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Moisture desorption and absorption isotherms for seeds of some cultivars of *Triticum dicoccum* wheat

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Moisture desorption and absorption isotherms for 50 seeds each of thirty varieties of *Triticum dicoccum* wheat in five replications were recorded at 30°C and 85% RH. Hysteresis loops were established for all the varieties from the average seed masses, normalized to equal curve heights for meaningful comparison. It is observed that the shapes and area enclosed by hysteresis loops for seeds of different varieties are different. Curiously enough, the seeds of varieties with smaller area under their moisture hysteresis loops hold more per cent initial water in them at initial saturation at 30°C and 85% RH, than the seeds of varieties with large area under hysteresis loops. Whereas the behaviour of tetraploid *Triticum durum* and *Triticum dicoccum* wheat varieties are parallel, the behaviour of hexaploid *Triticum aestivum* varieties is considerably different in respect of moisture absorption. Typical examples of the dynamics of moisture movements in seeds of two *Triticum dicoccum* varieties are presented and discussed. It is believed that the observations discussed in this paper would be of considerable help to wheat breeders for improving the *dicoccum* wheat for yield, particularly in the rainfed areas of Karnataka, Maharashtra and Gujarat, where varieties of this species are still being grown on commercial scales for some specific end-products.

MOHARIR[1], and Moharir and Nam Prakash[2] recently studied the moisture desorption and absorption isotherms, for seeds of some well-known cultivars of *Triticum aestivum* and *Triticum durum* wheats, at 30°C and 85% RH, and established moisture hysteresis loops from the average normalized masses of 50 seeds of each variety, during the dehydration and rehydration cycles. It has been shown[1,2] that not only the shapes of these hysteresis loops are different for different varieties, but also the area enclosed under them are different. Curiously enough, the area enclosed under the hysteresis loops for seeds of well-established rainfed cultivars of *T. aestivum* (bread wheat) is smaller than that for the seeds of well established irrigated varieties. Similar observations were also recorded for seeds of *T. durum* wheat varieties[1,2] as well. However, the range of variation in hysteresis loop area for seeds of *durum* varieties is considerably smaller[2]. This has been attributed to relatively shorter breeding history for *durum* wheat[2,3]. Further, the rates of absorption and desorption of water, for seeds of rainfed varieties, were slower as compared to those for the seeds of irrigated varieties[2]. This interesting observation on seeds is parallel in behaviour to that reported on excised plants[3–15], and is of immense practical significance.

In this paper, data on moisture absorption and desorption isotherms and normalized hysteresis loops for seeds of some 30 varieties of *T. dicoccum* wheat are presented and discussed. All the varieties were received from Dr V. S. P. Rao of the Maharashtra Association for Cultivation of Science, Pune, and grown in 1993–94 crop season.

The details of procedure for recording desorption and absorption isotherms and computing normalised moisture hysteresis curves, moisture retention index values and per cent hydration of seeds for each variety have been described earlier[2]. For brevity, only the data in respect of 30 varieties of wheat studied, together with values for initial and final per cent moisture held by the saturated seeds of these varieties are presented in Table 1, in which the varieties have been listed in the increasing order of the area under the hysteresis loops. The authentic data on the agronomic production conditions in respect of these varieties could not be procured from wheat breeders and agronomists as was possible in case of the varieties of *T. aestivum* and *T. durum*[1,2]. Nevertheless, it is believed that the observations would prove useful to plant breeders for improvement of *dicoccum* wheat in southern and western parts of India, where these are still being grown on commercial scales predominantly under rainfed conditions, for some specific end-products. Table 2 gives the computed values on initial and final per cent moisture held by the seeds of *T. aestivum* and *T. durum* wheat varieties previously reported[1,2], along with their agronomic production conditions. Table 3 shows the correlations and probability values of area under moisture hysteresis curves with other moisture parameters in respect of varieties within individual spe-

Table 1. Data on initial and final per cent moisture held by initially saturated and re-saturated seeds over dry mass, hysteresis loops and moisture retention index in respect of *Triticum dicoccum* wheat varieties

