Sagar lake. The observed sedimentation pattern reveals that sedimentation rate decreases from near-shore to far-shore and is a minimum at the central and deepest part in lakes of western Himalayas, while Sagar and Bhopal lakes have a different pattern of sedimentation.**

**Keywords:** Dating techniques, Himalayas, lakes, sedimentation rate.

A large number of natural lakes in India are picturesque and most of them are utilized for drinking and irrigation purposes. For example, Nainital, Dal, Sagar and Bhopal lakes supply drinking water to cities of their respective location. However, increasing anthropogenic activities in the past few decades have greatly affected the hydrological regime of the lakes in the country. Consequently, inflow of eroded material and other contaminants from the lake catchments has accelerated the rate of sedimentation and eutrophication process[1–4]. Higher rate of sedimentation has diminished the usefulness of several small lakes and many others are shrinking at an alarming rate. Hence, knowledge of accurate sedimentation rate and its causes are of utmost importance for appropriate management of lakes and future planning. Physico-chemical and biological characteristics of various lakes in the country have been studied in detail, but few studies[5–8] have been carried out to estimate the sedimentation rate and deposition pattern in lakes. Radiometric dating techniques are reliable tools for estimating sedimentation rates in lakes and are used worldwide. Although several radioisotopes are useful in geochronological studies of lake sediments, lead-210 ($^{210}$Pb) and caesium-137 ($^{137}$Cs) isotopes find the largest application[8–12]. Kumar *et al.*[7] have observed large variation in life-expectancy estimation of Nainital lake using dating techniques ($^{137}$Cs and $^{210}$Pb) and bathymetric data (B. M. Hukku *et al.*, unpublished)[13] due to errors associated with the lake sounding data.

In order to understand the recent sedimentation rates and patterns in lakes in North India, such as Nainital, Bhimtal, Naukuchiatal, Sattal, Dal, Mansar, Sagar and Upper Bhopal, an effort has been made in the present study by employing two environmental radioisotopes $^{137}$Cs and $^{210}$Pb.

Nainital, Bhimtal, Naukuchiatal and Sattal lakes, Uttarakhand; Dal and Mansar lakes, Jammu and Kashmir (J&K), and Sagar and Upper Bhopal lakes, Madhya Pradesh (Figure 1) with different geomorphological, geological and climatic conditions were studied for assessing the sedimentation rate. The detailed morphometric features of the lakes are presented in Table 1. Bhimtal, Naukuchiatal and Sattal lakes are located in close proximity of Nainital lake. Physiographically, these lakes are in the southern fringe of the Lesser Himalayas in the Kumaun region, Uttarakhand. Among all the Kumaun lakes, Nainital lake is one of the major tourist destinations. Since the 1980s, increased local population and tourist influx has resulted in a spurt in construction activities and unplanned development of infrastructure facilities at Nainital. This has resulted in rapid degradation of the lake environment.

Dal lake, located in the Lesser Himalayan region of Kashmir valley (J&K) is one of the most attractive freshwater lakes in India. The lake comprises of several subbasins and myriads of inter-connecting channels. It is divided into four major sub-basins, viz. Hazratbal, Bod-dal, Gagribal and Nagin. Mansar is one of the prominent lakes in Siwalik Himalayas of the Jammu region.

The Upper Bhopal lake is the largest freshwater lake in Central India and has been included in the Ramasar Convention for wetlands. It is a typical urban lake, mainly used for providing drinking water to Bhopal city. Sagar lake is situated in the middle of Sagar city and its catchment is made up of the Vindhyan group of rocks of the Bundelkhand region. The lake is divided into two parts,

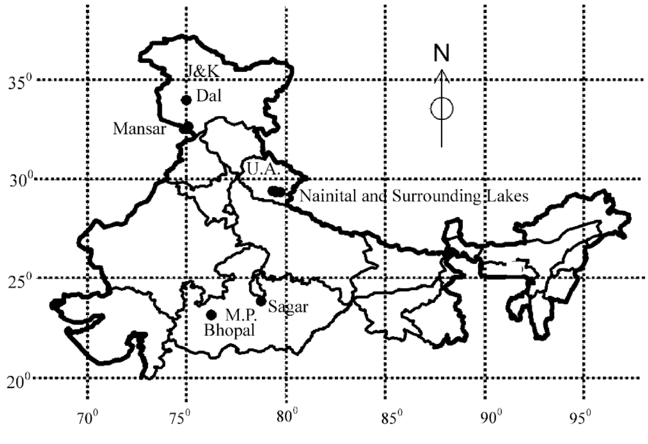

**Figure 1.** Location of lakes in different parts of North India.

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**Table 1.** Morphometric features and catchment characteristics of North Indian lakes

