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Comparison of Glucose Uptake Kinetics in Different Yeasts

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The kinetics of glucose uptake were investigated in laboratory wild-type strains of *Saccharomyces cerevisiae* of differing genetic backgrounds, in other species of *Saccharomyces*, and in other yeasts, both fermentative and respiratory. All yeasts examined displayed more than one uptake system for glucose. Variations in apparent K_m values, velocity of uptake, and effects of glucose concentration on carrier activity were observed. The three type strains for the species *S. cerevisiae*, *Saccharomyces bayanus*, and *Saccharomyces carlsbergensis* gave distinctive patterns, and each of the laboratory strains was similar to one or another of the type strains. Other fermentative yeasts (*Pichia guillermondi* and *Pichia strasburgensis*) regulated glucose uptake in a manner similar to that of *Saccharomyces* spp. Such was not true for the respiratory yeasts investigated, *Pichia heedi* and *Yarrowia lipolytica*, which did not demonstrate glucose repression of carrier activity; this finding suggests that this mechanism of control of transporter activity may be associated with fermentative ability.

It has been suggested that sugar transport is the rate-limiting step of catabolism during fermentative growth of *Saccharomyces cerevisiae*. The uptake of glucose by *S. cerevisiae* appears to be mediated by at least two types of transport, distinguishable as high-K_m (low-affinity) and low-K_m (high-affinity) systems (5). Low-affinity (K_m = 20 mM) glucose uptake appears to be constitutively expressed, whereas appearance of high-affinity (K_m = 2 mM) uptake activity is dependent on culture conditions. High-affinity uptake is reduced in the presence of a high glucose (2%, wt/vol) concentration and is increased when cells are grown on or shifted to medium containing low (0.05%) glucose. As a culture progresses through a growth cycle, high-affinity uptake increases during the later part of logarithmic growth, presumably as the substrate is reduced (7). Both high- and low-affinity uptake decrease as cells continue to be incubated in stationary phase. Uptake via both systems appears to be mediated by facilitated diffusion, and high-affinity uptake seems to require the activity or expression of at least one of the yeast hexokinases or glucokinase (5–7). Kinetic studies have been performed on several laboratory strains of *S. cerevisiae*: DFY1 (5), HSC (14), and derivatives of S288C (3, 8). All display these two modes of glucose uptake. High- and low-affinity sugar transport has also been described in the yeasts *Candida wickerhamii* (20), *Rhodotorula glutinus* (1), *Pichia pinus* (2), and *Kluyveromyces maxianus* (11) and in the fungus *Neurospora crassa* (18). The reduction of a high-affinity active transport system was evident in these organisms under elevated glucose conditions.

Because of the fundamental importance of glucose uptake and its regulation to control of the glycolytic pathway, we undertook an investigation of the kinetics of glucose uptake in various yeast strains. We compared different laboratory strains of *S. cerevisiae* and strains of *Saccharomyces* spp. which are only sometimes delineated as separate species and compared respirofermentative yeasts with related species that are strictly respiratory.

There is evidence for variation in glucose uptake kinetics among *S. cerevisiae* strains. Schuddemat et al. (19), using *S. cerevisiae* Delft 1 (CBS1172), were not able to demonstrate high- and low-affinity uptake of either 2-deoxy-D-glucose or 6-deoxy-D-glucose, two sugars which do display at least two uptake systems in DFY1 (5, 6). Furthermore, the complexity of glucose transport in *S. cerevisiae* and the effects of strain background on glucose transport activity are becoming apparent. The mutation *snf3* was originally obtained in MCY638 in a screen for sucrose-nonfermenting mutants (8). The *SNF3* gene has been shown to encode a protein homologous to the mammalian glucose transporter (9). Loss of *SNF3* function results in loss of high-affinity uptake in MCY638 (8). However, a *snf3* null mutation did not display Mendelian segregation in the DFY1 genetic background, and DFY1 strains carrying a gene disruption of *SNF3* still displayed high-affinity uptake of glucose (4).

Recently three species of *Saccharomyces*, *S. cerevisiae*, *S. bayanus*, and *S. carlsbergensis*, were combined into one, *S. cerevisiae* (13). These three species had originally been differentiated in part on the basis of fermentation characteristics. Studies of DNA hybridization between type strains of *S. cerevisiae*, *S. bayanus*, and *S. carlsbergensis* have led to the suggestion that the separate species designations should be maintained (15). Those conducting research on yeasts may, therefore, be working in very different genetic backgrounds, using strains that have all been classified as *S. cerevisiae*.

