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EFFECTS OF DIETARY YEAST CULTURE SUPPLEMENTATION DURING THE CONDITIONING PERIOD ON EQUINE EXERCISE PHYSIOLOGY

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SUMMARY

Two groups of previously unconditioned young adult horses participated in 6 weeks of gradually increasing exercise on an inclined plane treadmill while receiving a corn-oats-hay diet with or without a commercially available dietary yeast culture preparation. Forced treadmill exercise at a workload of 11.98 j/kg/m, equivalent to a workrate of 18.34 j/sec/kg and an estimated ground speed of 5.36 m/sec, began at 5 minutes per day (2.75 Mjoules/500 kg bodyweight) and was increased by 5 minutes per week to a maximum of 35 minutes per day (19.25 Mjoules/500 kg) after 6 weeks. Treadmill exercise increased venous plasma lactate concentrations in direct proportion to the duration of an exercise bout, but the increases tended to be smaller after a given amount of work as the horses became conditioned. At the end of 35 minutes of exercise, plasma lactate concentrations averaged 30.08 mg/dl in the supplemented horses and 41.29 mg/dl in the unsupplemented horses ($p<.01$). Plasma glucose concentrations decreased significantly and triglyceride concentrations increased significantly in both groups at exercise duration exceed 10 minutes. Changes in plasma glucose concentrations were not significantly affected by yeast culture supplementations, while the supplemented horses exhibited somewhat slower rates of increased plasma triglyceride concentrations. During the 35-minute exercise bouts, significantly lower heart rates were recorded in the supplemented horses during the first 5 and the final 10 minutes of the workouts ($p<.01$), suggesting an enhanced state of athletic fitness. The digestible energy required for work (Mcal/500 kg bodyweight) was calculated to be 0.454 (Mcal/Mjoule) (Mjoules of work/500 kg bodyweight) + 0.024 Mcal/500 kg bodyweight ($r^2=0.95$), with an efficiency of converting dietary DE to work of 53% for both groups of horses. Although the exercise challenges to these horses were not severe, these results suggest that dietary yeast culture supplementation of horses entering into conditioning programs may well enhance athletic training.

INTRODUCTION

Fuel availability, metabolism and efficiency of utilization are among the most important, if poorly understood, concerns of the performance horse. Because intensively managed equine athletes are dependent on effective and efficient nutritional programs, much recent equine nutrition and exercise physiology research has focused on the energetics of the performance horse and the dietary means for satisfying energy requirements.[8, 21]

Methods of increasing the digestible energy extractable from the rations of equine athletes has also attracted attention. In particular, the addition of commercially-available dried yeast culture supplements to equine feedstuffs has been reported to increase their digestible energy content, [9, 10] by increasing the extent of dietary hemicellulose and cellulose fermentation in hindgut. Increased volatile fatty acid production might exert a carbohydrate-sparing effect similar to that apparently accompanying dietary fat supplementation of racehorses, perhaps enhancing or prolonging performance.[18] Additionally, dietary supplementation of yearling horses with yeast cultures had been shown to increase the efficiency of nitrogen utilization and to increase net nitrogen retention.[9] Although the fate of the additionally retained nitrogen and whether nitrogen retention can be similarly enhanced in mature horses are not

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Table **1**. Ingredients and nutrient compositions of diets fed horses during 6 weeks of exercise conditioning.

Ingredients

Concentrates	Hays
44.8% crimped oats	60% grasses
44.8% cracked corn	40% alfalfa
9.0% molasses	
0.9% mineral mix	
0.5% salt	

Nutrient Composition

	Concentrate	Hays	Yeast Culture
		Mcal/kg dry matter	
Digestible energy	3.00	1.75	3.17
		g/kg dry matter	
Crude protein	112.5	133.0	125.0
Lysine	3.4	9.0	5.5
Methionine	3.3	2.6	2.5
Arginine	16.4	10.2	7.5
Leucine	17.6	13.9	12.5
Isoleucine	11.9	8.8	4.0
Valine	11.7	9.2	4.5
Hemicellulose	82.5	205.4	299.7
Cellulose	68.1	294.6	20.0

known, if muscle development is accelerated by dietary supplementation with yeast cultures during an exercise conditioning program, subsequent athletic performance might be improved.