| Parameter | Lake | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Bhopal | Sagar | Bhimtal | Nainital | Naukuchiatal | Sattal | Dal | Mansar |
| Altitude a msl (m) | 508.65 | 517 | 1340 | 1937 | 1300 | 1280 | 1583 | 666 |
| Latitude | 23°10′N | 23°50′N | 29°21′N | 29°24′N | 29°25′N | 29°21′N | 34°N | 32°40′N |
| Longitude | 77°15′E | 78°45′ E | 79°24′E | 79° 28′E | 79°20′E | 79°32′E | 75°E | 75°5′E |
| Surface area (sq. km) | 30.72 | 1.45 | 0.478 | 0.46 | 0.306 | 0.249 | 13.39 | 0.59 |
| Maximum length (m) | 10,600 | 1247 | 1974 | 1400 | 1050 | 1300 | 9117 | 1204 |
| Maximum width (m) | 37,500 | 1207 | 457 | 450 | 675 | 190 | 3588 | 645 |
| Mean depth (m) | 4.0 | 2.69 | 11.5 | 16.2 | 21.89 | 8 | 0.80 | 21 |
| Maximum depth (m) | 9.39 | 5.3 | 25.8 | 27.3 | 42.25 | 20 | 4.07 | 38.25 |
| Total volume ($Mm^3$) | 102 | 3.89 | 4.61 | 8.58 | 7.37 | 0.89 | 12.61 | 12.37 |
| Catchment area (sq. km) | 372 | 18.17 | 10.77 | 4.7 | 3.25 | 5.69 | 337.17 | 1.67 |
| Average rainfall (mm) | 1200 | 1196 | 2143 | 2488 | 2424 | 1500 | 869 | 1500 |
| Summer average temperature (°C) | 32 | 31 | 32 | 20 | 31 | 32 | 22 | 32 |
| Winter average temperature (°C) | 19 | 16 | 11 | 5 | 11 | 20 | 3 | 10 |
| Shape of lake | Not well defined | Not well defined | Kidney-shaped | Crescent-shaped | Suboval | V-shape | Not well defined | Oval |

the main lake and the small lake. There are a number of small inflowing channels through which wastewater is discharged into the lake.

Sediment cores ranging up to 60 cm in length were collected from different parts of the selected lakes using a gravity corer. Four to five of these cores were selected for dating the sediment and as representatives of the sedimentary environment of the lake on the basis of bottom topography and drains entering the lakes. The cores were sliced at every 2 cm intervals and analysed for $^{210}$Pb and $^{137}$Cs activities. The $^{137}$Cs and $^{210}$Pb activities in sediment samples were measured at the Nuclear Hydrology Laboratory, National Institute of Hydrology, Roorkee and the Bhabha Atomic Research Centre, Mumbai.

The $^{137}$Cs activity in each oven-dried section of sample was determined by gamma-ray counting of the oven-dried samples using Hyper Pure Germanium detector coupled with a 4096 multi-channel analyser system. A $^{137}$Cs standard (IAEA-300) having essentially the same geometry and density was used. About 10 g or less (if the weight of sliced sediment section was less than 10 g) weight of the sliced section was subjected to measurement for $^{137}$Cs activity for about 7200–28,800 s to obtain good statistical accuracy. The detection limit for $^{137}$Cs measurement was 0.25 mBq/g and the standard counting error was less than 10% in the core sections.