The genus *Pichia* is in the same subfamily, *Saccharomycetoideae*, as the genus *Saccharomyces*, and members of these two genera show very similar morphological and physiological traits (13). Within the genus *Pichia*, both fermentative and nonfermentative species exist. Differences in glucose uptake or its regulation might be expected among such species. Sugar transport may be the rate-limiting step of catabolism during fermentative growth; however, for species restricted to respiratory growth, maximum catabolic rate may be a function more of the catalytic activity of the enzymes of the pathway and respiratory capacity than of the availability of substrate to catabolic pathways (10, 12, 17). One would, therefore, not necessarily expect a derepressable sugar uptake system in an organism restricted to respiratory catabolism. We have compared glucose uptake in *Pichia strasburgensis* and *Pichia guillermondii*, both capable of fermentation, with that in a closely related species, *Pichia heedii*, which is strictly respiratory. *Yarrowia lipolytica*, another strict respirer, was also evaluated for the kinetics

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and regulation of glucose uptake. The results obtained were compared with those for the genus *Saccharomyces*.

MATERIALS AND METHODS

Materials. Reagents were obtained from the following sources: D-[U-^{14}C]glucose, Dupont, NEN Research Products, Boston, Mass.; glass microfiber filters (GF/A and GF/B), Whatman, Inc., Clifton, N.J.; medium constituents, Difco Laboratories, Detroit, Mich.). All other compounds were reagent grade. Opti-Fluor scintillation cocktail was from Packard Instrument Co., Inc., Rockville, Md. Radioactivity was determined by using a Packard model 2000 Tri-Carb liquid scintillation counter.

Strains. The following strains were provided by C. P. Kurtzman from the collection of the U. S. Department of Agriculture, Midwest area, Northern Regional Research Center, Peoria, Ill.: *S. cerevisiae* type strain NRRL Y-12632, *S. carlsbergensis* type strain NRRL Y-12693, *S. bayanus* type strain NRRL Y-12624 (15), *P. strasburgensis* NRRL Y-11981, *P. guillermondii* NRRL Y-2076, and *P. heedii* NRRL Y-10969. *Y. lipolytica* CX-161-1B (*MAT***a** *ade1*) was obtained from D. M. Ogrydziak (16). *S. cerevisiae* MCY638 (*MAT***a** *his4-539 lys2-801 ura3-52 SUC2*) was from Marian Carlson (8). DFY1 (585-11C) (*MAT***a** *lys1 SUC MAL*) has been described previously (5). X2180-1B (*MAT*α *SUC mal mel gal2 CUP*) was from the Yeast Genetics Stock Center. All are haploid strains.

Growth and uptake assays. Cells were grown with shaking at 25°C in a PsycroTherm incubator-shaker. For comparison with previous work, DFY1 was grown at both 25 and 30°C. The medium contained 2% (wt/vol) peptone, 1% yeast extract, and either 2% (110 mM) or 0.05% (2.8 mM) D-glucose, as indicated. For *Y. lipolytica*, the medium contained 0.3% yeast extract, 0.3% malt extract, and 0.5% peptone and glucose, as indicated. In all cases, growth was monitored by measuring A_{580}. A portion of cells harvested at mid-exponential phase of growth was collected by filtration, washed with a total volume of 40 ml of potassium phosphate buffer (0.1 M, pH 6.5), and resuspended to an A_{580} of 15 for measurement of the uptake of labeled glucose (358 mCi/nmol) essentially as described previously (7). Each strain was incubated further, and culture absorbance was monitored to confirm that the harvested cells were indeed taken at the midpoint of exponential growth. Weights of mid-exponential-phase cells were determined, using a Mettler Gramatic balance, by filtering 2 to 10 ml of culture through 2.4-cm-diameter GF/B filters, washing each with a total of 20 ml of 0.1 M KPO_4 (pH 6.5), and drying the filters under a vacuum at 95 to 100°C (National Appliance Co. vacuum oven) until no further change in weight occurred. Washing was done with buffer rather than water to ensure cell integrity. Media alone treated as above generated no detectable weight. Final cell yields were measured by using cultures grown to stationary phase in rich medium; the cellular weights obtained, therefore, were not strictly correlated on a gram-per-gram basis with the added glucose concentration.