Variety	Percentage hydration of seeds over initial mass of saturated seeds at the end of one cycle of dehydration and rehydration (*)	Initial moisture held by saturated seeds at 30°C and 85% RH over dry mass (%)		Final % moisture held by re-saturated seeds at 30°C and 85% RH over dry mass after one cycle of dehydration and rehydration		Area under the moisture hysteresis curve (cm^2)	Moisture retention index
HW-66	−0.34	6.08		5.72		10.175 (L)	8.7
Khapli-yellow	−0.14	4.18		4.02		13.450	10.3
HW-75	−0.46 (L)	4.67		4.19		15.400	7.3 (L)
Khapli-367	+0.17	4.02		4.21		20.525	13.3
HW-70	+0.36	5.62		5.65		21.200	10.9
KDH	+0.02	5.31		5.65		21.866	17.0
HW-24	+0.33	6.32 (H)		6.02 (H)		22.200	11.0
HW-19	−0.29	5.98	Av. of first fifteen varieties (4.94%)	5.94	Av. of first fifteen varieties (4.97%)	26.030	13.3
HW-28	−0.03	4.37		4.26		28.100	13.1
HW-63	−0.10	4.50		4.25		28.400	14.5
HW-72	−0.23	4.39		4.49		29.260	14.1
HW-2	+0.09	5.28		5.30		29.600	14.4
N-4914	+0.02	4.57		5.13		29.900	17.6
Khapli-P-882	+0.53	4.70		5.04		30.200	16.5
Khapli-pink	+0.32	4.17		4.73		30.550	19.3
P-862	+0.54	4.17		3.66 (L)		30.666	14.6
Khapli-53	+0.40	4.57		5.02		30.866	18.4
HW-71	+0.42	4.99		4.71		31.100	14.3
Rufrum-II	−0.26	5.13		5.63		31.433	17.2
NP-200	+0.47	4.29		4.58		32.466	17.0
HW-68	+0.27	4.83		4.77		33.000	18.8
RL-5045	−0.05	4.43		5.16		34.600	21.5
Khapli-33	+0.70	5.08	Av. of next fifteen varieties (4.45%)	5.57	Av. of next fifteen varieties (5.00%)	30.825	19.2
Farrum-II	+0.46	4.48		4.86		36.433	17.8
NP-201	+0.37	4.21		4.61		36.600	17.4
NP-202	+0.33	4.41		4.77		38.500	18.0
Khapli	+1.12	4.14		5.31		51.233	26.5
Khapli Ex-7	+1.10	4.42		5.51		55.966	33.3
Azar	+1.29	4.46		5.80		64.300	33.2
Khapli Ex-33	+1.94 (H)	3.16 (L)		5.17		72.466 (H)	38.7 (H)
Range of variation (H–L)	2.40	3.16		2.36		62.291	31.4

(H): Highest value within varieties of the species.
(L): Lowest value within varieties of the species.
(*): +ve or −ve indicate increase and decrease respectively in per cent seed hydration after one cycle of dehydration and rehydration over the initial mass of saturated seeds.

cies of wheat and also within mixture of varieties of different species taken together.

It may be observed from Table 1 that the percentage hydration of seeds varies from the lowest (– 0.46) to as high as (+ 1.94). In general, lower negative values correspond with lower values of area under moisture hysteresis loops and moisture retention indices (Table 1). This is also evident from high significant positive correlations of percentage hydration of seeds with moisture retention index (MRI) and area under the hysteresis loops (Table 3). The data on initial and final percentage moisture held by the saturated seeds of *T. dicoccum* varieties over their dry mass are also given in Table 1. It may be observed from Table 1 that the variety Khapli Ex-33 which has the largest value for area under its moisture hysteresis loop and moisture retention index, showed the lowest value for the initial moisture held by its seeds on saturation. In general, seeds of varieties

Table 2. Data on initial and final per cent moisture held by the seeds of *Triticum aestivum* and *Triticum durum* wheat varieties on initial and final saturation with moisture and their agronomic production conditions

