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Impact of *Agaricus bisporus* mushroom consumption on satiety and food intake

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ABSTRACT

Previous studies on mushrooms suggest that they can be more satiating than meat, but this effect has not been studied with protein-matched amounts. The objective of this study was to assess the differences with satiety and ten-day food intake between *A. bisporus* mushrooms (226 g) and meat (28 g) in a randomized open-label crossover study. Thirty-two healthy participants (17 women, 15 men) consumed two servings of mushrooms or meat for ten days. On the first day, fasted participants consumed protein-matched breakfasts. Participants rated their satiety using visual analogue scales (VAS) at baseline and at regular intervals after the meal. Three hours later, participants were served an *ad libitum* lunch. Participants were given mushrooms or meat to consume at home for the following nine days. Energy intake was assessed at the *ad libitum* lunch, and participants also completed diet diaries on the day of the study, day 2, and day 10. Participants reported less hunger ($p = 0.045$), greater fullness ($p = 0.05$), and decreased prospective consumption ($p = 0.03$) after the mushroom breakfast. There were no significant differences in participant ratings of satisfaction ($p = 0.10$). There were also no statistically significant differences in energy intake at the *ad libitum* lunch or with the diet diaries from days 1 ($p = 0.61$), 2 ($p = 0.77$), or 10 ($p = 0.69$). Mushroom consumption did increase fiber intake on days 1, 2, and 10 but the difference in fiber consumption was only statistically significant on day 2 ($p = 0.0001$). The mushroom intervention also did not affect energy intake over the ten day feeding period.

1. Introduction

Rising rates of obesity (CDC, 2016), which currently affects 34% of U.S. adults, has made understanding influences on satiety and food intake urgent. Satiety is the postprandial state responsible for the timing and intake of the next meal (Clark & Slavin, 2013; Slavin & Green, 2007; Blundell et al., 2010). Increasing scientific understanding of satiety is of great importance for both clinical treatment of obesity and public health prevention efforts. Consuming satiating meals that promote a feeling of fullness could result in decreased daily caloric intake and, over time, assist with weight loss and weight management (Drapeau et al., 2007; Slavin, 2013). A great deal of research has been conducted on the satiating abilities of different macronutrients (de Castro, 1987; de Castro & Elmore, 1988; Gerstein, Woodward-Lopez, Evans, Kelsey, & Drewnowski, 2004; Marmonier, Chapelot, & Louis-Sylvestre, 2000; Pai, Ghugre, & Udipi, 2005b; Slavin & Green, 2007; Stubbs & Whybrow, 2004). Protein appears to be more satiating than either carbohydrates or fat (Stubbs & Whybrow, 2004; de Castro & Elmore, 1988; de Castro, 1987). Yet not all carbohydrates exert the same influence on satiety (Gerstein et al., 2004). Fiber-rich foods, for instance, tend to be more satiating than foods high in sugars and starches (Pai, Ghugre, & Udipi, 2005a). The type and form of fiber in whole foods versus isolated fiber sources impacts its satiating effects (Delargy, O'Sullivan, Fletcher, & Blundell, 1997; Slavin & Green, 2007). While many studies have been conducted on isolated fiber types (Hess, Birkett, Thomas, & Slavin, 2011; Howarth et al., 2003; Karalus et al., 2012; Klosterbuer, Thomas, & Slavin, 2012; Korczak, Lindeman, Thomas, & Slavin, 2014; Mathern, Raatz, Thomas, & Slavin, 2009; Peters, Boers, Haddeman, Melnikov, & Qvyjt, 2009; Turnbull, Walton, & Leeds, 1993; Willis et al., 2010), less is understood about the satiety effects of fibers served in whole foods. (Bonnema, Altschwager, Thomas, & Slavin, 2015; Erickson & Slavin, 2016; Slavin & Green, 2007).

Abbreviations: BMI, Body mass index; PDCAAS, Protein digestibility corrected amino acid score; VAS, Visual analogue scales.

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A few previous studies have addressed the impact of white button mushroom consumption on satiety and food intake (Cheskin et al., 2008; Poddar et al., 2013). Cheskin et al. compared the impact of mushroom or meat-based lunches on satiety and energy intake in 76 individuals (Cheskin et al., 2008). There were no significant difference in satiety ratings between the meat and mushroom lunches. However, because this study matched the lunch meal interventions by volume, a lower amount of calories from mushrooms (339 kcal) was as satiating as a higher amount of calories (783 kcal) from meat. A second study (Poddar et al., 2013) conducted by the same research team found that replacing meat with mushrooms at three meals a week for one year increased the amount of weight lost over six months, helped participants maintain their weight loss for six months, and led to decreased body mass index (BMI) and waist circumferences. The results of these studies suggest that mushrooms enhance satiety and that substituting white button mushrooms for meat may decrease the energy density (kcal/g) of the diet, resulting in weight loss (Mack et al., 2014; Rolls, Hetherington, & Burley, 1988).