Increased energy extraction from feed, potentially increased muscle glycogen availability, enhanced protein deposition and decreased muscle protein catabolism might synergistically impact favorably on equine athletic performance. The possibility that dietary yeast culture supplementation of unconditioned adult horses could affect their performance during a 6-week forced exercise conditioning regimen was investigated by observing changes in plasma metabolite concentrations and heart rates during exercise bouts of increasing duration.

METHODS

The 10 horses used in this study had all been without forced exercise for at least 4 months prior to the beginning of the study. In order to remove any confounding effects of residual conditioning, the animals were subjected to an exercise bout of 5 minutes on an inclined plane treadmill. Following this experience they were paired according to a combination of body weight, age and average heart rate during the 5 minutes of exercise. One member of each pair was randomly assigned to one of two diet groups.

Both groups received a mixed diet of oats, corn, molasses, a mineral mix and mixed alfalfa/grass hays (Table 1), fed in amounts appropriate for each animal's body weight and the duration of forced treadmill exercise (Table 2), according to NRC recommendations.[20] One group ("+YC") also received a commercially-available dried yeast culture preparation (Diamond V Mills, Cedar Rapids, Iowa), added to the total daily ration at 1% by weight (Table 2). The digestible energy contents of the diets were estimated using values provided by the NRC,[20] their dry matter, crude protein, dietary fiber component and mineral contents were measured using standard laboratory analysis,[2, 11] and feedstuff amino acid compositions were determined by HPLC following hydrolysis of the peptide bonds in 8N methanesulfonic for 48 hours at 155 C.[26] The amounts of digestible energy, crude protein, lysine, methionine, arginine, leucine, isoleucine, valine, hemicellulose, cellulose, calcium, phosphorus, magnesium, copper and zinc fed during the study are given in Table 3.

Following a 3-week diet adjustment period, during which the horses were not exercised, forced treadmill exercise was begun at 5 minutes per session, at a steady walk (1.53 m/sec) on an inclined plane treadmill (Safe-T Mill, T. Carlson, Inc., Audubon, Iowa) set at an incline of 14.8° (a workload of 11.98 j/kg/m, a workrate of 18.34 j/sec/kg). The duration of exercise was increased an average of 1 minute per day, 5 days a week, so after 2, 4 and 6 weeks of conditioning the treadmill bouts were of 15, 25 and 35 minutes' duration, respectively, corresponding to 8.25, 13.75 and 19.25 Mjoules of daily work per 500 kg bodyweight (Table 2).

On the first exercise day and at 2-week intervals the horses participated in data collection during their individual exercise bouts (Trials 1, 2, 3 and 4). Indwelling jugular catheters were inserted and the electrodes of an external, non-invasive heart rate monitor (EQB, Unionville, PA) were attached and secured with a heart girth strap. Resting heart rates were recorded and pre-exercise blood samples were drawn. The horses then mounted the treadmill and exercise began immediately. Blood samples were drawn at 5 minute intervals during the exercise bouts and for up to 20 minutes following the completion of exercise. Heart rates

Table **2**. Bodyweights, workloads and diets of horses fed diets with or without supplemental yeast culture (YC) during 6 weeks of exercise conditioning (mean ± SEM).

	Exercise Duration (min/day)						
	0	5-10	11-15	16-20	21-25	26-30	31-35
Bodyweight (kg):							
-YC	508.2						509.5
	±28.5						±27.4
+YC	501.4						497.3
	±23.9						±22.1
Work Load[a] (Mjoules/500 kg bodyweight/day):							
±YC	0.00	2.8-5.5	6.1-8.3	8.8-11.0	11.6-13.8	14.3-16.5	17.1-19.3
Concentrate intake (kg dry matter/500 kg bodyweight/day):							
-YC	4.74	5.16	5.58	6.00	6.43	6.85	7.27
	±.31	±.31	±.31	±.31	±.31	±.31	±.31
+YC	4.57	4.98	5.41	5.83	6.26	6.68	7.10
	±.21	±.21	±.21	±.21	±.21	±.21	±.21
Hay Intake (kg dry matter/500 kg bodyweight/day):							
-YC	2.24	2.24	2.24	2.24	2.24	2.24	2.24
	±.15	±.15	±.15	±.15	±.15	±.15	±.15
+YC	2.16	2.16	2.16	2.16	2.16	2.16	2.16
	±.10	±.10	±.10	±.10	±.10	±.10	±.10
Yeast Culture (g dry matter/500 kg bodyweight/day):							
+YC	68	72	77	81	85	89	93
Total feed (kg dry matter/500 kg bodyweight/day):							
-YC	6.98	7.40	7.82	8.24	8.67	9.09	9.51
	±.46	±.46	±.46	±.46	±.46	±.46	±.46
+YC	6.80	7.21	7.65	8.07	8.50	8.93	9.26
	±.31	±.31	±.31	±.31	±.31	±.31	±.31

