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Life cycle analysis for the cultivation and combustion of Miscanthus for biofuel compared with natural gas

A. Ashworth, C. West, M. Popp, Mireille Montréjaud-Vignoles, Caroline Sablayrolles, Benoit Gabrielle

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UNIVERSITY OF ARKANSAS
DIVISION OF AGRICULTURE



UNIVERSITY OF ARKANSAS
1871

Cover: The Food and Agriculture Organization of the United Nations estimates that worldwide rice paddy production in 2008 may grow by about 2.3 percent for a new record level of 666 million tons. Yet rice prices will remain high in the face of input costs, natural disasters, and food shortages. Photo of US rice harvest by David Nance, USDA Agricultural Research Service.

Letter from the Dean

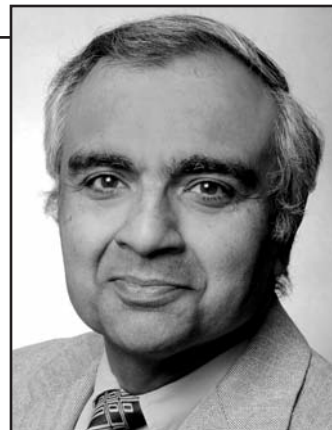
The Dale Bumpers College of Agricultural, Food and Life Sciences provides many opportunities for undergraduate students to engage in learning experiences beyond regular course work. Conducting quantitative/qualitative research projects with faculty mentors is one of those opportunities. Some sixty faculty members presently serve as mentors to students to assist them with research and creative projects. Most, but not all, such projects are designed to meet the requirements of an honors thesis in the Bumpers College Honors Program. Whether in the Honors Program or not, students who take advantage of such opportunities hone their intellectual capacities in a supportive, collaborative research environment that can lead to lifetime-long collegial, professional relationships.

The Bumpers College encourages student research by awarding undergraduate research grants, including the Carroll Walls Undergraduate Research Fellowship, which provides grants ranging from \$500 to \$2,000. We awarded 10 Undergraduate Research Grants in fall 2007.

DISCOVERY serves to showcase the research accomplishments of Bumpers College student scientists and allows them to participate fully in the process of shepherding their own research from project design through data collection to journal publication.

The 13 articles in this ninth annual volume of *DISCOVERY* include issues in food safety, nutraceuticals, rice, cover crops, animal husbandry, and forages. Topics also include environmental and quality-of-life issues such as watershed-based monitoring, phytoremediation of contaminated soils, and community-based gerontology research. We are proud to present these articles as examples of the research accomplishments of our undergraduate students.

I congratulate the student authors on their accomplishments and extend thanks to their faculty mentors and to the editors who reviewed their manuscripts. The UA Division of Agriculture, University of Arkansas Agricultural Experiment Station commendably provides funding for research, and Dr. Milo J. Shult, Vice President for Agriculture, generously supports students who participate in various competitions in their disciplines. Thanks are also extended to the Honors Committee for providing a structured program that encourages our students to enhance their academic and professional credentials.



Lalit R. Verma

A handwritten signature in black ink, appearing to read "Lalit R. Verma", with a long horizontal flourish extending to the right.

Lalit R. Verma, Interim Dean and
Associate Vice President—Academic Programs

Life cycle analysis for the cultivation and combustion of miscanthus for biofuel compared with natural gas

Amanda Ashworth^{*}, Charles West[†], Michael Popp[§], Mireille Montrejaud-Vignoles[‡], Caroline Sablayrolles^{§§}, and Benoît Gabrielle^{‡‡}