For $^{210}$Pb dating, the basic radiochemical procedure involves addition of $^{208}$Po/$^{209}$Po as a yield-tracer, leaching the sediment samples with aqua regia. The residual solids were filtered-off and the solution was dried and converted to chloride form with concentrated HCl. The final solution was taken in 0.5 M HCl. Polonium (Po-210) nuclides were then spontaneously deposited on silver planchettes by adding ascorbic acid in the HCl solution prior to alpha counting using Si surface-barrier detectors connected to a multi-channel analyser. Due care was given to get $^{210}$Po in secular equilibrium with $^{210}$Pb. The standard counting error was generally less than 10% in the upper sections of the cores, with slightly higher values at the deeper sections. As the supported $^{210}$Pb results from the decay of $^{226}$Ra present in the sediment core with which it is in equilibrium, $^{226}$Ra activity was determined directly by gamma-ray counting. The $^{210}$Pb activity was also measured in terms of beta radiations using $^{210}$Bi, which is its daughter product with a half-life of ~5 days. The extracted solution containing $^{210}$Pb was allowed to equilibrate for a period of one month, to elapse 4–5 half-lives for getting sufficient $^{210}$Bi in secular equilibrium with $^{210}$Pb activity. The activity of $^{210}$Bi was measured using an Ultra Low level Liquid Scintillation spectrometer. In the present study, constant rate of supply, constant flux and constant supply models have been used for estimating rate of sedimentation.

The $^{137}$Cs profiles of the sediment cores collected from different lakes (Figure 2) closely parallel to its weapon fall-out record pattern, as reported by earlier investigators[14,15], revealing an initial appearance in 1952–53, a subsidiary peak in 1957–58 and a major peak in 1963–64. Major peak of $^{137}$Cs activity has been observed at all sites, while the absence of initial and subsidiary peaks at few sites may be due to the higher rate of sedimentation and shorter length of the collected core. However, organic matter is more important in the complexation of lead and other trace metals in lake water and sediments than absorption on clays of hydrous oxides[16]. On the other hand, the dominant mechanism of ion exchange with the clay component of sediment and soils results in the removal of $^{137}$Cs from the water column[17]. Thus variation of $^{137}$Cs activities is due to varying sedimentation rates, sediment composition, organic matter content and different histories of deposition (Figure 2).

The $^{210}$Pb dating technique has been used to cross-check and authenticate the results obtained using the $^{137}$Cs dating technique in the present study. Estimation of sedimentation rate using $^{137}$Cs dating technique is easier in comparison to $^{210}$Pb dating technique, as the latter requires complicated chemical process for the separation of $^{210}$Pb from sediments. Therefore, only a few representative cores were analysed for $^{210}$Pb activity. The $^{210}$Pb profile of sediment cores belonging to different lakes (Figure 3) shows an approximate exponential decrease in concentration with depth. The sedimentation rates estimated by $^{210}$Pb dating technique are found close to those determined by $^{137}$Cs dating technique (Figure 4). The similarity in rate of sedimentation determined using both techniques indicates no post-depositional redistribution of lake sediments due to sediment slumping, focusing, delayed input and inhomogeneity in sediment composition[17].

The sedimentation rate determined from different sites in Nainital lake varies from 0.60 ± 0.07 to 1.35 ± 0.05 cm/y (Table 2). The rate is higher (1.35 ± 0.05 cm/y) in the intermediate portions located just adjacent to the bank zones, and comparatively moderate (0.70 ± 0.03 cm/y) in steeper bank zones. The deeper portions away from the edge of the lake (central part), receive sediments at lower rate (0.60 ± 0.07 cm/y). In Bhimtal lake, sedimentation rate at the debouching point of a major inflowing drain is highest (1.50 ± 0.03 cm/y), while it is minimum (0.43 ± 0.04 cm/y) in the deepest and central part of the lake. Similarly, the highest rate of sedimentation (0.95 ± 0.04 cm/y) is observed in the eastern part of the Naukuchiatal lake