[a] The work performed on a 14.8° inclined plane treadmill was calculated to be (mass) (g) (distance traveled) (ucos a + sin a),[b] where g = acceleration due to gravity = 9.80665 m/sec^2, u = coefficient of friction of treadmill surface = 1[33], and a = 14.8°, or 11.98 joules per kg bodyweight per m traveled, assuming the work of locomotion at a constant speed is independent of velocity in horses.[17, 32] Therefore:

Workload (Mjoules/500 kg bodyweight/day) =
(minutes on treadmill/day) (treadmill velocity) (work) (500 kg) =
(minutes on treadmill/day) (91.8 m/min) (11.98 joules/kg/m) (500 kg) =
(minutes on treadmill/day) (0.545 Mjoules/minute)

[b] Dr. A. Schmidt, Department of Physics and astronomy, Northwestern University, Evanston, IL, personal communication.

were manually recorded at 10-second intervals throughout the exercise bouts and post-exercise recovery periods. Plasma was separated from the blood samples and was stored frozen for later analysis of glucose, lactate and total triglyceride concentrations by a semi-automated method (TDX Systems, Abbott Laboratories, Abbot Park, IL). Heart rates were averaged over 60-second intervals for statistical analysis and graphical display, the resulting data were analyzed by analysis of variance for nested repeated measures.[25]

RESULTS AND DISCUSSION

Plasma glucose concentrations were significantly decreased in all horses during Trials 3 and 4 as exercise duration exceeded 10 minutes (Table 4), reflecting the relationship between the rate of glcolytic metabolism and work intensity in horses.[4, 31] However, the additional forced

Table **3**. Nutrient intakes by horses fed diets with or without supplemental yeast culture (YC) during 6 weeks of exercise conditioning (mean ± SEM).

	Exercise Duration (min/day)						
	0	5-10	11-15	16-20	21-25	26-30	31-35
Digestible Energy (Mcal/500 kg bodyweight/day):							
-YC	17.80	19.06	20.33	21.59	22.85	24.12	25.30
	±0.28	±0.24	±0.22	±0.24	±0.27	±0.32	±0.42
+YC	17.40	18.68	20.14	21.41	22.51	23.79	25.25
	±0.16	±0.20	±0.26	±0.33	±0.42	±0.49	±0.47
Protein (g/500 bodyweight/day):							
-YC	816	863	910	958	1005	1053	1097
	±11	±10	±9	±9	±10	±11	±15
+YC	809	860	911	962	1013	1063	1123
	±6	±7	±9	±12	±14	±17	±15
Lysine (g/500 kg bodyweight/day):							
-YC	35.8	37.2	38.7	40.1	41.6	43.0	44.4
	±0.5	±0.4	±0.4	±0.4	±0.4	±0.4	±0.6
+YC	35.5	37.1	38.7	40.3	41.9	43.5	45.4
	±0.3	±0.3	±0.4	±0.4	±0.5	±0.6	0.5
Methionine (g/500 kg bodyweight/day):							
-YC	21.1	22.5	23.8	25.2	26.6	28.0	29.3
	±0.3	±0.2	±0.2	±0.2	±0.3	±0.3	±0.4
+YC	20.8	22.3	23.8	25.2	26.7	28.2	29.8
	±0.2	±0.2	±0.3	±0.3	±0.4	±0.5	±0.4
Arginine (g/500 kg bodyweight/day):							
-YC	98.7	105.6	112.5	119.4	126.3	133.2	139.7
	±1.3	±1.1	±1.1	±1.1	±1.3	±1.5	±2.0
+YC	97.3	104.4	111.6	118.8	125.9	133.1	141.3
	±0.7	±0.9	±1.2	±1.6	±1.9	±2.3	±2.2
Leucine (g/500 kg bodyweight/day):							
-YC	112.4	119.8	127.2	134.6	142.1	149.5	156.4
	±1.5	±1.3	±1.2	±1.2	±1.4	±1.6	±2.2
+YC	111.2	118.9	126.7	134.6	142.3	150.1	159.1
	±0.8	±1.1	±1.4	±1.7	±2.1	±2.5	±2.3
Isoleucine (g/500 kg bodyweight/day):							
-YC	75.2	80.2	85.3	90.3	95.4	100.4	105.1
	±1.0	±0.9	±0.8	±0.8	±1.0	±1.1	±1.5
+YC	74.0	79.1	84.4	89.6	94.8	100.0	106.0
	±0.6	±0.7	±0.9	±1.2	±1.4	±1.7	±1.6
Valine (g/500 kg bodyweight/day):							
-YC	74.6	79.6	84.5	89.4	94.3	99.3	103.9
	±1.0	±0.9	±0.8	±0.8	±0.9	±1.1	±1.4
+YC	73.5	78.6	83.7	88.8	93.8	98.9	104.8
	±0.6	±0.7	±0.9	±1.1	±1.4	±1.6	±1.5