ABSTRACT

As negative environmental and economic impacts of fossil fuels have escalated, so has the importance of renewable bioenergy crops whose feedstocks are noncompetitive with food supplies. Compared with fossil fuels, use of lignocellulosic feedstocks offers potential for greenhouse gas reduction and highly positive net energy returns because of low input demand and high yields per unit of land area, thus making them advantageous for the emerging biofuel industry. The aim of this study was to simulate environmental impacts of producing a biofuel grass for combustion use based on the inventory of inputs and their effects on eutrophication of surface waters; acidification of land and water; photochemical ozone-creation potential (i.e. smog); global atmospheric warming; and nonrenewable resource depletion (mainly fossil fuels). Hybrid miscanthus (*Miscanthus x giganteus*, or giant miscanthus), a perennial C4 grass originating from East Asia, was compared with natural gas by using a life-cycle analysis model for biomass production in France. The analysis showed a trade-off between natural gas and miscanthus. The latter had a lower global-warming potential and consumed less primary nonrenewable energy but produced more emissions that promote acidification and eutrophication than did natural gas.

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MEET THE STUDENT-AUTHOR



Amanda Ashworth

I am from Fayetteville, Ark., and a graduate of Fayetteville High School. At present, I am a graduating senior at the University of Arkansas majoring in Environmental, Soil, and Water Science with minors in Spanish and Global Agriculture, Food, and Life Sciences. I am a member of the Crop, Soil, and Environmental Sciences Club.

During my career at the University of Arkansas, I spent a year studying at the Universidad de Granada to complete my Spanish minor. I also received two Americorp Education Awards through my completion of two Student Conservation Association (SCA) internships. One internship included conserving native-plant populations in Montana with the USDA Forest Service, and the second internship was with the Bureau of Land Management in California working on safeguarding dry-land species against extinction. Since last May, I have worked in the Crop, Soil, and Environmental Sciences Department as a lab and greenhouse assistant on native-plant propagation for wetland/riparian restoration and biomass production.

The research project reported in this paper was made possible by the Renewable Resources and Clean

Technology International Program, and through partnership of the National Polytechnic Institute of Toulouse, France, and the University of Arkansas. A poster presentation of this study was presented at the International Conference on Renewable Resources and Biorefineries in The Netherlands in June 2008.

I would like to give special thanks to Drs. Charles West and Michael Popp of the University of Arkansas for their advice on this project. Sincere appreciation is extended to Caroline Sablayrolles and Mireille Montrejaud-Vignoles for hosting my spring semester at the Ecole Nationale Supérieure des Ingénieurs en Arts Chimiques et Technologiques (ENSIACET), and for the expert knowledge and guidance they devoted to this project.

I started my master's degree program in the Crop, Soil, and Environmental Sciences Department in August 2008, with Dr. West as my advisor. My graduate research plans include continuing this study using bioethanol as the endpoint, and researching switchgrass biomass and nutrient accumulation in Arkansas.

INTRODUCTION

Life-cycle analysis (LCA) is a cradle-to-grave environmental diagnostic tool that calculates energy and material inputs and outputs of potential pollutants at every stage of fuel production and consumption. Such analyses are critical for comparing alternatives to fossil fuels to maximize energy efficiency and minimize environmental degradation. Replacing fossil fuels with plant-derived feedstocks causes a decrease in net carbon emissions because of withdrawal of carbon from the atmosphere during photosynthesis, thereby theoretically reducing net greenhouse gas (GHG) emissions. Little is known, however, about the magnitude of potentially negative environmental impacts and trade-offs in harnessing the

sun's energy through combusting plant biomass. Life-cycle analyses are also useful to determine the most efficient practices for biomass production, transport, storage, and processing in terms of being least cost and least detrimental to the environment (Schmer et al., 2008), and thus have relevance for policy making and industrial-scale design of bioenergy systems.

This LCA aims to quantify the nature and magnitude of pollution trade-offs when analyzing the perennial grass, hybrid miscanthus (*Miscanthus x giganteus*, or giant miscanthus), as an alternative to natural gas. Miscanthus is classified as lignocellulosic biomass feedstock because the entire plant is used. Most of the gross energy is contained in the fibrous (lignin, cellulose, and hemicellulose) component of the plant. Such a feedstock

can be used directly for heat and electrical power generation through simple combustion, which aids in reducing greenhouse gas emissions through direct replacement of fossil fuels. In comparison, production of corn (*Zea mays* L.) for bioethanol is currently the main source for ethanol production in the U.S.; however, corn provides minimal net benefits in terms of reducing fossil energy consumption and GHG emissions (Tillman et al., 2006).

