

after each consecutive year respectively. For the given aquifer characteristics, in 6 years the aquifer water pollution drops to about 10% of the original. In the absence of diffusion terms, the change in the slope of the profiles is an artifact due to a finite chosen value of the number of sublayers  $N$  and  $dz$ .

Implementation of such a scheme requires the following:

(1) An intervention in public policy that for towns and cities, all nearby aquifer catchments be declared vital state assets and be protected. To maintain water quality, the entire catchment area of the aquifer has to be protected – this area must fall outside the urbanized zone.

(2) Cooperatives or water companies to step in and manage drinking water services derived from these aquifers. This is highly profitable economically. The land we are talking about is strictly agricultural with its land use fixed and thus cannot be valued as regular real estate. The main cost is the remuneration to farmers who own the land. A remuneration of even four times the maximum agricultural income from the land, makes hardly a dent in the earnings from the service.

(3) A period of 5–7 years for such quality drinking water sources to be operational.

The main advantages of the process are that there is no use of chemical technology and no toxic waste is produced. It uses a natural percolation process for rainwater to come into the aquifer. Foresting the catchment provides good foliage and humus to supplement water retentivity. The roots of the trees consolidate the soil and provide additional natural filtration to enhance the quality of the water. Run-off and erosion are reduced, thereby increasing the groundwater recharge. Hence recharge estimates in the examples are lower bounds. Natural, green wooded area, which is less than 10% of the city area, is required for this purpose. This falls neatly into the urban planning norm of having about 20% green area in a city. Due to it being a natural process, the main costs involve the remuneration given to farmers whose land has been converted to wooded area. Even if the estimated remuneration is about five times the annual income of the farmer from the said land, the cost of generating pure drinking water of high quality is extremely cost effective compared to the ecological and financial costs involved in bottling and transporting water from remote, unpolluted wilderness sources, such as mountain streams, or purification of water by chemical or osmotic process.

At present, it is estimated that almost half the world's population has no access to good drinking water. This is considered an essential cause of several debilitating water borne diseases. This is the primary component in preventable human mortality. At a cost of US\$ 0.02/l, the annual cost of providing 2 litres of good drinking water per day per person works out to approximately US\$ 15 billion for every billion people. The UNEP experts have estimated<sup>8</sup> the cost of providing safe drinking water and

proper sanitation to everyone in the world by 2025 at US\$ 180 billion. Needless to say, the present cost in terms of health is much more. Providing a simple, natural, low cost, local and self-sustaining solution to the drinking water problem is vital. Organic water will do just that.

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## Role of sorption properties and water status in control of seed longevity patterns

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**The longevity behaviour of two oil-rich seeds, soybean (*Glycine max* (L.) Merrill) and safflower (*Carthamus tinctorius*) were compared using their water absorption properties. The nuclear magnetic resonance characterization of water in different moisture equilibrated seeds was studied in relation to the viability of both the crops. The component analysis of the transverse relaxation showed the presence of different components in soybean and safflower at corresponding relative humidity. Even though a more deleterious third component (structurally bound water) was observed at higher relative humidity in both the crops, the dif-**

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ference in its relative population clearly shows the linkage between molecular mobility of water and longevity. The dehydration and rehydration isotherms studied under the ambient relative humidity pointed towards the possible development of extra polar sites in soybean along with the varied behaviour of these two seeds under fluctuating relative humidity conditions, which is a common phenomenon in ambient storage conditions. Thus, the present study emphasizes that the sorption properties along with the structural partitioning of the seed water, which are influenced by the chemical composition of seed, play an important role in the longevity behaviour of seeds besides other factors like lipid peroxidation.