Glucose determinations. Samples were prepared by filtering culture through a 0.2-μm-pore-size MSI (Fisher Scientific Co., Pittsburgh, Pa.) filter. D-Glucose was assayed enzymatically (Biochemical Analysis-Food Analysis, UV Method for Glucose/Fructose reagent set; Boehringer-Mannheim Biochemicals, Indianapolis, Ind.). NADPH concentration was measured by an increase in A_{334} (model 2400 spectrophotometer; Gilford Instrument Laboratories, Inc., Oberlin, Ohio).

TABLE 1. Kinetics of glucose uptake in strains of *Saccharomyces* species

Strain	Growth temp (°C)	Kinetics after growth on: 2% Glucose V^a	2% Glucose $K_m{}^b$ (mM)	0.05% Glucose V^c	0.05% Glucose $K_m{}^d$ (mM)
S. cerevisiae DFY1	30	61.3	20–35	55.2	0.95–1.3
	25	65.4	38–64	61.0	0.96–1.2
S. cerevisiae MCY638	25	31.2	75–125	12.4	0.55–0.75
S. cerevisiae X2180-1B	25	37.0	40–60	31.0	0.35–0.5
S. cerevisiae type strain	25	71.2	13–22	33.2	0.9–1.2
S. carlsbergensis type strain	25	50.4	94–156	20.0	3.0–3.7
S. bayanus type strain	25	23.0	30–45	1.4	0.06–0.08

[a] Velocity of glucose uptake in a 20 mM solution (nanomoles per minute per milligram [dry weight]).

[b] Estimated K_m of the low-affinity component of glucose uptake. Determined from the steep slope of an Eadie-Hofstee plot of cells grown on high glucose.

[c] Velocity of glucose uptake in a 1 mM solution (nanomoles per minute per milligram [dry weight]).

[d] Estimated K_m of the high-affinity component of glucose uptake. Determined from the shallow slope of an Eadie-Hofstee plot of cells grown on low glucose.

RESULTS

Analysis of glucose uptake by *S. cerevisiae* DFY1 grown at 25 and 30°C. Because some of the strains examined in this study, such as *S. carlsbergensis*, grow more vigorously at 25 than at 30°C, all cultures were grown at 25°C. To provide a basis for comparison with previously generated data (7, 14), the glucose uptake parameters of *S. cerevisiae* DFY1 grown at 25 and 30°C were compared (Table 1). The velocities of glucose uptake were virtually identical whether the cells were grown at 25 or at 30°C. (Table 1 presents uptake velocities when the substrate concentration was 20 mM [when the cells were grown on 2% glucose], which primarily assesses low-affinity uptake, and when the substrate concentration was 1 mM [when the cells were grown on 0.05% glucose], which assesses high-affinity uptake.)

Low-affinity uptake is the major uptake system apparent during growth on high glucose, and high-affinity uptake is the major uptake system when cells are grown on low glucose. Therefore, an estimate of the K_m of low-affinity uptake can be obtained from cells grown on high (2%) glucose, and the K_m of high-affinity uptake can similarly best be estimated from cells grown on low (0.05%) glucose. The K_m values of the glucose uptake systems of DFY1 were quite similar when the cells were grown at 25 or 30°C (Table 1).

Analysis of glucose uptake in various strains of *S. cerevisiae*. The kinetics of glucose uptake were examined in four strains of *S. cerevisiae* (DFY1, MCY638, X2180-1B, and NRRLY-12632) under conditions that have been defined as repressing (early log, 2% glucose) and derepressing (early log, 0.05% glucose) for high-affinity transport in DFY1 (7). Eadie-Hofstee plots of glucose uptake for *S. cerevisiae* DFY1, MCY638, and NRRL-12632 (Fig. 1 and 2A) were all biphasic; at least two slopes were evident.

The kinetics of glucose uptake in DFY1 and the type strains for the species, NRRL-12632, were virtually identical under all conditions studied. MCY638 and X2180-1B (data not shown) resembled DFY1 and NRRL-12632 under high-glucose conditions, but when grown on low glucose they did not demonstrate the derepression of high-affinity uptake (the shallower of the two slopes) evident in DFY1 and the type