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Table 3. continued

Hemicellulose (g/500 kg bodyweight/day):							
-YC	831.3	865.6	900.0	934.4	968.7	1003.1	1034.3
	±11.0	±10.0	±9.3	±8.9	±8.9	±8.4	±13.2
+YC	838.9	879.2	921.3	965.2	1006.0	1047.5	1097.7
	±6.7	±7.2	±8.7	±10.1	±12.8	±14.3	±12.4
Cellulose (g/500 kg bodyweight/day):							
-YC	964.8	993.4	1022.1	1050.8	1079.4	1003.1	1133.4
	±12.8	±11.9	±11.3	±10.0	±10.4	±10.3	±14.7
+YC	946.9	976.2	1005.7	1035.3	1064.7	1094.2	1132.1
	±7.1	±7.8	±8.8	±9.9	±11.1	±12.4	±9.6
Calcium (g/500 kg bodyweight/day):							
-YC	26.1	26.8	27.5	28.2	28.9	29.6	30.2
	±.3	±.3	±.3	±.3	±.3	±.3	±.4
+YC	25.6	26.3	27.0	27.8	28.5	29.2	30.1
	±.2	±.2	±.2	±.3	±.3	±.3	±.2
Phosphorus (g/500 kg bodyweight):							
-YC	20.0	21.3	22.7	24.0	25.4	26.7	28.0
	±.3	±.2	±.2	±.2	±.3	±.3	±.4
+YC	20.1	21.5	23.1	24.6	26.1	27.6	29.3
	±.2	±.2	±.3	±.3	±.4	±.5	±.4
Magnesium (g/500 kg bodyweight/day):							
-YC	12.6	13.4	14.1	14.9	15.7	16.4	17.4
	±.1	±.1	±.1	±.2	±.2	±.3	±.3
+YC	12.7	13.4	14.1	14.8	15.5	16.2	16.8
	±.2	±.2	±.2	±.2	±.2	±.2	±.2
Copper (mg/500 kg bodyweight/day):							
-YC	90.1	94.9	99.7	104.6	109.4	114.2	118.7
	±1.2	±1.1	±1.0	±1.0	±1.0	±1.1	±1.6
+YC	88.6	93.6	98.6	103.6	108.6	113.6	119.4
	±.7	±.8	±1.0	±1.2	±1.5	±1.7	±1.5
Zinc (mg/500 kg bodyweight/day):							
-YC	221.4	233.9	246.3	258.8	271.2	283.6	295.2
	±2.9	±2.6	±2.4	±2.4	±2.5	±2.9	±3.9
+YC	220.9	234.4	248.1	262.2	275.8	289.5	305.5
	±1.7	±2.0	±2.5	±3.1	±3.9	±4.5	±4.1

exercise conditioning between Trials 3 and 4 was accompanied by slower rates of decrease of plasma glucose concentrations during Trial 4. Because equine intramuscular glycolytic capacity is not affected by repeated exercise,[13] this observation suggests that exercise conditioning may increase the efficiency of energy substrate oxidation in horses. The lack of any effects of yeast culture supplementation on plasma glucose concentrations during exercise suggests that neither dietary glucose supplies nor intramuscular glucose uptake or entry into the glycolytic pathway were affected by supplementation.

