Animal Feed Science and Technology xxx (2008) xxx–xxx

Contents lists available at ScienceDirect

Animal Feed Science and Technology

journal homepage: www.elsevier.com/locate/anifeedsci

Review

Effects of analyzable diet components on responses of lactating dairy cows to *Saccharomyces cerevisiae* based yeast products: A systematic review of the literature

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ARTICLE INFO

Article history:
Received 13 September 2007
Received in revised form 1 October 2008
Accepted 6 October 2008
Available online xxx

Keywords:
Yeast
Lactation
Saccharomyces cerevisiae
Systematic review

ABSTRACT

Feeding experiments that used lactating Holstein cows, from peer review publications since 1990, were used to determine the ability to predict production responses of lactating dairy cows to feeding *Saccharomyces cerevisiae* yeast products (YP) based upon the composition of their diets in a systematic review of the literature. The 22 published experiments reflected 6 YP, with one being used in 7 experiments, 2 in 6 experiments each, and 3 in one experiment each. There were analytical (*i.e.*, neutral detergent fiber (NDF) and starch) differences ($P<0.05$) in the diets fed, and milk yield, milk energy output and milk fat proportion differences ($P<0.05$) among the control group cows of the experiments of the 3 major (based upon numbers of published studies) YP. However, the proportional milk, milk component, milk energy and dry matter (DM) intake response of the cows to feeding of the 3 major YP did not differ. Simple correlation coefficients of the combined data set (*i.e.*, $n=22$) suggested that higher diet NDF or acid detergent fiber (ADF) levels reduced the production response to feeding any YP, while higher diet starch level had little impact. Increased milk and milk energy output of the control cows reduced productive benefits of feeding a YP, and results suggest that the YP milk yield response was absolute (about 0.9 kg/cow/d) and that it decreased proportional to control group milk yield as control group milk yield increased. Multiple correlation analysis showed that only milk output and milk protein output response to feeding a YP could be acceptably, but modestly

Abbreviations: ADF, acid detergent fiber (general term no specific procedure); BW, body weight; CP, crude protein; DIM, days in milk; DM, dry matter; DMI, DM intake; NDF, neutral detergent fiber (general term no specific procedure); NE, net energy; PTY, cow parity; YP, yeast products.

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doi:10.1016/j.anifeedsci.2008.10.003

(r^2 = 0.49 and 0.44, respectively), predicted based upon milk production of the control group cows and the chemical composition of the diet. However, the precision of these predictions appeared to be compromised by the unequal allocation of NE_l between milk and BW change by the YP fed cows among experiments. Thus, a reduced set of experiments (*i.e.*, n = 11) in which BW and BW change had been measured, thereby allowing the percentage response in NE_l output to feeding of a YP to be calculated, suggests that the percentage increase in NE_l output to feeding of a YP will be suppressed in diets with higher NDF and CP levels, although changes will be more positive as the fermentability of the NDF (*i.e.*, the ADF/NDF ratio in this analysis) decreases. These findings can be interpreted to support the currently proposed mode of action of *Saccharomyces cerevisiae* YP that they act to stimulate rumen microbes that increase fermentability of fiber, but not to support another currently proposed mode of action that they allow rumen microbes to more effectively metabolize end-products of ruminal starch fermentation. Regardless, overall benefits to feeding *Saccharomyces cerevisiae* YP on milk and NE_l output are modest (*i.e.*, 2.7 and 5.3%, respectively). Future feeding studies with YP should consider dose response designs at YP feeding levels higher than those used in past studies, as well as report BW and BW change to allow YP response on animal energetics to be assessed.

Contents

1. Introduction

Yeast products (YP) are widely utilized as feed additives for ruminant animals in many parts of the world. There are a number of corporate groups that produce them, and they are marketed under a variety of trade names. While the number of YP that have undergone evaluation in controlled research studies is somewhat limited, there is a widespread belief among dairy and beef producers, and ruminant nutritionists that they are beneficial by enhancing dry matter (DM) intake and overall animal performance.

Mechanisms have been proposed to explain why YP could stimulate DM intake and productivity in growing and lactating cattle. Perhaps the oldest is that the yeasts are able to grow, at least for a short period of time, in the rumen thereby directly enhancing fiber digestion (Fuller, 1989) and/or producing nutrients that stimulate growth of rumen cellulolytic bacteria (Dawson et al., 1990), which are responsible for the bulk of fiber digestion. It has also been suggested that yeasts utilize nutrients, such as lactic acid, which if allowed to accumulate in the rumen, could suppress bacterial growth and/or suppress DM intake by lowering rumen pH (Nisbet and Martin, 1990). A more recently suggested possibility is that growth of yeast in the rumen utilizes trace amounts of dissolved oxygen, particularly at the interface of the cellulolytic bacteria and fiber, thereby stimulating growth of rumen bacteria to which oxygen is toxic (Newbold et al., 1996). It seems clear that for these mechanisms to be functional, yeasts in the YP would have to be viable, in the sense of being able to grow, for at least a short period of time in the rumen.