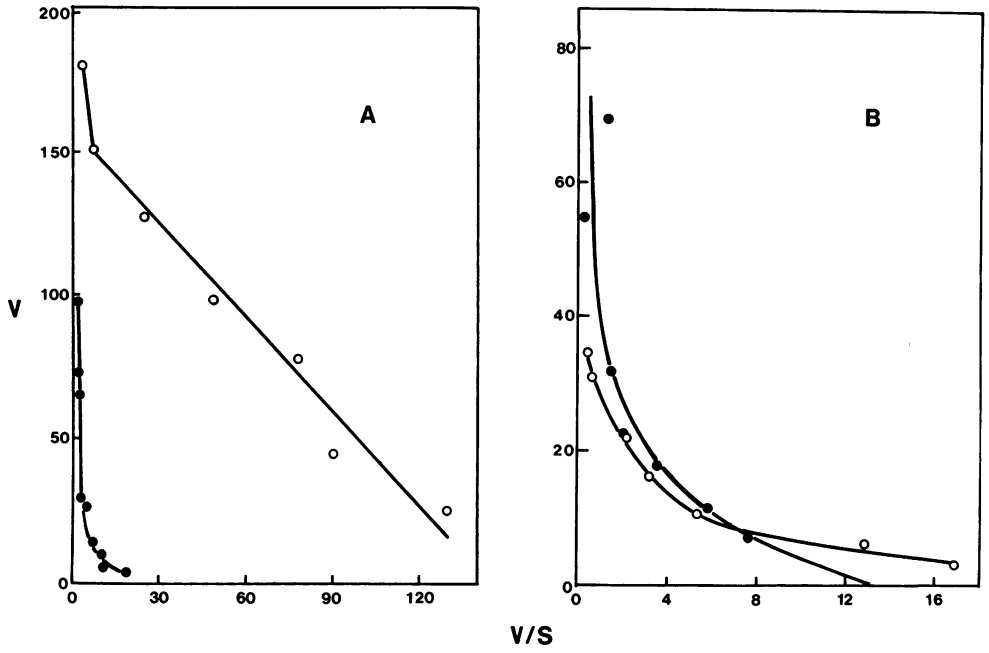

FIG. 1. Kinetics of glucose uptake in different laboratory strains of *S. cerevisiae*. *V* is expressed as nanomoles per minute per milligram (dry weight); *V/S* is expressed as nanomoles per minute per milligram (dry weight) per millimolar concentration. Cultures were grown to mid-exponential phase of growth aerobically at 25°C with 2% (wt/vol) (●) or 0.05% (○) glucose. (A) *S. cerevisiae* DFY1; (B) *S. cerevisiae* MCY638.

strain. The uptake velocities under both low- and high-glucose conditions were also somewhat lower for MCY638 and X2180-1B (Table 1). X2180-1B and MCY638 were derived from the same parental strain, S288C. Additional differences were apparent in the S288C derivatives during growth on low glucose. DFY1 and NRRL-12632 had doubling times of approximately 100 min whether grown on 2 or 0.05% glucose. For MCY638 and X2180-1B, growth rates slowed considerably on low glucose (for MCY638 from a doubling time of 120 min on 2% glucose to 400 min on 0.05%). Cell yields at stationary phase on rich medium also varied among the strains. (On 2% glucose, DFY1, MCY638, and X2180-1B yielded 13.7, 10.9, and 14.2 mg [dry weight]/ml, respectively. On 0.05% glucose, yields of 1.1, 4.8, and 6.2 mg [dry weight]/ml were obtained.) Under these conditions (rich medium), glucose serves as the primary energy source but is, naturally, not the only source of carbon for biosynthesis of macromolecules. An influence of growth rate or energy yield on the expression of high-affinity glucose uptake in the S288C-derived strains cannot be excluded and may override any signal for derepression of this transport system under these growth conditions.