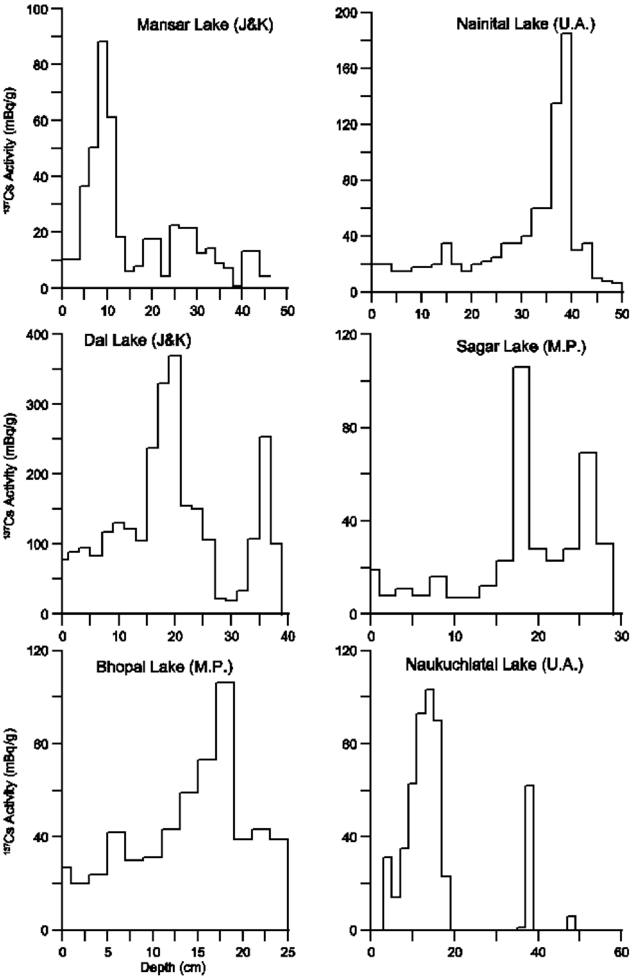

**Figure 2.** $^{137}$Cs activity in selected cores of different lakes.

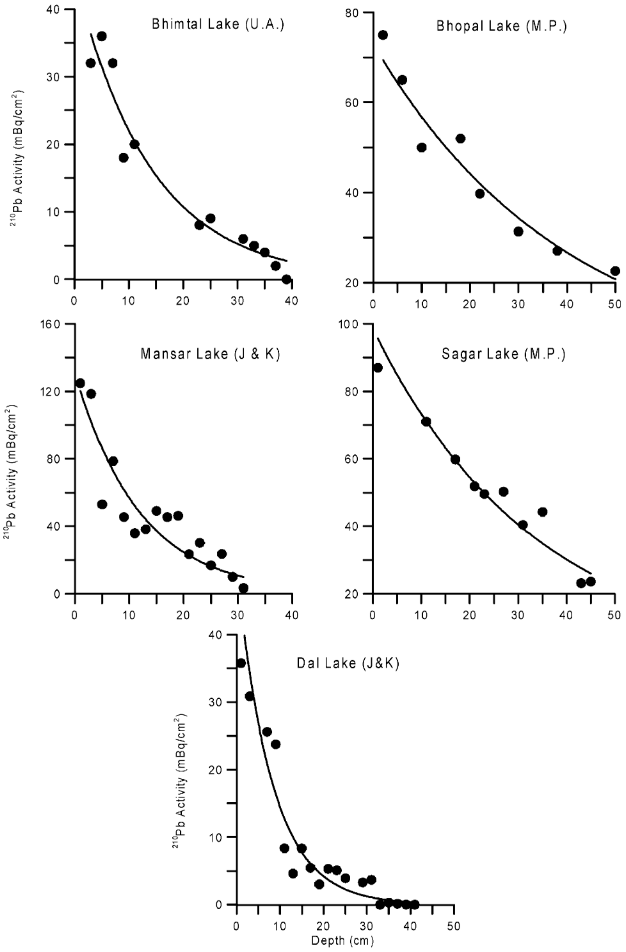

**Figure 3.** $^{210}$Pb activity profiles in selected cores of different lakes.

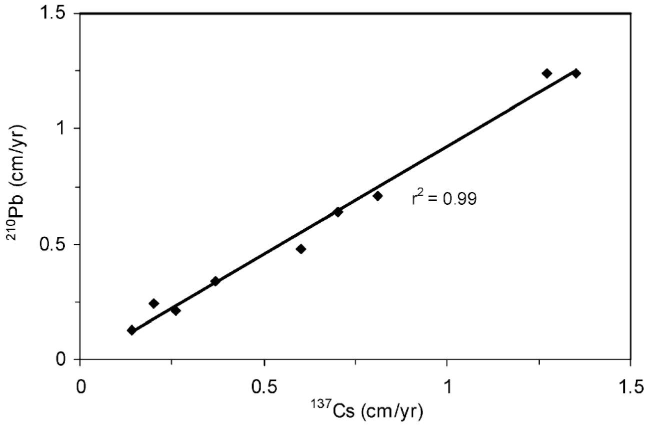

**Figure 4.** Comparison of sedimentation rate determined using $^{137}$Cs and $^{210}$Pb techniques.

**Table 2.** Sedimentation rate determined at different locations in the selected lakes

| | | Sedimentation rate from analysed cores (cm/y) | | | | |
|---|---|---|---|---|---|---|
| Lake | Dating technique | Core 1 | Core 2 | Core 3 | Core 4 | Core 5 |
| Nainital | $^{137}$Cs | 0.60 ± 0.07 | 0.70 ± 0.03 | 1.35 ± 0.05 | | |
| | $^{210}$Pb | 0.48 ± 0.04 | 0.64 ± 0.02 | 1.24 ± 0.04 | | |
| Bhimtal | $^{137}$Cs | ND* | ND* | ND* | 0.90 ± 0.03 | |
| | $^{210}$Pb | 0.43 ± 0.05 | 0.94 ± 0.04 | 1.50 ± 0.05 | ND* | |
| Naukuchiatal | $^{137}$Cs | 0.95 ± 0.04 | 0.59 ± 0.03 | 0.38 ± 0.03 | | |
| | $^{210}$Pb | ND* | ND* | ND* | | |
| Sattal | $^{137}$Cs | 0.54 ± 0.03 | ND* | ND* | ND* | |
| | $^{210}$Pb | ND* | ND* | 0.66 ± 0.05 | 0.81 ± 0.05 | |
| Dal | | | | | | |
| Hazaratbal sub-basin | $^{137}$Cs | 1.13 ± 0.10 | 1.60 ± 0.13 | 0.40 ± 0.05 | 0.66 ± 0.08 | 0.87 ± 0.09 |
| | $^{210}$Pb | ND* | ND* | ND* | ND* | ND* |
| Bod-dal sub-basin | $^{137}$Cs | 0.39 ± 0.05 | 0.61 ± 0.06 | | | |