**Keywords:** Dehydration–rehydration isotherms, nuclear magnetic resonance, safflower, seed deterioration, soybean.

THE deterioration of seeds, resulting in the loss of vigour and viability is inexorable<sup>1</sup>. Storage temperature and seed moisture content are the most important factors controlling seed longevity. The physical state of water in the seeds during storage or prior to pre-germination imbibition strongly influences the staying quality and success of subsequent germination. The importance of different properties of water in determining seed longevity has also been recognized<sup>2</sup>. Deteriorative reactions proceed more rapidly if the moisture content is high in the seed, and consequently the moisture status would constitute a threat to longevity. Water also acts as a solvent for most of the biochemical reactions, and hence loss of this solvent will reduce the diffusion rate of solute substances to an active site and thereby reduce the pace of deleterious metabolic activities. With decreasing water content the molecular mobility reaches a minimum, thereby increasing the seed longevity<sup>3</sup>.

Nuclear magnetic resonance (NMR) spectroscopy is a non-destructive method used to study the water status in different biological systems. Seed water status refers to the measurement of water properties in relation to the seed, and is used in a relative sense<sup>4</sup>. Water status can be described either by measuring the moisture levels of tissue water content or by measuring the energy status of cell water. Moisture levels of seeds are an important determinant of seed longevity<sup>5</sup>. The longitudinal and transverse components of NMR relaxation times of protons can be used in understanding both the compartmentation and transport of water in tissues of plants as well as seeds<sup>6</sup>. The differential mobility of water molecules can be determined using the difference in their relaxation rates, which also enables us to calculate their relative amounts in the tissue<sup>7–9</sup>. The NMR relaxation times have been used for the characterization of seed water in different species<sup>9–11</sup>. The water in dry seeds, mostly in the bound state, is structured and non-freezable<sup>12</sup>, but the storage quality of seeds is largely dependent on free or bulk water which fluctuates with the relative humidity of the surrounding air<sup>8</sup>.

The difference in the moisture sorption patterns and the thermodynamic status of water in seeds which controls the seed deterioration reactions<sup>1,4</sup>, may differ considerably between seeds of different species. The chemical compositions of seeds appear to play an important role in determining the general storability behaviour of seeds of different species, though information on comparative performance of seeds having different chemical composition is scanty. With lipid peroxidation playing a critical role in seed deterioration, seeds containing high levels of polyunsaturated fatty acids are expected to exhibit poorer longevity<sup>13,14</sup>. In the present study two oil-rich seeds, soybean and safflower, having different storability were compared with an objective of an in-depth understanding of the influence of water sorption properties on the deterioration patterns.

For the present study, seeds of soybean (*Glycine max* (L.) Merrill) cv JS 335 and safflower (*Carthamus tinctorius*) cv A-1 were obtained within three months of harvest from the National Research Centre for Soybean, Indore, and University of Agricultural Sciences, Dharwad respectively. The physically pure seeds were taken and the protein, carbohydrate and oil contents were estimated according to standard procedures<sup>15</sup>, for an overview of the chemical composition of these two crop seeds. The seeds were packed in polythene bags (700 gauge) under ambient conditions of storage, with an average temperature of  $25 \pm 2^\circ\text{C}$  (max  $40^\circ\text{C}$  and min  $13^\circ\text{C}$ ) and average relative humidity (RH) of  $65 \pm 2\%$  (max 93% and min 14%) up to one year.

The germination percentage was measured for both the crop seeds using the between-paper method, in four replications of 50 seeds each at  $25^\circ\text{C}$  following the standard ISTA method<sup>16</sup>. The germination test was conducted initially and at three months interval up to one year under ambient storage conditions.

Three sets of soybean and safflower seeds having an initial moisture content of 10.5 and 6.8% respectively, were weighed accurately to 30 g each. Seeds were taken in perforated muslin bags and equilibrated over saturated salt solutions at  $25^\circ\text{C}$  in air-tight desiccators. RH of 30, 50, 70 and 90 was obtained with the saturated salt solutions<sup>17,18</sup>. Seeds incubated for equilibration were weighed daily until constant weight was attained on four successive weightings (at which point the seeds seemed to be equilibrated), and absorption curves were drawn with equilibrium moisture content on the Y-axis and RH on the X-axis. The seed moisture content and spin–spin relaxation time ( $T_2$ ) were measured as follows.