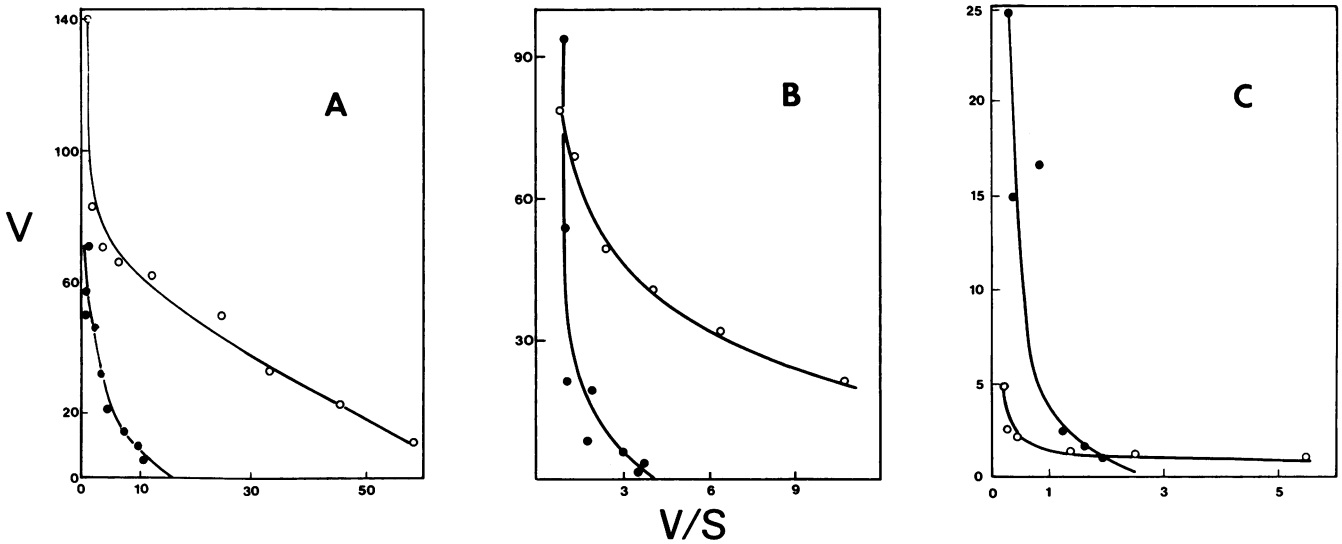

FIG. 2. Kinetics of glucose uptake in type strains of *Saccharomyces* species. *V* and *V/S* are expressed as for Fig. 1. Cultures were grown to mid-exponential phase of growth aerobically at 25°C with 2% (wt/vol) (●) or 0.05% (○) glucose. (A) *S. cerevisiae* type strain; (B) *S. carlsbergensis*; (C) *S. bayanus*.

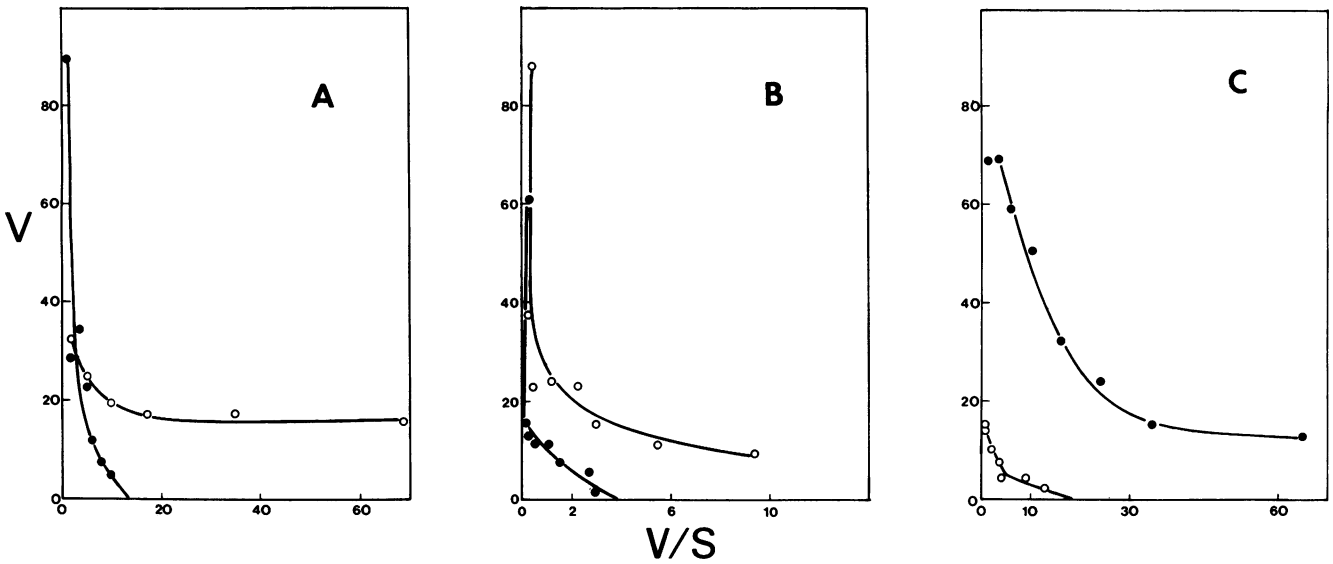

FIG. 3. Glucose uptake in members of the genus *Pichia*. *V* and *V/S* are expressed as for Fig. 1. Cultures were grown to mid-exponential phase of growth aerobically at 25°C with 2% (wt/vol) (●) or 0.05% (○) glucose. (A) *P. guillermondii*; (B) *P. strasburgensis*; (C) *P. heedii*.