Variety	Initial % moisture held by 50 seeds on saturation at 30°C and 85% RH	Final % moisture held by the same 50 seeds on resaturation at 30°C and 85% RH after one cycle of dehydration and rehydration (**)	Agronomic production conditions of wheat varieties (#)
Part-A (*Triticum aestivum*)			
K-65	5.35	– 4.70	TS-RF
C-306	6.68 (H)	– 0.08	TS-RF
K-8027	5.84	– 5.13	TS-RF
WL-410	5.00	– 4.57	LS-RF
Mukta	4.88	– 4.59	TS-RF
WL-711	5.02	– 4.68	TS-RF
WH-147	5.67	– 5.25	TS-IR
K-8020	5.79	– 5.50 (L)	LS-IR
DL-153-2	4.64 (L)	– 4.54	TS-RF
NI-5439	6.44	+ 6.69	TS-RF + IR
K-68	4.98	+ 5.03	TS-RF + IR
IWP-72	4.94	+ 5.43	TS-RF
Kalyansona	5.63	+ 6.04	TS-IR
HD-2009	5.12	+ 5.81	TS-IR
Sonalika	5.74	+ 7.44	LS-IR
HD-2329	5.49	+ 6.54	TS-IR
WH-157	5.54	+ 7.45 (H)	TS-IR
Part-B (*Triticum durum*)			
AKW-1811	6.67	– 5.67	TS-IR
AKW-1071	6.83	– 5.79	TS-IR
NP-404	6.34	– 5.80	TS-RF
DWR-162	6.44	– 5.46	TS-IR
Bijaga yellow	7.05 (H)	– 6.26 (L)	TS-RF + IR
MACS-1967	5.82	– 5.03	TS-RF
Bijaga-red	6.50	– 5.70	TS-RF + IR
Meghdoot	6.79	– 6.16	TS-RF
Raj-1555	6.48	– 5.65	TS-IR
JU-12	6.15	– 5.78	TS-RF
AKW-3018	6.38	– 5.39	TS-RF
MACS-2496	4.80	– 4.33	TS-IR
MACS-9 (Akola)	6.30	– 6.24	TS-RF
MACS-9 (Indore)	5.73	– 5.40	TS-RF
N-59	3.05 (L)	+ 3.09 (H)	TS-RF
Raj-911	6.74	– 6.07	TS-IR
A-9-30-1	5.27	– 5.14	TS-RF
AKW-381	6.29	– 6.12	TS-IR
NP-401	5.96	– 5.73	TS-RF + IR

(H): Highest value within varieties of the species.
(L): Lowest value within varieties of the species.
(**): +ve, Increase; –ve, decrease from the initial mass of saturated seeds.
(#): *Twentyfive Years of Coordinated Wheat Research* (eds Tandon, J. P. and Sethi, A. P.), All India Coordinated Wheat Research Project, 1986, IARI, New Delhi.
(TS-RF): Timely sown rainfed.
(TS-IR): Timely sown irrigated.
(TS-RF + IR):Timely sown rainfed and irrigated.

Table 3. Correlation coefficients and probability levels of moisture hysteresis loop area with other moisture parameters within varieties of individual species and within varieties of all the species taken together

Cultivar	Moisture retention index	% Hydration of seeds over initial mass of saturated seeds	% Initial moisture held by saturated seeds over dry mass at 30°C and 85% RH	% Final moisture held by seeds resaturated at 30°C and 85% RH over dry mass after one cycle of dehydration and rehydration
Triticum dicoccum (tetraploid) 30 varieties	0.96 $P > 0.001$	0.87 $P > 0.001$	−0.49 $P > 0.01$	0.23 (NS)
Triticum durum (tetraploid) 19 varieties	0.82 $P > 0.001$	0.72 $P > 0.001$	−0.39 $P > 0.05$	−0.15 (NS)
Triticum aestivum (hexaploid) 17 varieties	0.97 $P > 0.001$	0.93 $P > 0.001$	0.01 (NS)	0.67 $P > 0.01$
Triticum dicoccum, *Triticum durum* and *Triticum aestivum* taken together; 65 varieties	0.90 $P > 0.001$	0.78 $P > 0.001$	−0.28 $P > 0.05$	0.33 $P > 0.01$

P: Probability values. (NS): Not significant.