| | $^{210}$Pb | ND* | ND* | | | |
| Gagribal sub-basin | $^{137}$Cs | 0.22 ± 0.05 | 0.14 ± 0.03 | | | |
| | $^{210}$Pb | ND* | 0.13 ± 0.03 | | | |
| Nagin sub-basin | $^{137}$Cs | 1.06 ± 0.10 | 0.26 ± 0.04 | | | |
| | $^{210}$Pb | ND* | 0.21 ± 0.03 | | | |
| Mansar | $^{137}$Cs | 0.37 ± 0.03 | 0.14 ± 0.03 | 0.20 ± 0.03 | 0.20 ± 0.03 | 0.37 ± 0.03 |
| | $^{210}$Pb | 0.34 ± 0.03 | ND* | ND* | 0.24 ± 0.01 | ND* |
| Bhopal | $^{137}$Cs | ND* | 1.27 ± 0.04 | 0.14 ± 0.03 | 0.51 ± 0.03 | 1.54 ± 0.04 |
| | $^{210}$Pb | 0.58 ± 0.03 | 1.24 ± 0.04 | ND* | ND* | ND* |
| Sagar | $^{137}$Cs | 0.92 ± 0.03 | 0.81 ± 0.03 | 0.42 ± 0.03 | 0.31 ± 0.03 | 1.08 ± 0.03 |
| | $^{210}$Pb | ND* | 0.71 ± 0.02 | ND* | ND* | ND* |

*ND, Not determined.

closer to the debauching point of a major inflow stream. In the northern part of the lake, the rate of sedimentation is about 0.59 ± 0.04 cm/y and at the central portion the rate of sedimentation is lowest (0.38 ± 0.03 cm/y). It is interesting to note that sedimentation rate in Nainital and Bhimtal lakes is higher in comparison to Sattal and Naukuchiatal. This is probably because rocks in the catchments at the Nainital and Bhimtal lakes are more susceptible to weathering, and increasing anthropogenic activities in the catchments have accelerated the erosion and sedimentation rates.