Analysis of glucose uptake by the type strains of selected *Saccharomyces* species. Glucose uptake kinetics of the type strains of *S. cerevisiae*, *S. carlsbergensis*, and *S. bayanus* were compared (Fig. 2). *S. bayanus* displayed greatly reduced sugar uptake velocities, although the K_m values of the uptake systems appeared similar to those of the *S. cerevisiae* type strain. In addition, this organism did not demonstrate the same pattern of glucose uptake regulation as was shown by the *S. cerevisiae* type strain. *S. bayanus* displayed an increase in high-affinity uptake concomitant with a decrease in low-affinity uptake during growth on a low glucose concentration (Fig. 2C) and significantly lower rates of uptake than were found for the other two strains. The K_m estimated for high-affinity uptake of approximately 0.07 mM was an order of magnitude lower than that for any of the other *Saccharomyces* strains (Table 1).

In the case of *S. carlsbergensis*, regulation of glucose uptake appeared more similar to that of *S. cerevisiae* than to that of *S. bayanus* (Fig. 2). The velocity of uptake for *S. carlsbergensis* was intermediate to that of *S. cerevisiae* and *S. bayanus* (Table 1). Clearly, *S. carlsbergensis* displayed a higher K_m value for uptake of glucose than did *S. cerevisiae* or *S. bayanus* under high-glucose conditions. In general, the three different patterns of glucose uptake demonstrated by *S. cerevisiae*, *S. carlsbergensis*, and *S. bayanus* differed most remarkably in the apparent K_m values of their low-affinity transport systems and in regulation of carrier activity. These differences in the kinetics of glucose uptake when cells were grown on differing substrate levels were reproducible.

Analysis of glucose uptake in other yeast genera. The kinetics of glucose uptake were also investigated in *P. strasburgensis*, *P. guillermondii*, *P. heedii*, and *Y. lipolytica* (Fig. 3 and 4). All four yeasts demonstrate at least two transport systems, as described above for *S. cerevisiae* DFY1. Although rate of uptake was lower in *P. strasburgensis*, K_m values for the uptake systems were quite similar to those of *S. cerevisiae* (Table 2). When grown in the presence of high glucose, the K_m values for glucose uptake in *P. guillermondii* were also similar to those of *S. cerevisiae*; on low glucose, however, a much lower K_m value was obtained, as was also observed with *P. heedi*. *Y. lipolytica* also displayed apparent K_m values for both high- and low-affinity transport significantly lower than those of the fermentative strains (Table 2). The K_m for high-affinity uptake was similar in magnitude to that observed for *S. bayanus*. The rates of glucose uptake in either condition were quite similar between *S. cerevisiae* and *P. guillermondii*. *P. heedii*, like *Y. lipolytica*, demonstrated a lower uptake rate.

P. guillermondii and *P. strasburgensis* are fermentative organisms similar to *Saccharomyces* spp. Both of these

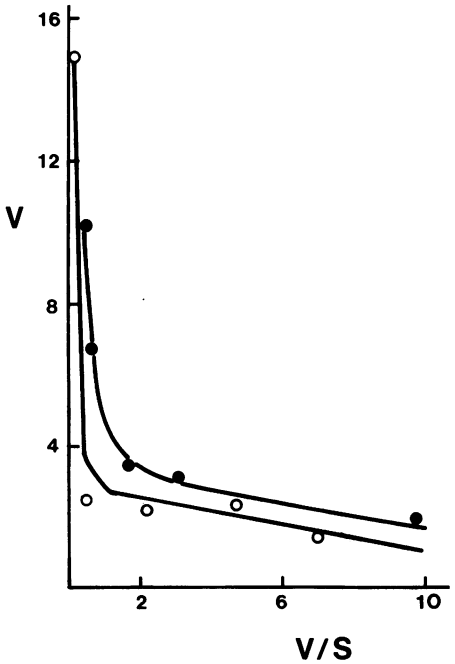

FIG. 4. Eadie-Hofstee plot of glucose uptake in the respiratory yeast *Y. lipolytica*. *V* and *V/S* are expressed as for Fig. 1. Cultures were grown to mid-exponential phase of growth aerobically at 25°C with 2% (wt/vol) (●) or 0.05% (○) glucose.