with smaller area under their moisture hysteresis loops hold more moisture in them at initial saturation. As a parallel example, Dedio[8], while comparing the usefulness of water potential, water saturation deficit, water content, and rate of moisture loss of excised leaves as indices in screening for drought resistance, also observed that the most drought-resistant cultivar always had the highest water content and that the water content was more useful parameter in screening wheat for drought resistance. This is also borne out by the significant negative correlation between initial moisture content in seeds on saturation and the area under the moisture hysteresis loops for varieties of tetraploid *T. dicoccum* and *T. durum* wheat (Table 3). Varieties of hexaploid *T. aestivum* however show no such correlation within the species, but the combined correlations of a mixture of varieties of all the three species of wheat, also indicate significant negative correlation (Table 3). It may be interesting to note from Table 1 that the final percentage moisture held by saturated seeds for varieties with larger area under their moisture hysteresis loops is considerably more than that held by the same seeds at their initial saturation. In general, the varieties listed in the upper half of Table 1 have higher average value for the initial percentage moisture held by the seeds than for the varieties listed in the lower half. Further, the varieties in the upper half of the Table 1 have lower average values for the final percentage moisture held by the seeds than for the varieties listed in the lower half of the Table 1. This clearly shows that the varieties that have smaller area under their moisture hysteresis loops also hold relatively more moisture in their seeds on initial saturation, after one cycle of dehydration and rehydration. Assuming that the earlier conclusions[1,2] e.g. seeds of rainfed varieties enclose smaller area under their moisture hysteresis curves than the seeds of irrigated varieties, as obtained in respect of bread and *durum* wheats also hold good for the *T. dicoccum* varieties as well, then the varieties with lower values for area under moisture hysteresis loops and MRI should perform relatively better, under rainfed cultivation and hold more moisture in their seeds on initial saturation with water than the varieties with larger area under moisture hysteresis curves. Fresh analysis of data on varieties of *T. aestivum* and *T. durum*[2] on these lines (Table 2) indicates that, whereas this argument holds good for the tetraploid *T. durum*, it does not do so for the varieties of hexaploid *T. aestivum*. The answer to this may be sought in the historical fact, that the varieties of only *T. dicoccum* and *T. durum* have been the mainstay for cultivation in the entire arid and semi-arid regions of the world[3,16–18]. I wonder, if this argument implies/suggests that any search or selection for a truely drought-resistant cultivar of wheat should be sought from amongst the varieties of tetraploid *dicoccum* and *durum* species of wheat! This conviction is further strengthened in the light of the reports[8,18] that the tetraploid wheats and crosses were consistently superior in most screening tests conducted for drought tolerance.

It may be seen from Table 1 that the area under the hysteresis loops varies from the lowest 10.17 cm^2 for HW-66 to as high as 76.46 cm^2 for Khapli Ex-33. Figures 1 and 2 show the regular hysteresis curves for two extreme varieties Khapli-yellow and NP-202 respectively. Figures 3 and 4 represent the hysteresis curves for two varieties namely HW–66 and Khapli Ex-33 respectively and are indeed typical in that they clearly bring out the variations in the dynamics of moisture/water across their seed matrix and cuticular membranes during dehydration and rehydration cycles. It may be noted that whereas the rate of dehydration for HW-66 (Figure 3) is rapid, the rate of rehydration is correspondingly slow and therefore the desorption and absorption isotherms intersect each other. Such varieties are agronomically unsuitable for rainfed cultivation[2]. Khapli Ex-33 (Figure 4) is again very typical in that the rehydration isotherm shows a steep depression, indicating rapid suction of water into the seeds and then gradually increasing at slower rate, resulting in an enlarged area under the normalized hysteresis curve. For lack of ag-