Seed moisture content was determined in three replicates by oven-drying the seeds at  $103^\circ\text{C}$  for 17 h to constant weight<sup>16</sup>. The moisture content (%) was calculated as  $((W_1 - W_2)/W_1) \times 100$ , where  $W_1$  is the initial weight of the seed (g) and  $W_2$  the final weight of the seed after drying (g).

NMR relaxation times were measured in six replications on moisture-equilibrated seeds. The seeds were

placed in 10 mm diameter glass tubes with a column height of about 2 cm and corked immediately to avoid exchange of moisture with the surrounding atmosphere. The tubes were then placed in the probe of Bruker NMS 120 pulsed NMR spectrophotometer according to the procedure described by Krishnan<sup>8</sup>.

Seed water spin-spin relaxation time ( $T_2$ ) was measured using Bruker NMS 120 minispec NMR analyser at 20 MHz and ambient temperature of 25°C, by studying the decay of the transverse component of magnetization using the Carr-Purcell Meiboom Gill method<sup>19</sup>. Seed materials were tested with the following settings. Number of datapoints, 150; pulse separation, 0.5 ms; dummy echo, 3, and number of scans, 4. The  $T_2$  values were determined by measuring the exponential decay of the signal and the in-built program of the instrument was used to calculate this. According to Ratkovic<sup>10</sup>, three different water components can be identified in seed systems using spin-spin relaxation time. The three components of  $T_2$  ( $T_{2a}$ ,  $T_{2b}$  and  $T_{2c}$ ) are given by the equation

$$M_t = C_a[\exp(-t/T_{2a})] + C_b[\exp(-t/T_{2b})] + C_c[\exp(-t/T_{2c})],$$

where  $C_a$ ,  $C_b$  and  $C_c$  are related to the relative populations of the three components<sup>20,21</sup>. The components of spin-spin relaxation were analysed using least square fit analysis in the region of specified limits using a computer program<sup>22</sup>.

The procedure followed to estimate the hysteresis loop through moisture absorption and desorption isotherms was modified after Moharir and Nam Prakash<sup>23</sup>. Two replications of 100 seeds each of soybean and safflower were weighed separately and hydrated in a closed desiccator at 100% RH and 27°C for conditioning or hydration of seeds. The increase in weight was recorded after 2, 4, 6, 24, 26, 28, 30 and 48 h. The hydrated seeds were then kept in an open petri plate of 6" diameter and left to be dried at 27°C and ambient RH (60 ± 2%). The decrease in weight was recorded after 2, 4, 6, 24, 26, 28, 30 and 48 h. This is termed as the dehydration cycle. The dehydrated seeds were again transferred to 100% RH at 27°C and their weight was recorded at intervals as before. This is the rehydration cycle. By plotting the dehydration and rehydration values at each interval, the dehydration-rehydration curve was drawn.

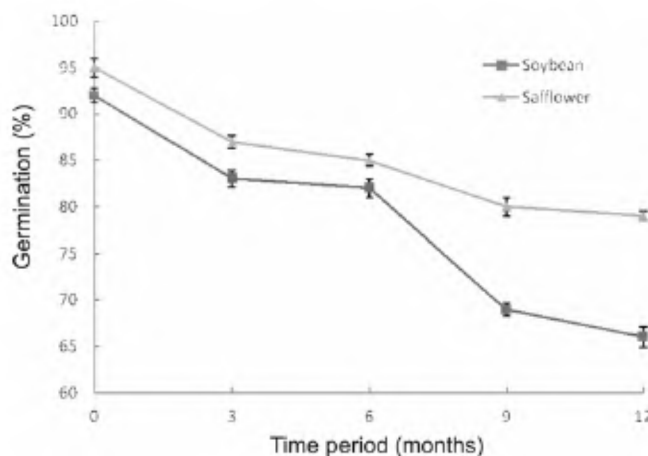
The major chemical constituents of the seed, i.e. carbohydrates, proteins and lipids were determined in two replications of 10 g seed of soybean and safflower at a moisture content of 9.39 and 7.49% respectively. The safflower seed had high carbohydrate content of 48% followed by 38% oil content and 10% protein content, whereas the soybean seed had 37% carbohydrates, 19% oil and 39% protein. Thus, even though both are rich in oil their chemical composition was different, with soybean being a protein oil-rich and safflower a starch oil-