The alternate mechanism is that it is the yeast culture that is created in the yeast fermentation process which provides a mixture of micronutrients that stimulate bacterial growth in the rumen thereby facilitating increased fermentation of fiber and/or utilization of the end-products of fiber fermentation in order to prevent their accumulation in the rumen (Callaway and Martin, 1997). Support for this theory is a limited data base showing that when cultures of live brewers or fermentation yeasts are fed to ruminants, there are few, if any, changes to rumen fermentation and/or animal performance (Seymour et al., 1995; Blauwiekel et al., 1995; Besong et al., 1996; Ando et al., 2004).

Our objective was to examine dairy cattle lactation studies, which have been published in peer reviewed scientific journals, and examined impacts of defined YP on animal performance in order to determine, in a systematic review of the literature, if analyzable diet characteristics can be utilized to predict changes in animal performance due to feeding YP. Mechanisms by which YP could be efficacious will only be addressed indirectly. This manuscript was prepared from data summarized in preparation for an invited presentation to the American Dairy Science Association in July of 2007.

2. Materials and methods

This study was based upon feeding experiments using lactating Holstein cows fed YP as reported in peer review publications. The principle was that responsiveness of animal production parameters to YP feeding might be predictable based upon analyzable characteristics of the diets fed to the cows by using a systematic review of the literature.

2.1. Source of data

Experiments utilized in this study were selected based upon criteria that included publication in a peer review scientific journal, use of lactating Holstein cows, feeding of a defined YP based upon *Saccharomyces cerevisiae* to a treatment group, reported intake of DM, reported yield of milk, as well as milk protein and fat proportions, and reported average diet neutral detergent fiber (NDF), acid detergent fiber (ADF) and crude protein (CP) proportions (or that sufficient information on diet ingredients was provided in order to allow them to be estimated with confidence). All experiments covered relatively brief time periods, typically from 9 to 18 weeks, or in crossover designs with 4-week experimental periods. In some cases, control and treatment groups were averaged among experiments within a publication, particularly if cow numbers were judged to be low and/or differences between experiments within publication were judged not to be important. Data were tabulated within experiment and summarized among YP (Table 1).

Overall, 22 experiments (from 17 publications) were utilized in this study. These publications were from the Atlantic Dairy and Forage Research Institute (Fredericton Junction, New Brunswick, Canada; 2 publications and 3 experiments), the Lennoxville Research Centre (Lennoxville, Quebec, Canada; 1 publication and 1 experiment), the Ohio State University (Columbus, OH, USA; 1 publication and 1 experiment), Pennsylvania State University (State College, PA, USA; 1 publication and 1 experiment), the Rowett Research Institute (Aberdeen, Scotland; 1 publication and 2 experiments), Rutgers University (New Brunswick, NJ, USA; 2 publications and 3 experiments), the South Dakota State University (Brookings, SD, USA; 1 publication and 1 experiment), the University of California (Davis, CA, USA; 1 publication and 1 experiment), the University of Cattolica (Piacenza, Italy; 1 publication and 1 experiment), the University of Delaware (Newark, DE, USA; 1 publication and 2 experiments), the University of New Hampshire (Durham, NH, USA; 1 publication and 2 experiments), the University of Pretoria

Table 1
Individual study data as utilized in the statistical analysis.