TABLE 2. Kinetics of glucose uptake in *Pichia* species and in *Y. lipolytica*

Strain	Growth temp (°C)	Kinetics after growth on:			
		2% Glucose		0.05% Glucose	
		V^a	$K_m{}^b$ (mM)	V^c	$K_m{}^d$ (mM)
P. strasburgensis	25	11	15	9.4	1.3
P. guillermondii	25	44	21	17.0	0.05
P. heedii	25	9	3	4.3	0.16
Y. lipolytica	25	10	1.3[e]	2.6	0.14

[a] Velocity of glucose uptake in a 20 mM solution (nanomoles per minute per milligram [dry weight]).
[b] Estimated (±25%) K_m of the low-affinity component of glucose uptake.
[c] Velocity of glucose uptake in a 1 mM solution (nanomoles per minute per milligram [dry weight]).
[d] Estimated (±10%) K_m of the high-affinity component of glucose uptake.
[e] Difficult to estimate because of interference from high-affinity uptake.

Pichia species displayed some glucose inhibition or repression of high-affinity uptake when grown in the presence of a high glucose concentration (Fig. 3). Unlike the other yeasts investigated, *P. heedii* and *Y. lipolytica* are strictly respiratory. It is clear that these two yeasts did not reduce high-affinity uptake under high-glucose conditions, as the other yeast did. *Y. lipolytica* maintained similar transport capabilities under both conditions (Fig. 4), whereas *P. heedii* appeared to increase uptake capacity under higher-glucose conditions (Fig. 3C). A further investigation of *P. heedii* (Fig. 5) substantiated this observation. Samples of *P. heedii* were assayed for glucose transport at various points during the growth cycle. Cells evaluated in stationary phase (sample C) had insignificant glucose remaining in the medium (inset, Fig. 5). Samples taken at A_{580} of 4.5, 10.5, and 15.6 and at 100 h, as indicated, showed decreasing high-affinity uptake. This degradation of uptake upon entry into stationary phase has been demonstrated previously for DFY1 (7). However, in this case, no increase in uptake as glucose levels fell was apparent. Thus, in contrast to the fermentative yeasts, the strictly respiratory yeasts displayed glucose-insensitive uptake of glucose.

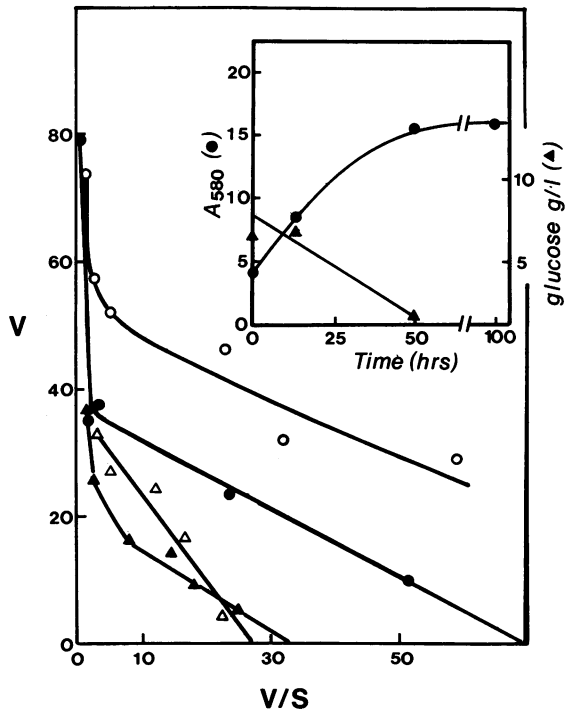

FIG. 5. Eadie-Hofstee plots of glucose uptake at different times during growth of *P. heedii* on 2% glucose: sample A, at early exponential phase (A_{580} of 4.5) (○); sample B, at late exponential phase (A_{580} of 10.6) (●); sample C, at stationary phase (A_{580} of 15.6) (△); and sample D, at late stationary phase (100 h, A_{580} of 15.6) (▲). Inset shows the glucose concentration remaining in the medium and the increase in cell density.

DISCUSSION

The kinetics and regulation of glucose uptake were examined in four strains of *S. cerevisiae*. Two of these strains, DFY1 and NRRL Y-12693, gave essentially identical patterns of glucose uptake in high- and low-glucose-containing media and yielded essentially identical transport velocities and apparent K_m values for the two uptake systems. The other two strains, MCY638 and X2180-1B (both derivatives of S288C), had significantly lower transport rates and minimal increases of high-affinity uptake. In previous studies, MCY638 (8) and X2180-1B (3) displayed a more significant derepression after a shift from high- to low-glucose-containing medium; however, this result was obtained under different growth conditions (30 versus 25°C and with more vigorous aeration).