rich seed. The germination was recorded at three months interval up to one year under ambient laboratory conditions with an average temperature of 25 ± 2°C (max 40°C and min 13°C), and average RH of 65 ± 2% (max 93% and min 14%). A gradual decline was observed during this period, with germination falling from 92–95 to 66–79% in soybean and safflower respectively. Decline in germination was rapid in soybean beyond 6 months of storage which coincided with higher RH and temperature conditions, whereas it was steady and gradual in safflower throughout (Figure 1).

The equilibrium moisture content was determined at 30, 50, 70 and 90% RH at 25°C in soybean and safflower seeds having initial moisture content of 6.8 and 5.4% respectively. The equilibrium moisture content (EMC) values attained by both the seeds were almost equal up to 50% RH; at higher RH levels the soybean seeds attained higher EMC, which was almost 1.5 times higher than that of safflower. The absorption curves were of sigmoidal type for both the species, albeit a steeper slope was observed for soybean (Figure 2). Total increase in moisture content with respect to initial moisture content was 3.5 times in soybean and 2.3 times in safflower.

The spin-spin relaxation time  $T_2$  (ms) of seeds equilibrated at different RH levels showed a progressive decrease with increase in EMC values (Table 1). The  $T_2$  values varied from 84 to 65 ms in soybean, as against 114 to 103 ms in safflower. At a given RH or at similar EMCs (up to 50% RH), the spin-spin relaxation times were higher for safflower seeds than for soybean seeds.

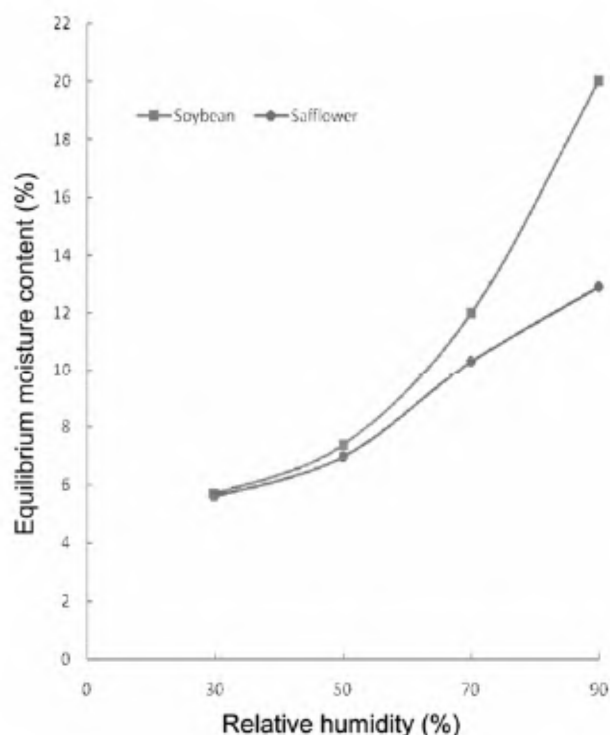
$T_2$  was further partitioned to determine different components of seed water and their relative populations at increasing levels of RH. Initially only two components were observed up to 70% RH. At 90% RH, three components were found in both species. The component with long relaxation time ( $T_{2a}$ ) increased with increase in RH



**Figure 1.** Germination (%) at 25°C of soybean and safflower seeds stored under ambient storage conditions of average temperature 25 ± 2°C (max 40°C and min 13°C) and an average relative humidity of 65 ± 2% for one year period.

up to 70% (Table 2). The relative populations of two components ( $T_{2a}$  and  $T_{2b}$ ) were not altered with increase in RH (70%) but at 90% RH there was an alteration in the populations in both soybean and safflower seeds. Interestingly, the proportion of the slow relaxing component was higher in safflower at any given RH level (Figure 3).