	Diet			DIM[2] (d)	PTY[3] (#)	Performance of control cows				
	CP (g/kg of DM)	NDF (g/kg of DM)	ADF (g/kg of DM)			DMI (kg/d)	Milk (kg/d)	Fat (g/kg of milk)	Protein (g/kg of milk)	Milk NE (MJ/d)
Alltech 1026										
Chiquette (1995)[1]	132.8	345	169	–	2	20.10	34.00	31.4	28.7	92.6
Erasmus et al. (1992)	165.0	315	191	150	2	21.80	18.90	31.9	34.1	54.0
Putnam et al. (1997)										
Low diet CP	161.0	283	172	–	1	18.10	31.00	30.4	30.3	84.3
High diet CP	188.0	262	169	–	1	18.30	31.60	32.3	30.8	88.5
Williams et al. (1991)										
Hay based diets	172.0	413	251	63	2	16.75	22.90	34.9	32.2	67.0
Straw based diets	181.9	345	196	63	2	17.70	23.35	34.5	34.8	69.2
Chr. Hansen Biomate										
Kung et al. (1997)[1]										
Primiparous cows	151.0	364	210	117	1	22.80	39.60	29.9	25.6	103.1
Multiparous cows	170.0	413	237	196	2	20.80	32.90	35.8	31.3	96.8
Soder and Holden (1999)[1]	165.0	332	205	46	1/2	22.10	40.20	39.2	31.5	123.6
Wohlt et al. (1991)	171.0	312	178	63	1	19.20	26.00	39.6	32.3	80.8
Wohlt et al. (1998)										
Early lactation	177.4	352	204	14	2	18.00	34.30	42.6	30.9	109.4
Mid lactation	177.4	352	204	77	2	23.85	40.40	33.1	30.5	114.4
Diamond V 'YC'										
Arambel and Kent (1990)	165.0	474	294	100	2	21.90	37.90	33.3	29.7	106.7
Diamond V 'XP'										
Cooke et al. (2007)[1]	180.0	389	175	210	2	26.20	37.40	38.7	31.9	114.6
Erasmus et al. (2005)[1]	181.0	312	192	49	2	22.20	36.30	37.4	30.3	108.3
Robinson and Garrett (1999)[1]										
Primiparous cows	171.9	293	166	28	1	14.34	25.36	38.8	31.6	77.7
Multiiparous cows	171.9	293	166	28	2	19.45	38.60	38.8	30.5	117.3
Robinson (1997)[1]	142.5	325	193	14	2	17.38	34.09	41.7	32.6	108.8
Schingoethe et al. (2004)[1]	175.0	308	202	147	2	23.10	34.90	33.4	28.5	97.5
Wang et al. (2001)[1]	190.0	304	210	70	2	24.40	42.65	33.5	30.9	121.3
Thepax Dry										
Piva et al. (1993)	176.0	335	211	126	2	21.10	25.40	32.5	33.8	72.9
Vi-cor A-Max										
Bruno et al. (2009)	170.5	351	220	80	2	26.00	42.20	35.8	30.4	123.4

[1] These studies are also a part of the reduced data set in which BW and BW change data were reported (used in Table 6).
[2] Days in milk.
[3] Parity number of the cows where 1 = primiparity and 2 = multiparity.

Please cite this article in press as: Robinson, P.H., Erasmus, L.J., Effects of analyzable diet components on responses of lactating dairy cows to *Saccharomyces cerevisiae* based yeast products.... Anim. Feed Sci. Technol. (2008), doi:10.1016/j.anifeedsci.2008.10.003

(Pretoria, South Africa; 2 publications and 2 experiments), The University of Georgia (1 publication and 1 experiment) and Utah State University (Logan, UT, USA; 1 publication and 1 experiment). If an eligible (relative to the above stated criteria) publication is not included in Table 1, it is simply because the authors did not find it.

Overall, the studies represent 6 experiments using the Alltech'1026' product (Alltech. Inc. Lexington, KY, USA), 6 experiments using the Chr. Hansen 'Biomate' product (Chr. Hansen Biosystems, Milwaukee, WI, USA), 1 experiment using the Diamond V Mills 'YC' product (Diamond V Mills Inc., Cedar Rapids, IA, USA), 7 experiments using the Diamond V Mills 'XP' product (Diamond V Mills Inc.), 1 experiment using the Dox-Al 'Thepax Dry' product (Dox-Al, Correzzana, Italy) and 1 experiment using the Vi-Cor 'A-Max XTRA' product (Varied Industry Company, Mason City, IA, USA). All products were fed at the same daily dose level per cow within product.

2.2. Assumptions and some calculations based upon reported data

Using published literature among experiments (and among experimental sites) is always difficult as there is substantial variation among experiment and experimental site in reported parameters. To meet the stated objective, accurate estimates of DM intake, milk production, milk fat and protein proportions and some dietary analytes were critical. These criteria, particularly the need for dietary information, eliminated some studies whose authors either did not measure or did not report these values. In a very few cases, dietary CP, NDF or ADF was estimated from assays of feeds that were presented in the publication and/or tabular values. The exception is the values reported for starch in Table 1. As no authors reported diet or diet ingredient starch values, starch values of all diets were estimated from the same tabular base (MAFF, 1992) with the same starch value used within ingredient among studies.