That strains of these genetic backgrounds are different in glucose uptake ability is supported by investigation of the segregation of a mutated gene, *snf3*, that encodes a protein homologous to the mammalian glucose transporter (9). The mutation (originally isolated in MCY638) confers loss of high-affinity uptake in an MCY638 genetic background but not in the DFY1 background (4). It might be suggested that derivatives of S288C possess a background mutation in a gene that is either important to the regulation of glucose uptake, encodes a duplicate high-affinity carrier gene, or encodes yet another carrier that exists in DFY1 and NRRL Y-12693. It is apparent that there are many differences between these strains, as evidenced by very different growth kinetics on low substrate concentrations.

The fundamental genetic differences among yeast species seem to be reflected in glucose uptake capability and in regulation of uptake. Martini and Kurtzman (15) have used DNA hybridization and G+C determinations to investigate the relatedness of 29 *Saccharomyces* strains. They suggested that *S. carlsbergensis* shows relatedness intermediate between that of *S. cerevisiae* and *S. bayanus*, has a larger genome, and may represent a partial amphidiploid derived from a hybidization of the two. It is interesting that the glucose uptake capability of *S. carlsbergensis* as demonstrated here also was intermediate to that of the other two species. *S. bayanus* displayed the lowest rate of glucose uptake of the *Saccharomyces* strains examined. High-affinity uptake appeared to increase at the expense of low-affinity uptake. The uptake capability of any given strain might be determined by the gene dose for the carrier and/or its regulator(s) or by other factors in its genetic background.

Glucose uptake was investigated in fermentative and nonfermentative species of the genus *Pichia*. The two fermentative strains *P. strasburgensis* and *P. guillermondii* resembled *Saccharomyces* spp. in increasing the activity of high-affinity uptake upon glucose limitation. In contrast, *P. heedii* did not lose high-affinity uptake when grown on high glucose; however, a decrease in carrier activity was evident

late in the growth cycle. Similarly, in *Y. lipolytica*, another nonfermenter, the presence of a high glucose concentration in the medium did not result in loss of high-affinity uptake. However, in *Y. lipolytica* the activity of both uptake systems remained constant, whereas in *P. heedii* the activity of both systems appeared to be affected by substrate concentrations in the medium. *S. bayanus* is respirofermentative but resembles the nonfermentative yeasts, displaying overall low rates of glucose uptake with no dramatic derepression of uptake upon limitation for glucose. Perhaps the evolution of *S. bayanus* involved an increased reliance on respiratory growth. If so, there would be no advantage for the organism to maintain the glucose uptake regulatory system apparent in *S. cerevisiae*.

Uptake of glucose is a highly regulated step. The activity of the glucose carriers is influenced by the concentration of glucose in the medium and the stage of growth as well as by nutrient limitation (7). During fermentative growth in yeasts, glucose uptake is viewed as the rate-limiting step of glycolysis because rate of uptake is generally equivalent to rate of flux through the pathway. However, it is not yet possible to distinguish between a model where uptake is rate limiting and one in which the rate is regulated or adjusted to allow the appropriate flux through glycolysis. The rate at which energy can be derived from hexoses is a function of the activity of the enzymes of catabolism and the ability of the cell to take up glucose. In a cell where the overall K_m of the enzymes of catabolism is lower than that of uptake, the derepression of uptake activity provides a mechanism whereby the availability of sugar for catabolism can be held reasonably constant while the concentration of sugar outside the cell is dropping. In cells where the flux through catabolism is the limiting step, however, no advantage can be gained by such regulation. The step(s) limiting catabolism may vary from species to species of yeasts. Evaluation of yeasts with different carbon and energy utilization strategies provides insights into which metabolic steps might be linked to the regulation of glucose uptake. Since the repressibility of high-affinity uptake did not appear to be an advantage to the nonfermentative yeast strains studied, this regulation may be a function of fermentative rather than respiratory signals.

In conclusion, variation exists among yeast strains in the regulation and expression of glucose uptake. Analyses of glucose uptake components require consideration of the genetic backgrounds involved. Yeasts that are fermentative in general show a derepression of high-affinity uptake upon limitation for glucose. Those depending more on respiration, on the other hand, display a variety of regulatory strategies.

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