The moisture adsorption and desorption patterns of soybean and safflower were determined on the basis of dehydration and rehydration behaviours under vapour-saturated atmospheres. The moisture content of soybean and safflower seeds reached 14.3 and 18.8% after conditioning for 48 h at 100% RH and 27°C. These were then subjected to air-drying for different periods. At the end of the dehydration cycle of 48 h at ambient RH and temperature, the moisture content of these two kinds of seeds was found to be 10.6 and 5.8% respectively. A second cycle of rehydration at 100% moisture vapour-saturated condi-



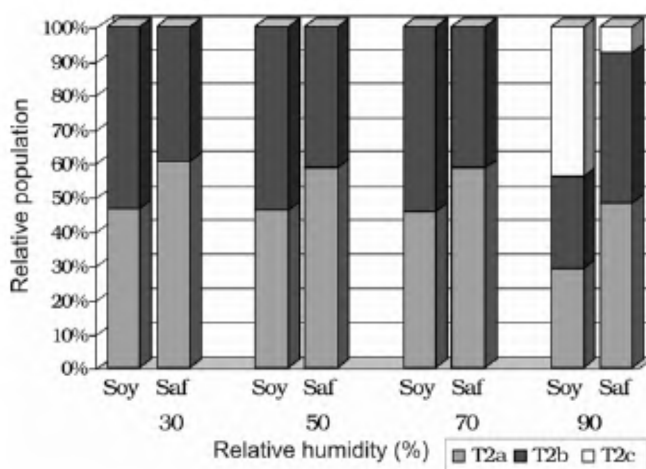
**Figure 2.** Absorption equilibrium moisture content curves of soybean and safflower seeds at different RH levels at 25°C.

**Table 1.** Equilibrium moisture content (EMC) and spin-spin relaxation times ( $T_2$ ) of soybean and safflower seeds at different relative humidity (RH) levels

RH (%)	Soybean		Safflower	
	$T_2$ (ms)	EMC (%)	$T_2$ (ms)	EMC (%)
30	$84 \pm 0.9$	5.7	$114 \pm 2$	5.60
50	$82 \pm 1$	7.4	$111 \pm 2$	6.96
70	$80 \pm 1$	11.98	$106 \pm 2$	10.28
90	$65 \pm 2$	20	$103 \pm 2$	12.92

tion resulted in an increase in seed moisture content to 17.5 and 18.4% in soybean and safflower seeds respectively. Thus, after the rehydration cycle the safflower seeds attained almost the same moisture content as that recorded in first hydration cycle, whereas soybean seeds gained more moisture upon rehydration. The difference in moisture content attained at saturation after the first (hydration) and second (rehydration) cycles of moisture vapour conditioning was 3.2% in soybean and 0.4% in safflower. Thus, even though the difference in moisture absorption upon rehydration following dehydration was more in soybean, interestingly, there was a larger area under the hysteresis loop in the case of safflower (Figure 4).

The pattern of loss of germination under ambient conditions of storage was similar in the two species up to 6 months of storage, which coincides with the low moisture content of soybean and safflower seeds (7.83 and 6.94% respectively) during this period. After 9 months of storage a marked difference was noted in the moisture content and germination of soybean and safflower seeds, which was even more pronounced after 12 months of storage, by which time the moisture content and germination of soybean were 11.13 and 66% respectively, compared to 8.96 and 79% in safflower. Survival of seeds under ambient storage depends more on their moisture content than on any other factor<sup>24</sup>. This has been attributed to the notion that physiological reactions, deleterious to seed longevity, increase with the increase in seed moisture content, in addition to influencing the incidence and survival of storage pathogens. In the present study, a clear-cut difference was observed in soybean and safflower seeds with respect to germination (Figure 1), patterns of moisture sorption, moisture equilibrium (Figure 2) and physical status of seed water, determined by partitioning of different components of seed water at different levels of relative humidity, and retention and release of moisture by the seed in a fluctuating environment (Figure 4).