There was a need for some other assumptions and presumptions. Relative to diet analyses, DM was determined by either 105 °C oven or toluene procedures, NDF and ADF were certainly assayed by a variety of methods, but CP was almost always based on a Kjeldahl analysis and no attempt was made to correct any of these reported values to a common base. In the absence of any consistent index of fiber fermentability among experiments, the dietary fiber ratio of ADF to NDF (*i.e.*, the only method possible based upon common data reported in the publications to create a replacement for a lignin(sa)/NDF ratio) was calculated as a surrogate for it as:

$$\frac{\text{ADF}}{\text{NDF}} = \left(\frac{\text{ADF (g/kg diet DM)}}{\text{NDF (g/kg diet DM)}}\right)$$

Relative to the cows, it was not always clear if reported milk protein was crude or true protein, although most were likely the former, but they were not corrected to a common base. Data in Table 1 were used to calculate some other animal values (Table 1) including the energy content of milk as:

$$\text{NE}_\text{l}\text{milk}\ \left(\frac{\text{MJ}}{\text{d}}\right) = \left(\frac{((4.072 \times (\text{milk CP(g/kg)})) + (2.265 \times (\text{milk fat (g/kg)})) + 102.77)}{2204}\right) \times 4.18$$

according to the Tyrrell and Reid (1965) equation where the factor 2204 converts Kcal/lb to Mcal/kg and the factor 4.18 converts Mcal/kg to MJ/kg.

In a smaller set of data (noted in Table 1), where average BWs and BW changes were listed in the original publication, total NE_l output was calculated as the sum of maintenance, BW change and milk energy as:

$$\text{NE}_\text{l}\ \text{output}\left(\frac{\text{MJ}}{\text{d}}\right) = ((((\text{BW}^{0.75}) \times 0.08 \times 4.18) + (\text{BW change (kg/d)}) \times 4.97 \times 4.18) + (\text{NE}_\text{l}\ \text{milk})) \times (\text{milk (kg/d)})$$

where NE_l for maintenance (*i.e.* $((\text{BW}^{0.75}) \times 0.08)$) is based on National Research Council (NRC, 1989), energy of BW change (*i.e.* ((BW change (kg/d)) × 4.97)) is the average of that for BW loss and gain (NRC, 1989), as gain and loss were likely occurring simultaneously among cows within treatment groups within experiment, and that for milk energy was as defined above.

Table 2
Characteristics of the diets and performance of the control group cows in the studies that used the three main yeast products.

	Alltech 1026	Chr. Hansen Biomate	Diamond V 'XP'	SEM
Experiments (*n*)	6	6	7	
Publication date	1994[a]	1995[a]	2002[b]	2.4
Intake and diet				
DM intake (kg/d)	18.8	21.1	21.0	2.14
CP (g/kg diet DM)	167	169	173	10.8
NDF (g/kg diet DM)	327	354	318	29.0
ADF (g/kg diet DM)	191	206	186	16.4
Starch (g/kg diet DM)	308[a]	258[b]	280[a,b]	27.8
Production				
Milk (kg/d)	27.0[b]	35.6[a]	35.6[a]	4.01
Milk Energy (MJ/d)	76.1[b]	104.5[a]	106.6[a]	10.5
Milk composition				
Fat (g/kg)	32.6[b]	36.7[a]	37.5[a]	2.37
Protein (g/kg)	31.8	30.4	30.9	1.45
N efficiency[1]	0.271	0.296	0.303	0.0420

Means on the same line with different superscripts (a and b) differ ($P<0.05$).
[1] Defined as: (milk N/intake N).

2.3. *Statistical analysis*

Differences among the three major YP (*i.e.*, as defined by numbers of experiments) in characteristics of the cows and diets on the control treatments as well as their responsiveness to YP addition (*i.e.*, Tables 2 and 3), were analyzed using a systematic review of the literature with the GLM option of SAS (1998) with a model that considered each experiment (6 or 7 per YP) as observations. Statistical implications within reported experiments were not considered in inputting treatment means.

Correlative statistics using the proc stepwise (backward elimination) procedure of SAS (2006) was used to assess relationships between output and input parameters. Parameters significant at $P<0.2$ were generally retained in models. It is not common to use ratios of variables, as has been done here in some cases, in regression analysis and it is possible that ratios of normally distributed variables may not fully meet the assumptions of equal normally distributed errors required by standard regression techniques.

3. Results and discussion

The statistical procedure used to determine impacts of defined characteristics of diets among experiments on changes in animal performance will be considered to be biased by some statisticians due, perhaps, to the use of proportional responses as the predicted parameters rather than absolute

Table 3
Percentage changes in some animal response parameters compared to the control group as impacted by feeding the three main[1] yeast products.