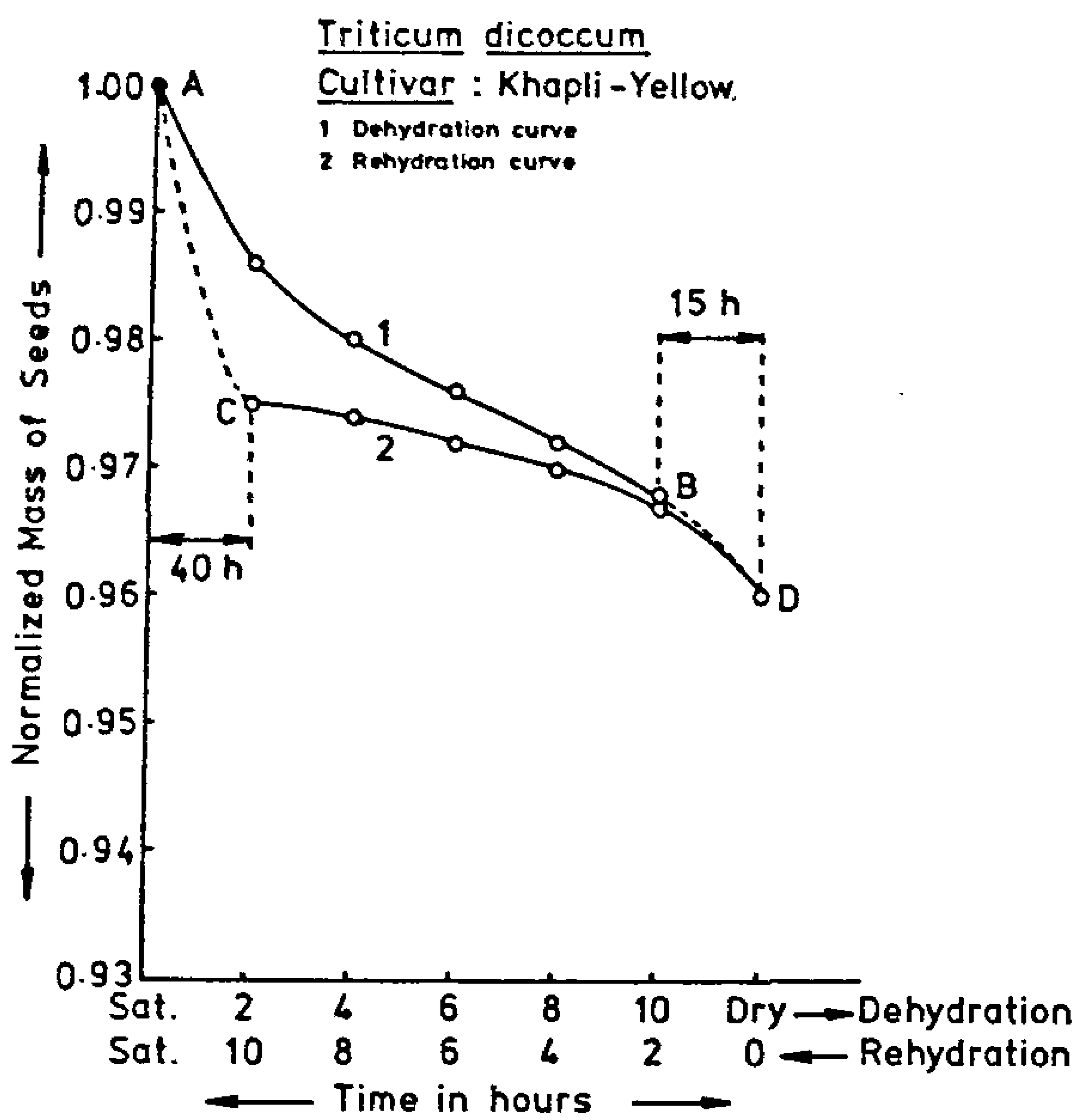

Figure 1. Normalized moisture hysteresis curve for the variety Khapli-yellow.