Plasma triglyceride concentrations increased during and immediately following exercise (Table 5). Such increases have been associated with increases in plasma free fatty acid concentrations in horses,[18, 31] and may result from increased mobilization of body fat subsequent to the secretion of catecholamines during exercise.[4,28] Increased plasma triglyceride concentrations tended to occur more rapidly as the horses became conditioned to longer exercise bouts, suggesting a gradual conditioning-dependent increase in fatty acid mobilizing capabilities. Concurrently, conditioning may also increase fatty acid oxidizing capacity in

Table **4**. Effect of supplemental yeast culture (YC) on plasma glucose concentrations (mg/dl) in horses exercised on a treadmill.

Plasma Glucose (mg/dl)

Exercise Time (min)	Trial 1		Trial 2		Trial 3		Trial 4	
	-YC	+YC	-YC	+YC	-YC	+YC	-YC	+YC
0	82.81	88.47	84.14	85.45	91.37^{b}	89.89^{b}	93.09^{b}	89.15^{b}
5	80.42	86.94	85.32	77.36	88.86^{b}	81.21^{b,c}	84.75^{b,c}	79.94^{b,c}
10			73.81	74.64	71.40^{c}	70.59^{c}	80.73^{b,c}	79.83^{b,c}
15			82.81	80.93	66.41^{c}	62.27^{c}	72.45^{c}	70.41^{c}
20					61.60^{c}	61.03^{c}	68.58^{c}	68.62^{c}
25					73.69^{c}	66.36^{c}	69.05^{c}	62.21^{c}
30							72.80^{c}	67.96^{c}
35							77.10^{c}	65.63^{c}
Post Exercise:								
5	79.24	86.13	80.30	86.24	77.99^{b,c}	79.63^{b,c}	86.79^{b,c}	82.69^{b,c}
10			85.44	85.81	80.82^{b,c}	83.60^{b,c}	86.62^{b,c}	83.50^{b,c}
15					81.27^{b,c}	84.25^{b,c}	87.17^{b,c}	81.11^{b,c}
20					89.94^{b}	88.26^{b}	90.98^{b,c}	88.26^{b}

pooled SEM: 3.29

^{b,c}Means for a given diet and Trial with different superscripts are different, p<.01.

horses.[27] The initial increases in plasma triglyceride concentrations tended to be slower in the supplemented horses than in the unsupplemented horses during Trials 3 and 4 (Table 5), suggesting that fatty aid clearance from the plasma, presumably via uptake by working muscle, may have become more efficient.[18] Alternatively, exercise-induced fatty acid mobilization may have been delayed in response to yeast culture supplementation.

Jugular venous plasma lactate concentrations have been shown to reflect systemic circulating lactate concentrations and to be proportional to the rate of intramuscular production of lactic acid and work intensity and duration in horses.[15,19,31] In this experiment, plasma lactate concentrations steadily increased during forced exercise (Table 6). Peak concentrations occurred 5 to 10 minutes after the cessation of forced exercise, and the rates of post-exercise declines in plasma lactate concentrations were inversely proportional to the peak lactate concentrations and the total work output, as have been reported by Harris and Snow.[12]

The yeast culture supplemented horses exhibited significantly smaller and slower increases in plasma lactate concentrations at a given workload than did the unsupplemented horses, after 15 or more minutes of exercise in Trial 3 and after 20 or more minutes of treadmill and work in Trial 4. Differences in the rates of change of plasma lactate concentrations in response to a given exercise challenge may reflect differences in relative aerobic capacity or level of conditioning or “fitness.”[5, 24] In practice, measures of relative athletic performance in horses have been shown to be inversely proportional to maximum blood lactate concentrations during a given exercise challenge.[15,24,30] It has been suggested that decreased intramuscular pH resulting from increased intramuscular lactic acid concentrations may interfere with myofibrillar contractility.[16] However, the physiologic significance of changes in equine intramuscular pH are uncertain.[17]

Interestingly, it has been reported that feeding horses supplemental fats during a conditioning program was accompanied by slower rates of lactic acid production and lactate accumulation during an exercise challenge.[18] Although the horses in this study were not fat-supplemented *per se*, supplementation of horses with dietary yeast culture may be accompanied by increased fermentation of dietary substrates,[9, 10] potentially increasing circulating volatile fatty acid concentrations. Whether such a process mimics the benefits of fat supplementation on exercise energetics is an intriguing if unexamined possibility.

All of the horses in this experiment exhibited the relative bradycardia (Table 7) typical of conditioned horses during exercise.[3, 18, 24] Lower heart rates in horses indicate relatively reduced cardiac output and therefore increased efficiency in energy metabolism and oxygen utilization and a greater capacity for performing a given amount of work

Table **5**. Effects of supplemental yeast culture (YC) on plasma triglyceride concentrations (mg/dl) on horses exercised on a treadmill.