	Alltech 1026	Chr. Hansen Biomate	Diamond V 'XP'	SEM
Experiments (*n*)	6 (% change *vs.* control)	6 (% change *vs.* control)	7 (% change *vs.* control)	
Milk yield (kg/d)	2.7	2.6	3.6	2.23
Milk fat yield (kg/d)	4.3	4.0	4.9	2.95
Milk CP yield (kg/d)	2.8	1.2	2.4	1.93
Milk energy output (MJ/d)	3.4	2.8	3.0	2.17
DM intake (kg/d)	4.3	−0.8	1.8	3.00
N efficiency[2]	−1.4	2.1	2.9	2.85

[1] As defined by the number of available lactation experiments.
[2] Defined as: (milk N/intake N). No means on a line differed at $P<0.05$.

responses. However, as the control values varied sharply among studies, the authors believe that absolute responses would be misleading and that proportional responses are most appropriate in this case. Nevertheless, readers are cautioned to critically evaluate this approach prior to accepting its biological implications.

While the authors are aware that meta analysis approaches are widely used in our science at this time, its fundamental assumption that differences in responses among experiments are due to random events among (or within) experiments is not accepted by the authors. While randomness is a well accepted statistical term, it should have no place in the biological sciences where apparently random events merely represent our inability as biologists to explain them. A systematic approach, in contrast to an approach that uses ‘experiment’ as a random factor, seeks to explain and predict an outcome from known, or suspected, factors that influence it among studies. In this context, a systematic approach that uses known differences among studies to predict an outcome, rather than an approach that allocates unexplained biological variation to random events, is a better way to predict future events when those predictive factors are known.

No comments in this, or other, sections should be interpreted as support for, or criticism of, any particular YP that was in any publication cited in this study.

3.1. *Differences among yeast products*

It is not common in scientific literature to discuss impacts of a concept or principle relative to commercial products. However, the literature of YP, at least as it pertains to dairy cattle, is virtually all based upon corporate products that were utilized in lactation studies. Thus, discussion of impacts of YP must inevitably address differences (or the lack thereof) among corporate products. However, as only the Alltech^{1026}, Diamond V Mills (*i.e.*, ‘XP’) and Chr. Hansen Biomate YP had a sufficient number of experiments to support statistical analysis of differences between them, only these materials were compared statistically.

It is clear that the characteristics of the diets fed to the cows varied among the major YP (Table 2), with the Chr. Hansen studies having higher (P<0.05) dietary NDF levels than the Diamond V Mills studies, with Alltech^{1026} studies intermediate. However, diet starch levels were higher (P<0.05) for the Alltech^{1026} *versus* Chr. Hansen studies, with the Diamond V Mills studies intermediate. The Alltech^{1026} studies used cows with lower (P<0.05) milk yield, milk energy output and milk fat proportion, perhaps partly reflecting its older data base and that 3 of its 6 experiments were completed in Britain and South Africa.

In spite of these differences among YP experiments, there were no differences among them in production characteristics (defined as the percentage increase in the YP *versus* the control group),

Table 4
Simple correlation coefficients between available input parameters and percentage change in some output parameters due to feeding a yeast product (represents all experiments listed in Table 1).

	Milk[1] (kg/d)	Input parameters				
		Diet				
		CP (g/kg DM)	NDF (g/kg DM)	ADF (g/kg DM)	Starch (g/kg DM)	ADF/NDF
	Correlation co-efficient (r)					
Milk yield (kg/d)	−.35	.24	−.54[c]	−.55[c]	.35	−.05
Milk fat yield (kg/d)	−.07	−.02	−.23	−.19	.22	.08
Milk protein yield (kg/d)	−.37[a]	.35	−.53[b]	−.37[a]	.26	.26
Milk energy output (MJ/d)	−.46[b]	.17	−.30	−.19	.31	.16
DM intake (kg/d)	−.24	.14	−.45[b]	−.40[b]	.32	.09
N efficiency[2]	.29	.11	.06	−.12	−.12	−.26

[1] Milk production of the control group cows within experiment.
[2] Defined as: (milk N/intake N).
[a] Coefficient indicates a correlation (P<0.10).
[b] Coefficient indicates a correlation (P<0.05).
[c] Coefficient indicates a correlation (P<0.01).