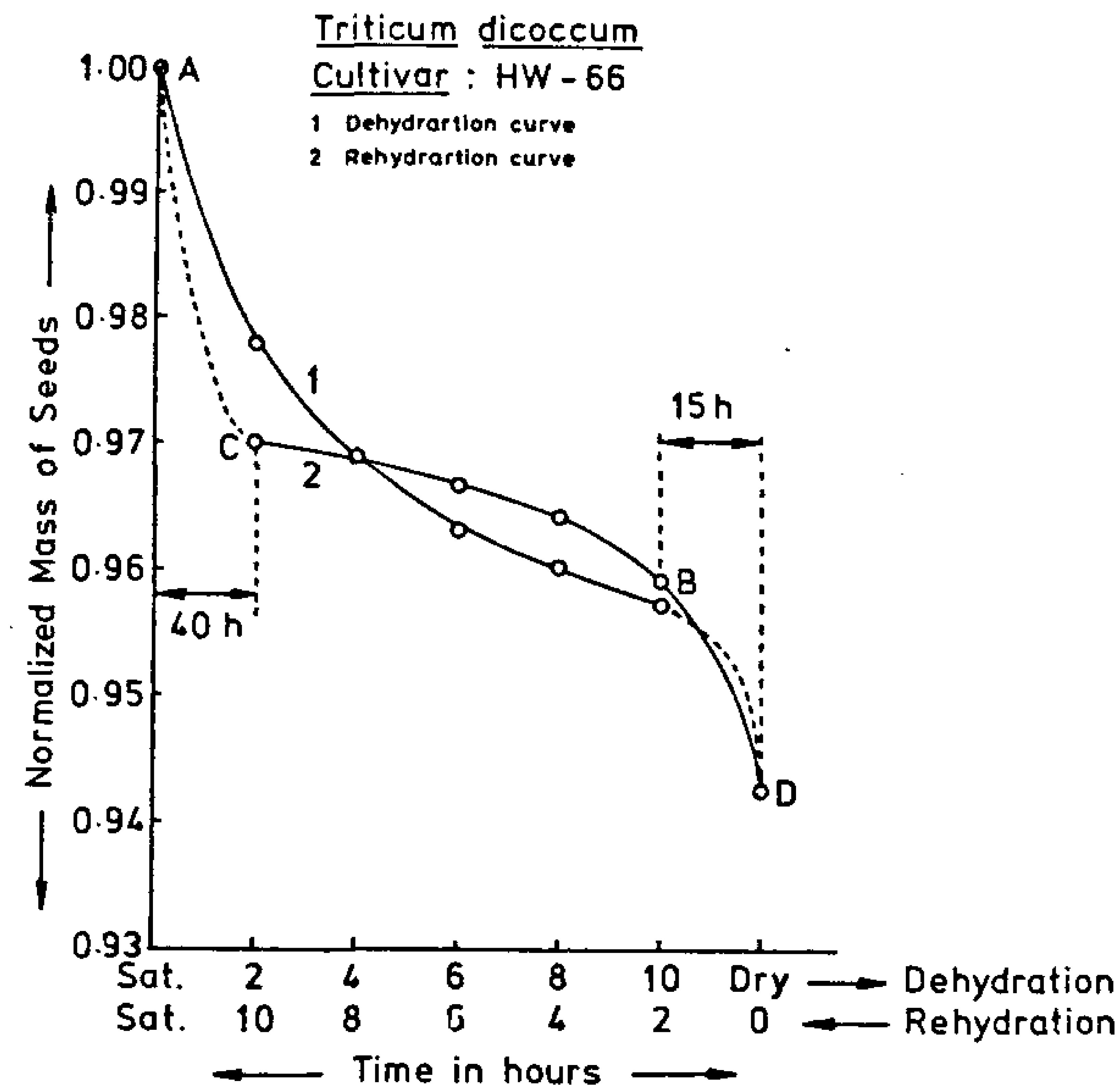

Figure 3. Normalized moisture hysteresis curve for the variety HW-66.