Plasma Triglycerides (mg/dl)

Exercise Time (min)	Trial 1		Trial 2		Trial 3		Trial 4	
	-YC	+YC	-YC	+YC	-YC	+YC	-YC	+YC
0	10.91	8.38	6.80^{b}	9.62	7.60^{b}	9.98	8.37^{b}	11.55^{b}
5	13.73	9.10	$10.62^{b,c}$	11.30	$20.63^{b,c}$	13.50	22.64^{c}	14.01^{b}
10			$17.97^{b,c}$	13.14	26.63^{c}	22.09	$21.76^{b,c}$	$18.76^{b,c}$
15			$17.54^{b,c}$	12.42	21.51^{c}	20.77	$20.82^{b,c}$	$23.20^{b,c}$
20					$19.67^{b,c}$	21.58	24.90^{c}	$23.45^{b,c}$
25					22.48^{c}	22.69	$19.34^{b,c}$	$25.24^{b,c}$
30							24.10^{c}	$23.56^{b,c}$
35							24.14^{c}	$23.42^{b,c}$
Post Exercise								
5	8.71	7.45	21.64^{c}	16.19	23.43^{c}	19.30	$19.81^{b,c}$	28.28^{c}
10			$16.67^{b,c}$	16.10	21.42	16.94	$17.54^{b,c}$	$13.80^{b,c}$
15					$18.35^{b,c}$	18.99	$17.29^{b,c}$	13.80^{b}
20					$12.67^{b,c}$	11.17	$16.98^{b,c}$	$17.72^{b,c}$

pooled SEM: 2.88

^{b,c}Means for a given diet and Trial with different superscripts are different, p<.01.

Table **6**. Effects of supplemental yeast culture (YC) on plasma lactate concentrations (mg/dl) in horses exercised on a treadmill.

Plasma Lactate (mg/dl)

Exercise Time (min)	Trial 1		Trial 2		Trial 3		Trial 4	
	-YC	+YC	-YC	+YC	-YC	+YC	-YC	+YC
0	3.90^{b}	4.85^{b}	5.36^{b}	6.04^{b}	5.51^{b}	5.72^{b}	6.25^{b}	6.09^{b}
5	11.63^{c}	10.47^{c}	11.47^{c}	$8.14^{b,c}$	$9.70^{b,c}$	$9.79^{b,c}$	$10.11^{b,c}$	7.52^{b}
10			9.61^{c}	$7.15^{b,c}$	10.30^{c}	10.56^{c}	$9.69^{b,c}$	6.86^{b}
15			13.17^{c}	10.77^{c}	15.94^{d}	$11.21^{a,c}$	11.82^{c}	$10.58^{b, c}$
20					15.22^{d}	$11.59^{A,c}$	19.58^{d}	$14.70^{a,c}$
25					26.24^{e}	$20.29^{a,d}$	26.62^{e}	$20.80^{a,d}$
30							34.12^{f}	$25.96^{a,e}$
35							41.29^{g}	$30.08^{a,f}$
Post Exercise:								
5	13.34^{c}	11.45^{c}	13.98^{c}	11.63^{c}	37.03^{f}	$23.84^{a,d}$	57.18^{h}	$40.58^{a,g}$
10			10.15^{c}	9.60^{c}	26.02^{e}	$20.60^{a,d}$	45.64^{g}	$30.75^{a,f}$
15					19.50^{d}	$12.65^{a,c}$	31.24^{f}	$20.32^{a,d}$
20					$9.74^{b,c}$	$7.65^{b,c}$	21.07^{d}	$11.01^{a,c}$

pooled SEM: 1.49

^{A}Means for a given exercise or post-exercise time within a particular Trial differ between diets, p<.05.

^{a}Means for a given exercise or post-exercise time within a particular Trial differ between diets, p<.01.

^{b,c,d,e,f,g,h}Means for a given diet and Trial with different superscripts are different, p<.01.