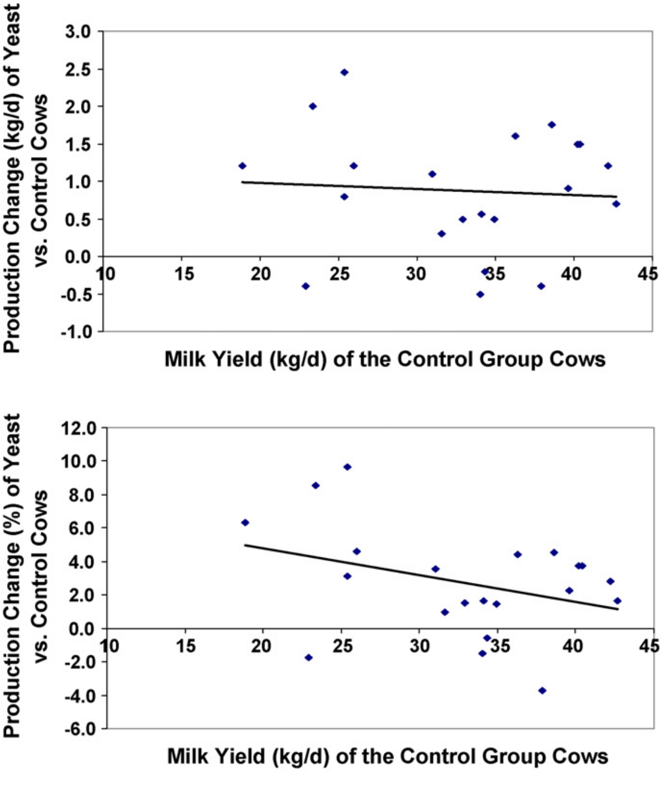

Fig. 1. Relationships between control group milk yield (MlkC: kg/d) and change in milk yield (kg/d) with yeast feeding (upper) and the percentage change in milk yield (lower) [upper: $y = 1.26 - (0.0135 \times \text{MlkC})$ $r^2 = 0.01$, P=0.66 and lower: $y = 8.06 - (0.162 \times \text{MlkC})$ $r^2 = 0.12$, P=0.12].

with only differences among YP in their DM intake response approaching statistical significance (Table 3).

3.2. Relationships between individual diet characteristics and production responses to feeding a yeast product

Based upon the lack of difference among the three major YP in their production responses (Table 3), they were pooled for subsequent correlative analysis and the other 3 experiments (1 for each of 3 products) were added to the data set.

It became clear early in this procedure that the response to feeding YP was impacted by the absolute milk production of the control group. However, this impact seemed limited to the proportional, rather than absolute, response. Illustrated for the change in milk yield in response to feeding a YP in Fig. 1, it is clear that the absolute response in milk yield was relatively constant (at about 0.9 kg/d of milk) regardless of the level of milk production of the control cows. In contrast, the proportional response tended (P=0.12) to decline as the milk production of the control cows increased. For this reason, the milk production of the control cows was added to diet characteristics as a predictor of proportional changes in production characteristics relative to feeding of a YP.

Nevertheless, higher milk production of the control cows only impacted (P<0.05) the response in milk energy output (which was negative) to feeding a YP (Table 4). A higher CP level of the experimental diet only tended (P<0.10) to impact the YP effect on milk protein output (which was positive). In contrast, increasing the NDF level of the diet had a strong negative impact (P<0.05) on the response of

Table 5
Multiple correlations between available input parameters and the percentage change in some output parameters[1] due to feeding a yeast product (all experiments listed in Table 1). Values represent multiple regression coefficients with the ‘*P*’ value of each in parentheses.

	Intercept	Input parameters					*P*	r^2
		Milk[2] (kg/d)	Diet					
			CP (g/kg DM)	NDF (g/kg DM)	Starch (g/kg DM)	ADF/NDF		
Output parameters (percentage change in yeast vs. control cows)								
Milk yield (kg/d)	51.31 (0.01)	−0.1510 (0.08)	–	−0.0618 (<0.01)	−0.0321 (0.04)	−23.18 (0.11)	0.02	0.49
Milk protein yield (kg/d)	5.73 (0.49)	−0.1325 (0.09)	0.0560 (0.16)	−0.0263 (0.02)	–	–	0.01	0.44
Milk energy output (MJ/d)	−36.2 (0.53)	−1.154 (0.05)	–	–	0.100 (0.22)	89.7 (0.24)	0.07	0.31
DM intake (kg/d)	12.46 (<0.01)	–	–	−0.0273 (0.04)	–	–	0.04	0.20
N efficiency (milk N/intake N)	−108 (0.94)	20.35 (0.13)	9.31 (0.22)	–	–	−3460 (0.09)	0.18	0.23

1 There was no fit for fat yield with *P*<0.20.

2 Milk production of the control group cows within experiment.

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Table 6
Multiple correlations between available input parameters[1] and the percentage change in two output parameters[2] due to feeding a yeast product[3]. Values represent coefficients in the multiple regression with the 'P' value of each in parentheses.