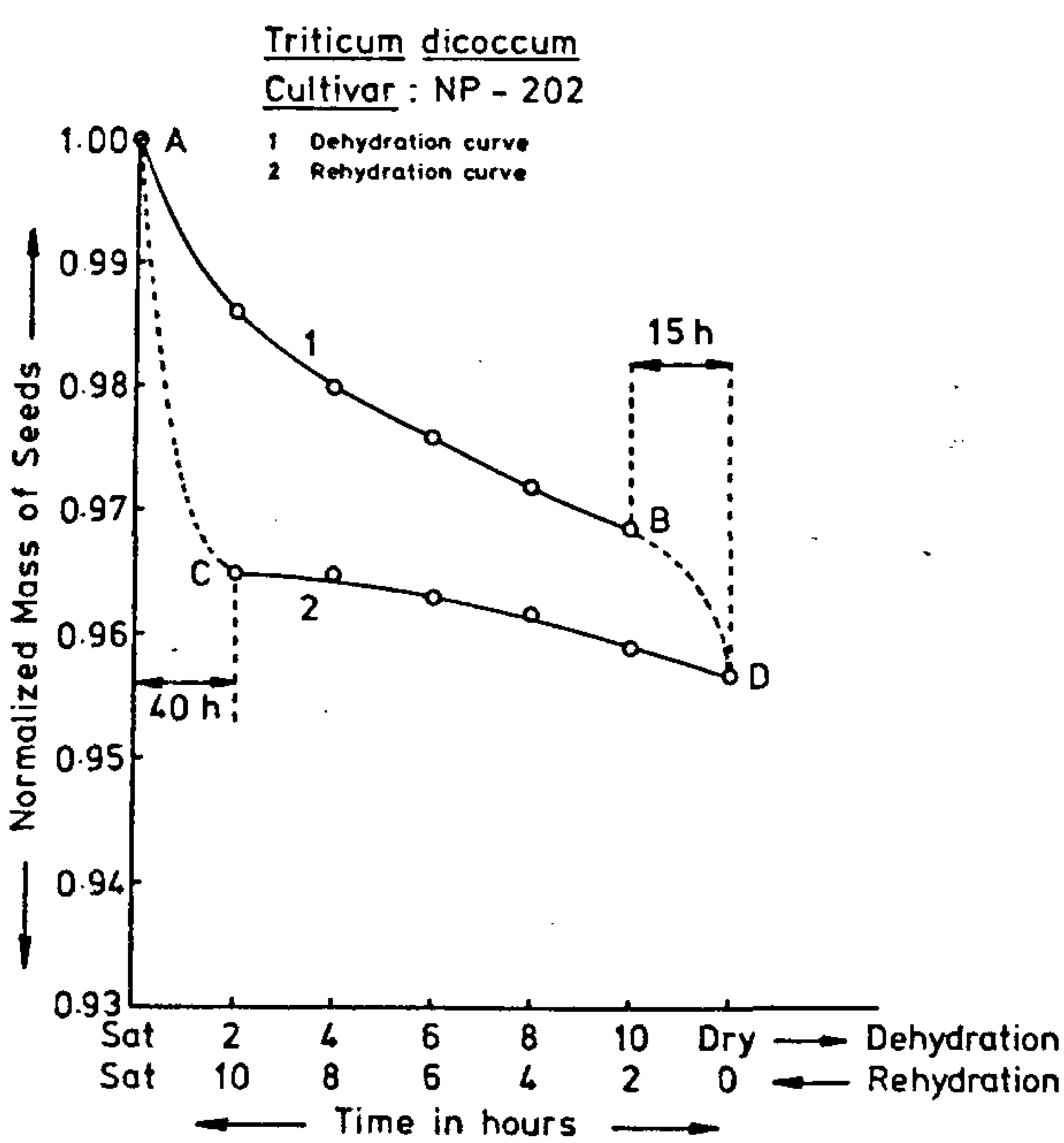

Figure 2. Normalized moisture hysteresis curve for the variety NP-202.