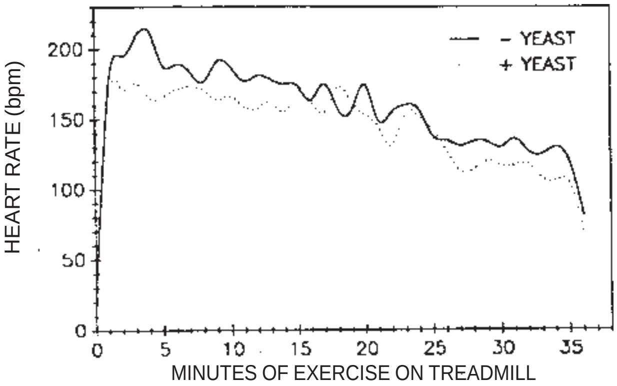

Figure 1. Heart rates during 35 minutes of treadmill exercise of horses fed dites with (+YEAST) or without (-YEAST) supplemental yeast culture.

during a comparable exercise challenge.[3, 5, 24] The possibility of an additional conditioning effect due to yeast culture supplementation is suggested by the further reduction in heart rates exhibited by the supplemented horses during (Figure 1) and at the end of 35 minutes of exercise (Table 7). If relative heart rates and plasma energy metabolite concentrations in response to a given workload are indicative of the relative level of fitness of horses,[24] then exercise conditioning and yeast culture supplementation appeared to exert additive effects on equine performance potential.

The horses in this study maintained relatively constant bodyweights (mean net change: -0.32 kg), indicating that the additional dietary digestible energy required by the horses during this graduated conditioning program was adequately provided by the adjustments made to their diets. Therefore, assuming the digestible energy requirement for maintenance to be 16.4 Mcal per day per 500 kg bodyweight,[21] the digestible energy above maintenance required to perform each incremental workload can be calculated (Figure 2), and the DE requirement for work estimated:

total DE (Mcal/kg) = 0.454 (Mcal/Mjoule) (Mjoules/kg)
+ 0.033 Mcal/kg
total DE (Mcal/500 kg) = 0.454 (Mcal/Mjoule) (Mjoules/500 kg)
+ 16.424 Mcal/500 kg
DE for work (Mcal/kg) = 0.454 (Mcal/Mjoule) (Mjoules/kg)
+ 0.00005 Mcal/kg
DE for work (Mcal/500 kg) = 0.454 (Mcal/Mjoule) (Mjoules/500 kg.)
+ 0.024 Mcal/500 kg

For all equations, r^2=0.95. These data indicate that these horses converted dietary DE in excess of maintenance requirements to work with an efficiency of approximately 53%, compared to about 57% reported by Pagan and Hintz[22] and Frape.[8]

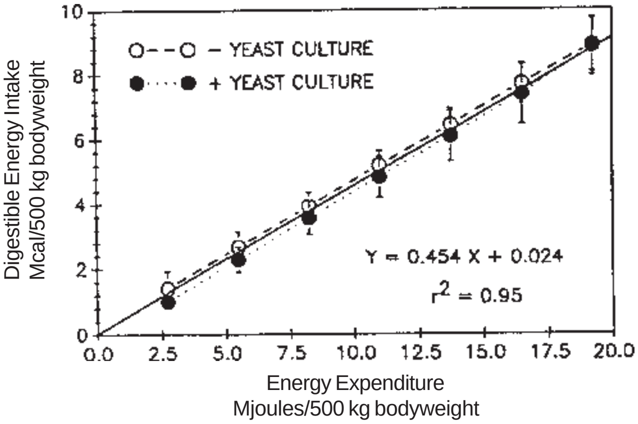

Figure 2. Digestible energy intakes above maintenance (Mcal/500 kg bodyweight) ingested at each increment of energy expenditure (Mjoules/500 kg bodyweight) by horses fed diets with or without supplemental yeast culture. The solid line displays the linear regression of digestible energy intake (Y) on energy expenditure (X):Y = 0.454X + 0.024; r^2 = 0.95

The workload generated by these horses (11.98 j/kg/m) was comparable to that generated by other horses in other experiments when moving at greater speeds along smaller inclines. At 2.58 m/sec on a 9° incline, the workload was 11.23 j/kg/m;[1] at 3 m/sec on a 9° incline, 11.23 j/kg/m;[18] and at 4.5 m/sec on a 6° incline, 10.79 j/kg/m.[19] However, the work rates of the horses in these other experiments were greater (28.97, 33.39 and 48.56 j/sec/kg, respectively) than that experienced by the horses in this study ((11.98 j/kg/m) (1.53 m/sec) = 18.34 j/sec/kg). Unfortunately, work rate is not strictly proportional to velocity, but is confounded by the slope of the work surface, making comparisons among equine exercise physiology experiments difficult.