	Intercept	Input parameters					P	r^2
		Milk[2] (kg/d)	Diet					
			CP (g/kg DM)	NDF (g/kg DM)	Starch (g/kg DM)	ADF/NDF		
Output parameters (% change in yeast vs. control cows)								
Milk yield (kg/d)	1.15 (0.89)	−0.3356 (0.07)	0.0829 (0.09)	–	–	–	0.09	0.46
Total NE_l output (MJ/d)	330.7 (<0.01)	–	−0.586 (0.09)	−0.265 (0.10)	–	−211.5 (0.05)	0.04	0.68

[1] This is the reduced data set (as indicated in Table 1) for studies that reported BW and BW change by treatment in addition to the values listed in Table 1.
[2] There was no fit for milk energy output with $P<0.20$.
[3] Milk production of the control group cows within experiment.

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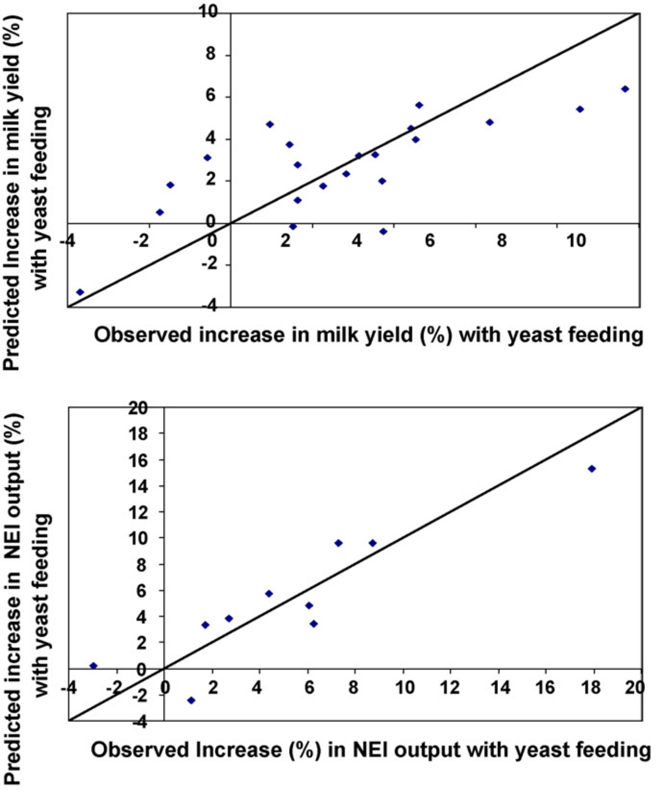

Fig. 2. Relationships between the observed and predicted (from the equation listed in Table 5) increases in milk yield (%) with yeast feeding (upper) and those observed and predicted (from the equation listed in Table 6) increases in NEl output (%) with yeast feeding (lower). Lines of equality are illustrated [upper: full data set of 21 studies and, lower: reduced data set of 10 studies (see Table 1 for designation of studies between the two data sets].

the cows to feeding of a YP in terms of milk yield, milk protein yield and DM intake. Increasing the ADF level of the diet had an even stronger effect than NDF (P<0.01) on suppressing a response to feeding of a YP, although its impact on the milk CP response was less than for NDF (*i.e.*, P<0.10). Starch level of the experimental diet, and the ADF/NDF ratio, were poor predictors of the impact of feeding a YP on any response parameter.

3.3. Relationships between combined diet characteristics and production responses to feeding a yeast product

Multiple correlative predictions of responses of several production characteristics of the cows to feeding of a YP are in Table 5. In general, as the milk production of the control group cows increased, the percentage production benefit to feeding a YP declined, and it was strongest for milk protein yield (P=0.03) and milk yield (P=0.053). The negative impact of increasing NDF in the diet on the production response to a YP was similar to the milk production of the control cows, with both milk and milk protein yield most strongly impacted (P<0.01). Starch level and the ADF/NDF ratio in the diet were weak predictors of the response to feeding a YP.

Overall, the percentage change in milk yield and milk protein yield due to feeding a YP were the most precisely predicted output parameters by the multiple correlation equations (P=0.01 and 0.02 and r^2 = 0.52 and 0.45, respectively) but, based upon the number of input parameters in the correlation analysis, these are not strong predictors. The relatively poor prediction of the milk yield response to feeding a YP is illustrated in Fig. 2 (upper).