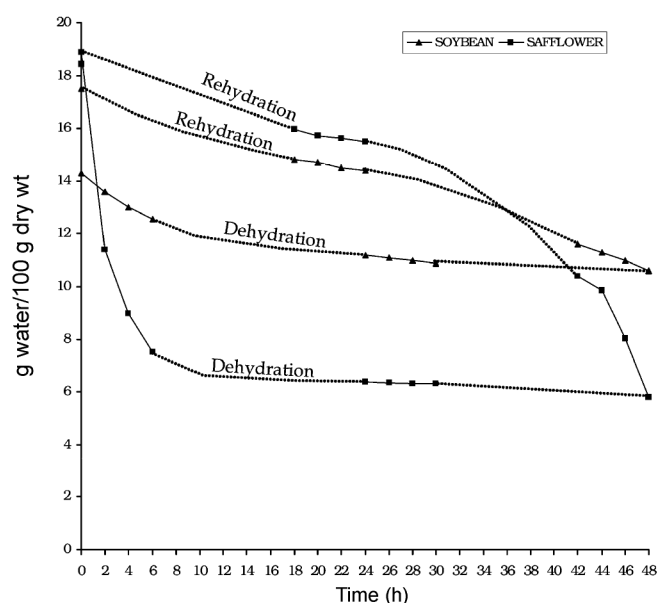


**Figure 3.** Relative population of  $T_2$  components ( $T_{2a}$  represents extra-cellular free water,  $T_{2b}$  cytoplasmic bulk water and  $T_{2c}$  structurally bound water) at different RH levels in soybean (Soy) and safflower (Saf) seeds.

**Table 2.** Different components of spin-spin relaxation time ( $T_2$ ) of soybean and safflower seeds at different RH levels

RH (%)	$T_{2a}$ (ms)		$T_{2b}$ (ms)		$T_{2c}$ (ms)	
	Soybean	Safflower	Soybean	Safflower	Soybean	Safflower
30	575.2	530.4	46.2	50.7	—	—
50	598.2	530.6	47.7	50.8	—	—
70	709.4	555.3	50.6	51.0	—	—
90	650.4	726.8	47.3	57.2	3.15	1.7

$T_{2a}$ ,  $T_{2b}$ ,  $T_{2c}$  are three different components of  $T_2$  ( $T_{2a}$  represents extracellular free water,  $T_{2b}$  cytoplasmic bulk water and  $T_{2c}$  structurally bound water).

**Figure 4.** Hysteresis loop of dehydration and rehydration cycles measured as gram water/100 g dry wt of seeds over a time period in soybean and safflower seeds.

The pattern of moisture absorption by the soybean and safflower seeds was similar in the two crops up to 50% RH, but it shot up dramatically in soybean at RH of 70% and above, whereas the rise remained slow and gradual in safflower, resulting in a difference of about 7% in the EMC at 90% RH between the two crops (Figure 2). The higher absorption values in soybean can be attributed to higher amount of macromolecules other than lipids, viz. proteins and starch, which are hygroscopic in nature<sup>24</sup>. Walters<sup>1</sup> compared the results from studies made by different workers on water-sorption isotherms of seeds of a number of crop species having different chemical compositions, viz. pea, soybean, lettuce, peanut and sunflower, and noted that at similar levels of RH protein oil-rich seeds of soybean achieved a significantly higher EMC compared to that of lettuce, peanut and sunflower respectively, whereas high protein, low oil pea seed attained EMC even higher than that of soybean. Walters inferred that the relative hygroscopicity of the major seed constituents, i.e. proteins, starch and lipids, plays a major