Such comparisons would be facilitated if a common measure of equine work output could be developed, especially if such a measure could also apply equally well to work performed on level ground. Estimates of the V_{02} of equine energy expenditure can be used to calculate the “horizontal work equivalent” ” of exercise on an inclined plane and thus an “equivalent ground speed” can be estimated (Table 8). Using an average of 0.17 ml 0_2 per kg bodyweight per m traveled, equivalent to 3.42 j/kg/m, Table **7**. effects of supplemental yeast culture (YC) on the end-of-exercise heart rates (beats per minute) of horses exercised on a treadmill.

Trial	Duration of Exercise (minutes)	Heart Rates -YC	Heart Rates +YC
1	5	185[b]	180[b]
2	15	186[b]	165[a,b]
3	25	129[c]	116[c]
4	35	120[c]	99[a,c]

pooled SEM: 8.95

[a] Means for a given trial are different between diets, $p<.01$.

[b,c] Means for a given diet are different among Trials, $p<.01$.

Table **8**. Calculated “Equivalent Ground Speeds: (m/sec) using various estimates for the energy cost of locomotion for horses.

Energy Cost of locomotion[a] (ml 0_2/kg/m)	Horizontal Work equivalent[b] (j/km/m)	Equivalent ground speed[c] (m/sec)
.05[6]	1.01	18.16
.10[7]	2.01	9.12
.13[29]	2.61	7.03
.15[7]	3.02	6.07
.20[14]	4.02	4.56
.22[23]	4.42	4.15
.23[32]	4.62	3.97
.28[18]	5.63	3.26
.17	3.42	5.36

[a] Energy Cost of Locomocotion (ml O_2/kg/m) = ml O_2) required to transport 1 kg a distance of 1 m[7] - V_{02}.

[b] Horizontal work equivalent (j/kg/m) = estimated energy per m of distance on level groung = (V_{02}) (20.1 j/ml).[7]

[c] Equivalent ground speed (m/sec) = (work rate) / (horizontal work equivalent) = (18.34 j/sec/kg) / (horizoneal work equivalent).

Table **9**. Calculated equivalent ground speeds (m/sec) using various equations to estimate the energy requirements of work.

Workload (j/kg/m)	Work Rate (j/sec/kg)	Equivalent ground speed (m/sec)[a]	(m/sec)[b]	(m/sec)[c]
11.98[d]	18.34[d]	5.36	5.30	5.24
11.23[e]	28.97[e]	8.47	8.74	6.31
11.23[f]	33.69[f]	9.85	10.28	6.80
10.79[g]	48.56[g]	14.20	15.10	7.71

[a] Calculated as in Table 8.

[b] Calculated as per McMiken:[17] Equivalent ground speed. (m/sec) = (0.01439) (workrate) - 0.0289) (22.523).

[c] Calculated as per Pagan and Hintz.[22] Equivalent ground speed (m/sec) = log (workrate) (0.40) + 0.68) /0.169.

[d] Workload calculated from the data in this study; Workrate = (11.98 j/kg/m) (1.53 m/sec) = 18.34 j/sec/kg.

[e] Workload calculated from Anderson et al.:[1] Workrate = (11.23 j/kg/m) (2.58 m/sec) - 28.97 j/sec/kg.

[f] Workload calculated from Meyers et al:[18] Workrate = (11.23 j/kg/m) (3.0 m/sec) = 33.69 j/sec/kg.

[g] Workload calculated from Miller-Graber et al:[19] Workrate = (10.79 j/kg/m) (4.5 m/sec) = 48.56 j/sec/kg.

“equivalent ground speeds” for various experiments and treadmills can be calculated and compared (Table 9).

These estimates are similar to those obtained using an algebraic rearrangement of the linear equation for energy expenditure of McMiken[17] (Table 9), which assumes that when natural gait changes are allowed, energy expenditure is a constant function of distance traveled. However, estimates using linear equations diverge rapidly from the estimates obtained using the logarhythmic equation of Pagan and Hints.[22] Conversely, they would be expected to underestimate the “equivalent ground speeds” calculated using the asymptotic equation of Anderson et al.[1] Additional research at high “equivalent ground speeds” and at different gaits will be necessary to reconcile these disparate observations. The approach illustrated here can be used to define the treadmill conditions required to mimic a desired racing or exercise velocity on level ground.

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