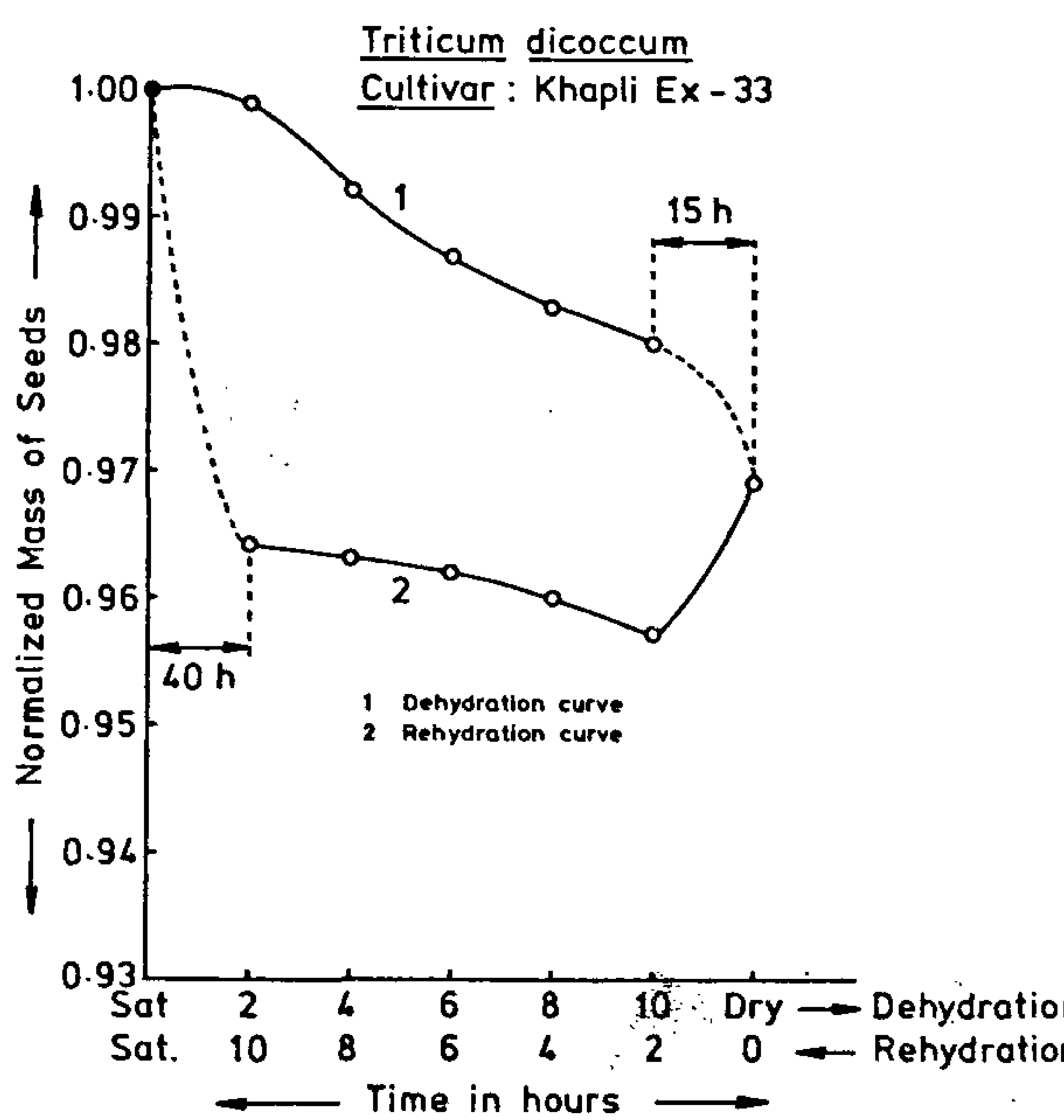

Figure 4. Normalized moisture hysteresis curve for the variety Khapli Ex-33.

ronomic data on the actual production conditions for these varieties of *T. dicoccum*, their correspondence and segregation into rainfed and irrigated categories on the basis of the magnitude of area under moisture hysteresis curve and MRI could not be ascertained as was possible earlier[1,2]. Nevertheless, it is my conviction that the varieties listed in the upper half of the Table 1 should actually perform better than those listed in the lower half of the table, under rainfed field conditions.

Area under hysteresis loops bears significant positive correlations with MRI and percentage hydration of seeds and significant negative correlations with per cent initial moisture held by the saturated seeds, bringing out clearly that the seeds of varieties with larger area under hysteresis loops, hold less amount of moisture in them on initial saturation, a condition obviously undesirable for varieties meant for cultivation under arid and semi-arid conditions (Table 3). With final per cent moisture held by the seeds on resaturation after one cycle of dehydration and rehydration, the hysteresis area does not bear any consistent significant correlations within tetraploid *durum* and *dicoccum* wheats, but bear a significant positive correlation within varieties of hexaploid *aestivum* species (Table 3).

In conclusion, wide variations are observed in moisture absorption and desorption characteristics and in the area enclosed under the normalized moisture hysteresis curves for seeds of 30 *T. dicoccum* wheat varieties. The moisture desorption and absorption isotherms also reveal the variations in the rate and extent of permeability of moisture across the seed matrix and seed cuticular membranes from one variety to the other. It is believed that the data would help the wheat breeders in their selection of parents for improvement of *dicoccum* wheat for increased productivity/tolerance to drought under arid and semi-arid regions.

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Hydrolysing enzymes and respiration during ripening of tomato (*Lycopersicon esculentum*) fruits

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Two varieties of tomato fruits, viz. Pusa *Ruby* and Pusa *Gaurav*, were studied with an attempt to get a better understanding of the relationship between respiration rate and hydrolysing enzymes during ripening. Pectin methyl esterase (PME) and polygalacturonase (PG) increased as ripening proceeded and reached a peak on 4th day after harvest followed by a decline. Respiration rate increased along with the activity of PME and PG with cyanide-resistant respiration being increasingly dominant compared to cyanide-sensitive respiration. There seems to be a close relation between the respiration (alternate) and hydrolysing enzymes during ripening of tomato fruit.

DURING ripening of climacteric fruits, a considerable increase in metabolic activities has been reported. Respiratory activity rises and shows a peak coinciding with a large volume of ethylene evolution in many fruits like banana[1] and avocado[2,3]. In tomato also hydrolysing enzymes like polygalacturonase (PG) and pectin methyl esterase (PME) have been reported to increase[3] during ripening.

In some fruits, the involvement of cyanide-resistant respiration has been reported to be responsible for raising temperature inside the fruits[4,5] required for increasing activity of enzymes. Whether there is any relationship between cyanide-resistant respiration and hydrolysing enzymes in tomato, which is also a climacteric fruit, is