3.4. Relationships between combined diet characteristics and milk, milk energy and net energy for lactation output responses to feeding a yeast product

Visual inspection of the predictability of production responses within experiment suggested that, in some experiments, the milk production response to feeding a YP may have been impacted by the change in body weight (BW) between treatments. Unfortunately, only 11 of the 22 experiments reported average BW and BW change of the control and treatment groups, which would have allowed total energy for lactation (NE_l) output (as opposed to only milk energy output) to have been calculated. Nevertheless these experiments were used in a second multiple correlation analysis to determine the predictability of total energy output response to feeding a YP (*i.e.*, NE_l as defined as the sum of energy in milk, for maintenance and in BW change).

While this is a very low number of experiments to attempt such a correlation analysis, and results should be considered with due care, results (Table 6) suggest that the response in NE_l output to feeding a YP is much more predictable (*i.e.*, P=0.04; r^2 = 0.68) than for milk yield or milk energy output. However, in this analysis, the diet ADF/NDF ratio is the strongest (negative) predictor of a response to feeding a YP, although increasing dietary levels of NDF are likely to suppress a response and increasing levels of starch are likely to increase a response to feeding a YP. The much improved ability to predict the change in NE_l output to feeding of a YP, *versus* milk *per se* in the full data set, is illustrated in Fig. 2 (lower). It is noteworthy that the very high increase in NE_l output to feeding of the YP in Chiquette (1995) is well predicted.

4. Conclusions and recommendations

There is no evidence that the responsiveness of dairy cows to feeding any of the three most published YP varied, in spite of differences in the characteristics of the diets, and/or control group cows, among YP studies. Examination of all published lactation experiments with a *Saccharomyces cerevisiae* based YP (*i.e.*, 22) suggests that the response in milk production to feeding a YP is absolute (about 0.9 kg/d), and declines proportionally as level of milk yield of the cows increases. This may be because all YP were fed relative to cow, rather than relative to DM intake (at least among experiments), meaning that cows with higher DM intakes (among experiments) consumed less YP per kg of DM intake. Future experiments should use dose response designs in feeding of YP, particularly at levels above those that have been examined in past studies, in order to determine if higher animal responses to YP are possible. This might particularly be true for cows consuming higher levels of DM since, if YP function in the rumen, it seems biologically sensible that YP should be fed relative to DM intake rather than cow.

The response in milk and milk protein yield, to feeding of a YP, could be predicted with only modest precision based upon milk yield of the control cows and some analyzable characteristics of the diet that was fed. However, the precision of these predictions appeared to be compromised by unequal allocation of the increased NE_l between milk and BW change among experiments. A reduced set of experiments (*i.e.*, 11) in which BW and BW change were measured, thereby allowing the response in NE_l output to feeding of a YP to be calculated, suggests that the percentage increase in NE_l output in response to feeding a YP will be suppressed in diets with higher NDF levels, although changes will be much more positive as the fermentability of the NDF (*i.e.*, decreased ADF/NDF ratio in this analysis) increases. Future studies should report BW and BW changes of cows in order to examine energetic responses to feeding of YP, which seems to be a fundamentally different biological question than how cows use that extra energy.

These findings can be interpreted as support for the commonly proposed mode of action of *Saccharomyces cerevisiae* based YP, that they act to stimulate rumen microbes that increase fermentability of fiber, since the negative impact of increasing NDF levels in the diet suggests that as the ratio of NDF/YP consumed increases, that the response declines. In contrast, the general lack of any impact of increasing dietary levels of starch (that were calculated for each experiment based upon tabular values) on

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the relative YP response can be interpreted as a lack of support for another commonly proposed mode of action of *Saccharomyces cerevisiae* based YP, that they allow rumen microbes to more effectively metabolize the end-products of ruminal starch fermentation, since increasing starch levels in the diet would have been expected to reduce the impact of YP, if this was the mode of action.

The modest benefits in milk yield, milk energy yield and NE_l output (*i.e.*, 2.7, 3.1 and 5.3%, respectively) further support the previous recommendation of future experiments with dose response designs in feeding of YP to determine if higher animal responses are possible, while suggesting that higher per cow feeding levels of YP may be suggested in cases where DM intake and or the NDF concentration of the diet increase.

Acknowledgments

The authors thank Dr. Bill Sanchez for encouraging them to undertake this project. The authors very much appreciate the efforts of Dr. Tom Famula relative to comments and thoughts on the statistical methods that were used.

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