The current sedimentation rate in different sub-basins of Dal lake determined using $^{137}$Cs dating technique varies between 0.14 ± 0.03 and 1.60 ± 0.13 cm/y. In the Hazratbal basin, it varies from 0.40 ± 0.05 to 1.60 ± 0.13 cm/y, in Bod-dal basin from 0.39 ± 0.05 to 0.61 ± 0.06 cm/y, in Gagribal basin from 0.14 ± 0.03 to 0.22 ± 0.05 cm/y and in Nagin basin from 0.26 ± 0.04 to 1.06 ± 0.10 cm/y (Table 2). The results show that the rate of sedimentation is comparatively higher in Hazaratbal sub-basin of Dal lake. In Mansar lake, sedimentation rate varies from 0.14 ± 0.03 to 0.37 ± 0.03 cm/y. Minimum rate of sedimentation is in the central and deepest part of the lake, while the maximum has been observed closer to the debauching point of an inflow stream, similar to the Kumaun lakes. This is also in agreement that sediment distribution and sedimentary processes in a lake depend on the water-inflow velocity, gravitational forces and other factors such as bottom slope[18]. The results reveal that sedimentation pattern within all the western Himalayan lakes is more or less similar. Therefore, the lake can be subdivided in different zones on the basis of spatial variation of sedimentation rates within the lakes.

The sedimentation rate in Sagar lake varies from 0.31 ± 0.03 to 1.08 ± 0.03 cm/y (Table 2). Higher rate of sedimentation is observed in the portion of the lake, where it receives the inflow from Kanera canal and eroded materials from upland areas adjacent to the lake. The next higher rate of sedimentation is found near the sluice gate. In case of Upper Bhopal lake, sedimentation rate varies from 0.21 ± 0.03 to 1.27 ± 0.05 cm/y. The results reveal that the rate of sedimentation in the upstream portion of Upper Bhopal lake is higher due to silt load carried out by Kolans stream. The rate of sedimentation decreases from the upper to the lower part of the lake. In these lakes, maximum rate of sedimentation is found near the entry point of the main drain and also in some other parts. This variation in sedimentation rate may be due to different types of activities carried out with different intensities in the lake catchments.

The sedimentation rate in the Lesser Himalayan lakes of Kumaun region varies between 0.38 ± 0.03 and 1.50 ± 0.03 cm/y; in the Lesser and Siwalik Himalayan lakes between 0.14 ± 0.03 and 1.60 ± 0.13 cm/y, and in the Central India lakes between 0.21 ± 0.03 and 1.27 ± 0.05 cm/y. This indicates that Himalayan lakes are getting silted at a higher rate than the Central India lakes. The Himalayan lakes show a distinguished depositional pattern, i.e. sedimentation rate decreases from near-shore to the deepest portion (central part) of the lakes. In case of Central India lakes, maximum rate of sedimentation is found near the entry point of the main drain, but overall there is no resemblance in sedimentation pattern of these lakes.

The study reveals that $^{210}$Pb and $^{137}$Cs dating techniques are useful to determine recent sediment accumulation rates and patterns in lakes. As the $^{137}$Cs dating technique provides the sedimentation rate based on the depths recorded in 1963–64, this technique is a powerful tool for determining the sedimentation rate and pattern in water bodies, particularly in Himalayan lakes where anthropogenic activities have accelerated the sedimentation rate in the past 50 years.

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# Sustained activities of carbon metabolizing enzymes determine seed size in *Vigna radiata* (mungbean)

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**The activities of enzymes involved in the control of carbon flux of two genotypes of *Vigna radiata* (mungbean) differing in seed weight were compared in order to elucidate the factors controlling seed size and to analyse the relationship between seed development and metabolism. Biomass accumulation in 'large' seeds was maintained till maturity. However in 'small' seeds, maximum accumulation was achieved approximately five days earlier. Sucrose synthase (SuSy, EC 2.4.1.13) activity for small seeds increased sharply from 10 to 15 days after flowering (DAF) and then declined till maturity. However in large seeds, the activity increased more slowly but rapidly after 15 DAF till maturity. Lesser activity of SuSy in podwall of large genotype indicated more assimilate channelling into the seeds, a much stronger sink for sucrolysis. Enzymes UDP-glucose and ADP-glucose pyrophosphorylase (UGPase, EC 2.7.7.9 and AGPase, EC 2.7.7.27) corresponded to the pattern of SuSy in large seeds, showing coordination between these enzymes regulating carbon**

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