These results from mushrooms may also be due to their macronutrient composition. Mushrooms contain both protein and fiber (Dikeman, Bauer, Flickinger, & Fahey, 2005; Manzi, Aguzzi, & Pizzoferrato, 2001; USDA, 2016). While white button mushrooms contain a relatively small amount of protein (3.09g/100 g) (USDA, 2016), mushroom protein is of moderate quality (Dikeman et al., 2005; Miles & Chang, 2004). Mushroom protein has protein quality rating, or protein digestibility corrected amino acid score (PDCAAS), of 0.66. (Roupas, Peter; Margetta, Christine; Taylor, Pennie; Krause, Debra; Noakes, 2012) PDCAAS scoring evaluates protein quality based on limiting amino acids, fecal digestibility, and the protein needs of preschool-aged children, with higher values given to higher quality proteins. (FAO/WHO Expert Consultation, 1989) The highest quality protein sources in this index are animal sources, such as milk and eggs (PDCAAS value of 1.00), while wheat protein has a PDCAAS value of 0.42 (FAO/WHO Expert Consultation, 1989). Cooked lentils have a PDCAAS value of 0.66, like mushrooms (Porres et al., 2002). Mushrooms have a protein quality rating higher than grains but comparable to other non-animal protein sources (FAO/WHO Expert Consultation, 1989; Porres et al., 2002). Mushrooms also contain several different types of non-digestible carbohydrates including chitin, β-glucans, raffinose, oligosaccharides, and resistant starch (Dikeman et al., 2005; Manzi et al., 2001; USDA, 2016).

To build on the results of previous studies on white button mushrooms, we designed a study to assess the satiety response and food intake of 32 participants after consuming protein-matched amounts of mushrooms and meat in a randomized crossover study. Participants consumed test foods at breakfast and at dinner for a total of ten days. On the first day of each intervention, participants visited the lab to consume a mushroom or meat-based breakfast sandwich. Following this meal, we measured energy intake at an *ad libitum* lunch and for forty-eight hours following the test visit. We also assessed dietary intake for twenty-four hours prior to the test visit and after nine days of test food consumption. Our hypothesis was that the mushroom intervention would provoke a greater satiety response than the control (meat) meal and that the treatment diet would result in a lower average energy intake (kcals/day) than the control diet. Unless indicated otherwise, in the remainder of this manuscript, the word “mushrooms” indicates “white button mushrooms” or white, immature *Agaricus bisporus*.

2. Materials and methods

In this randomized crossover study, we compared the impact of mushroom consumption and meat consumption on satiety and ten day food intake. Participants were provided with test foods to consume for ten days, beginning with an in-lab test meal containing either mushrooms or meat.

2.1. Subjects

The University of Minnesota Institutional Review Board Human Subjects Committee reviewed and approved all methods for human participants, and all participants provided written informed consent. Participants were recruited by flyers placed around the University of Minnesota campus and were asked to complete an online screening survey (Qualtrics, Provo, UT). Eligible subjects included healthy men and women between the ages of 18 and 65 with a body mass index between 18.5 and 30 kg/m^2. Subjects had to be regular breakfast and lunch consumers ($\geq$4 times per week) willing to consume meat and mushrooms. Participant demographics are listed in Table 1.

Excluded individuals included people with serious preexisting health conditions (diabetes, kidney/liver disease, cancer, eating disorder) and individuals taking medications for blood sugar, cholesterol, blood pressure, or weight loss as well as individuals taking laxatives or anti-diarrhea medications. Individuals who had gained and lost more than 10 pounds in the last three months, were regular participants in vigorous endurance exercise (marathons, endurance bike races, triathlons), or were tobacco users were also excluded. In addition, individuals could not have participated in another dietary intervention study within the last month, had to be willing to make dietary changes for a total of 20 days, and could not have food allergies. Pregnant or lactating females were excluded. Participants could not be regular fiber consumers (had to consume $\leq$3 servings of fiber-rich foods per day) and could not take supplements besides a multivitamin. Individuals with a score >11 on the dietary restraint portion of the Three Factor Eating Questionnaire were also disqualified. Participants had to be available to attend two in-person visits on weekend mornings from 7:45am to 11:30am.

Before arriving for the first in-person study visit, participants made an initial study visit to review the informed consent paperwork and provide their height and weight measurements. Height was self-reported by study participants, and weight was measured

Table 1
Participant demographics overall and by treatment group.

	Overall (N = 32)	Mushroom-Meat (N = 16)	Meat-Mushroom (N = 16)	P-value
Sex, N (%)				
F	17 (53%)	7 (44%)	10 (62%)	0.29
M	15 (47%)	9 (56%)	6 (38%)	Chi-Square statistics (df = 1) = 1.13
Age, mean (SD)	23.4 (4.4)	23.6 (4.8)	23.3 (4.0)	0.81 t (df = 30) = 0.24
BMI (kg/m^2), mean (SD)	24.2 (3.2)	25.3 (3.1)	23.0 (2.8)	0.03 t (df = 30) = 2.27