role in their sorption behaviour. The present study has clearly established this point under identical conditions of RH and temperature by examining the pattern of water sorption in two different crop species, i.e. soybean and safflower. Results of the present study also indicate that more than the absolute moisture content attained by the seed, it is the proportion of various seed water components that plays a greater role in seed deterioration.  $T_2$ , which represents the mobility of water molecules within the seed, is modified by seed structure and chemical constituents of its tissues. The  $T_2$  values are influenced by many factors such as proton relaxation, cell size and structure, chemical composition and viscosity of cellular constituents, and their magnetic susceptibility<sup>9</sup>. The delicate balance between the total water content, macroscopic and microscopic distribution of water in different sites, macromolecule–water interactions and exchange between different water phases (liquid, glass or gaseous) determines the NMR relaxation times of seed tissue water. Soybean seed with its high protein + carbohydrate content showed a rapid moisture uptake at higher RH, and a slow release upon dehydration, which probably was due to the development of additional polar sites of attachment of water molecules in it. At high moisture content, changes will occur in the properties of macromolecular structure and hence, in the status of water in their vicinity<sup>25</sup>. These irreversible macromolecular structural changes can advance the process of deterioration, resulting in the non-viability of the seed. In the present study,  $T_2$  decreased with increase in moisture content at different RH levels. The reduction in  $T_2$  could be due to the increase in interaction between water and the macromolecules in the tissues<sup>26</sup>. Further,  $T_2$  was partitioned into two fractions based on the relaxation time up to 70% RH. The slow relaxing fraction with long relaxation time was identified as extracellular free water, since the macromolecular concentration was comparatively less in the extracellular space of the tissues<sup>8,10</sup>. The fast relaxing  $T_2$  fraction was generally identified as intracellular bulk water due to its short relaxation time<sup>20</sup>. At 90% RH, with the increase in EMC level, interestingly, a third component,  $T_{2c}$ , appeared in both soybean and safflower seeds. Based on its shortest relaxation time, it was identified as macro-

molecular-bound water. This kind of tissue water partitioning was earlier followed by many workers<sup>9,20,21</sup>. In the present study, it was significant to note that a larger proportion of seed water content in soybean remained as cytoplasmic bulk water, whereas in safflower the major proportion of total seed water content remained as extracellular free water, which could be rapidly released upon dehydration. At RH above 70%, the EMC attained by soybean seed was nearly 65% higher than that of safflower, of which nearly more than 30% was found to be in the bound form as against less than 10% in safflower (Figure 3). This is of a significant relevance during deterioration, as the nature and kinetics of chemical reactions are greatly influenced by the state of water, rather than the absolute water content within the seed<sup>1</sup>.

The phenomenon of hysteresis, which occurs in absorptive substances with a high degree of structural rigidity, was examined on the desorption and reabsorption patterns of the two species. Due to its rapid dehydration in the initial stages and virtual lack of any moisture gain (over the initial level) during rehydration, safflower seeds showed a larger hysteresis loop than soybean (Figure 4). The faster dehydration seen in safflower could possibly be the result of a larger proportion of the seed water content remaining as extracellular free water than the cytoplasmic bulk water as found by NMR  $T_2$  partitioning and needs further confirmation. The gain of excess moisture by soybean seeds, upon rehydration may be due to appearance of additional polar sites for bound water at higher RH as a result of tissue swelling<sup>27</sup>. The ability to readily release moisture at a lower external RH and gain slowly at a higher one, as in the case of safflower, is a property favourable for better seed longevity. Discrete changes in the proportion of seed water also suggested that seed ageing reactions were regulated by the thermodynamic status of water in the seeds<sup>12,28</sup>.

Thus differential absorption and desorption patterns of soybean and safflower seeds, coupled with differential partitioning of water components in the two species due to their characteristic chemical constituents, are identified as one of the key factors contributing towards better longevity of safflower compared to soybean seeds under fluctuating environmental conditions (temperature and RH), particularly at RH above 70%.

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## Species and site effects on leaf traits of woody vegetation in a dry tropical environment

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**Selected leaf traits (leaf area, leaf weight, specific leaf area and chlorophyll content) from eight woody species at four sites in the dry tropical Vindhyan forest were investigated in order to assess their variability across species and site conditions. The morphological traits such as leaf area and leaf weight were more variable than biochemical traits such as chlorophyll content. There was significant effect of species and site, and the site × species interaction was also significant for all traits. These traits were correlated except for specific leaf area, which was independent of leaf area. A combination of traits could discriminate between the sites. Between-site variability in leaf traits was smaller (1.3–1.5-fold) than between-species variability (1.7–12.5 fold). The larger inter-species variability reflects marked genotypic variability in the leaf traits, while the smaller between-site variability reflects phenotypic plasticity leading to adaptation to site conditions.**

**Keywords:** Dry tropical forest, inter-species variability, leaf traits, woody species.

LEAF traits are often cited as the principal traits to relate plant resource use, biomass and ecosystem functioning<sup>1–4</sup>. In addition, these traits are easy to quantify and convenient to compare among a large number of plant species. Leaf traits may be divided into two groups: functional traits and structural traits. Functional traits reflect the index of plant growth and metabolism. On the other hand, structural traits are indexes of biological characteristics of different plant species, and reflect the adaptation strategies

of plants to the environment. These traits, among others, include leaf area, leaf dry weight, specific leaf area (SLA) and chlorophyll content. SLA is the ratio of leaf area to leaf dry weight and, being strongly correlated with relative growth rate, maximum rate of photosynthesis<sup>3</sup> and competitive ability, is often considered a key trait linked to plant functioning<sup>5–8</sup>. It has been argued that SLA can provide important clues regarding future changes in community composition due to global change, if dryness is going to be altered in much of the tropics. The high-SLA leaves are productive<sup>6,9</sup> but are necessarily also short-lived and vulnerable to herbivory<sup>10,11</sup>. On the other hand, low-SLA leaves perform better in resource-poor environments<sup>7</sup>.

Leaf area plays an important role in light interception, water and nutrient use, growth and yield potential<sup>12–14</sup>. Leaf size and SLA decline along gradients of decreasing moisture and/or nutrient availability<sup>15–20</sup>. Lower SLA, due to thicker and/or denser leaves contributes to long leaf survival, nutrient retention, and protection from desiccation<sup>21</sup>, whereas small leaf size reduces boundary layer resistance, and helps maintain favourable leaf temperatures and higher photosynthetic water-use efficiency under the combination of high solar radiation and low water availability<sup>22,23</sup>.

Chlorophyll is the most important pigment for photosynthesis<sup>24–26</sup>. Chlorophyll concentration in leaves and canopies can be an indicator of photosynthetic capacity, developmental stage, plant productivity, environmental stress and nutrient management<sup>27–30</sup>. Measurement of leaf chlorophyll content is also an indirect approach to estimate soil nitrogen<sup>31–33</sup>.

Since the leaf traits are considered important for understanding vegetation response to a broad range of environmental factors, we examined four leaf traits, viz. leaf area, leaf weight, SLA and chlorophyll content in eight woody species on four sites of a dry tropical forest in the Vindhyan highland. We addressed the questions: (i) How much do the woody species occurring in a dry tropical environment differ in these leaf traits and how much are these leaf traits affected by site conditions? (ii) Can a combination of these leaf traits across species discriminate between the sites?

The study was conducted on four sites, viz. Ranitalli, Neruiadamar, Bokrakhari and Hathinala of the Vindhyan dry tropical region (21°29'–25°11'N lat.; 78°15'–84°15'E long.), Sonbhadra District, Uttar Pradesh in 2008. The elevation above the mean sea level ranges between 313 and 483 m. The area experiences a tropical monsoon climate. The sites are located between two meteorological stations, Obra and Renukut. Ranitalli site is nearest to Obra and Hathinala site is nearest to Renukoot. Mean annual rainfall is 926 mm at Obra and 1146 mm at Renukoot<sup>34</sup>. The soils are residual ultisols, sandy loam in texture, reddish to dark grey in colour and are extremely poor in nutrients<sup>35</sup>. Among the four sites, the mean rainy

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