Miscanthus was chosen for this study because it produces high biomass yields with low levels of industrial inputs, such as fertilizer, pesticides, and irrigation (Clifton-Brown et al., 2004), when compared with annual crops like corn. In contrast, annual crop production destabilizes soil through repeated cycles of soil cultivation, crop establishment, and harvest, which lead to higher erosion than perennial crops (Lewandowski and Schmidt, 2006). Perennial crops such as miscanthus have the added advantage of not requiring annual tillage and planting operations, which further reduces energy inputs and negative environmental impacts. We hypothesized that miscanthus production for use in heat and power generation results in a lower release of GHG and ozone-creating compounds that induce smog, but a greater release of compounds inducing eutrophication and acidification when compared with fossil fuels such as natural gas.

MATERIALS AND METHODS

Four phases of this analysis included 1) goal and scope definition, 2) life cycle inventory, 3) life cycle inventory assessment, and 4) interpretation of data. Figure 1 illustrates the production and collection stages for the two fuels in this comparison. The analysis included all the agricultural processes involved in producing biomass and subsequent direct combustion, such as stand establishment, application of fertilizers, machinery for transportation and harvest, and pesticides as well as estimating GHG emitted during these processes. A range of environmental parameters were analyzed and aggregated into the following impact categories: resource depletion (comprising primary, mainly fossil, energy consumption to supply electricity and buildings, machinery, chemicals, etc.); acidification; eutrophication; creation of photochemical ozone (smog) via nitrous oxide emission (e.g. depletion of the protective stratospheric ozone); and greenhouse gas emissions for calculating global warming potential (GWP) with a time horizon of 500 years (Table 1). Global warming potential is an indicator of the heat retention capacity of a gas to impact climate. This LCA does not include any economic or social functions, nor does it calculate net energy

yield or net energy ratio of biofuel production systems. Renewable energies that contribute to the primary energy pool and other indirect energies that contribute to crop production, such as human labor, are considered as outside the system.

We used the LCA methods and input/output outlined by Institut für Energie und Umweltforschung (IFEU) (Institute of Energy and Environmental Research Heidelberg, 2000) and the pollution standards of the Association Française de Normalisation (2006a, 2006b). The database for calculating the LCA was described by Gabrielle et al. (2001). The fuel use and production are expressed as megajoules (MJ) per hectare, and emissions (environmental impacts) as grams (g) of emission equivalents per hectare.

The values for miscanthus management and yield were applicable to France using data and default values from the Institut National de la Recherche Agronomique (INRA) (Gabrielle et al., 2001). We assumed standard agricultural inputs and practices including the use of typical machinery for field preparation, planting, harvest, and transportation, from which we calculated the corresponding emissions using the IFEU standards. Miscanthus plants were presumed to have a useful stand life of sixteen years. Establishment requires two years before the first harvest, followed by a single harvest annually yielding 25 metric tons per hectare (ha). Weed control was required only in the first year, and fertilizing started in the second year at 50 kg per ha of N. Phosphorus and potassium were not added because soil levels were assumed to be adequate, and plant uptake and removal were very low (Lewandowski and Kircherer, 1996). The harvest method was chopping for loose hauling, presuming a loss of plant dry matter of 5%. This compares with 10-30% loss from the round-baling method (ADEME, 1998). Ash disposal to a landfill after combustion was also considered as a byproduct. The environmental impacts of the agricultural production processes were averaged over the lifetime of the crop to obtain annual values. Economic evaluations, not conducted to date, will use discounting.

The fossil fuel life-cycle analysis was carried out similarly to the miscanthus LCA by taking into account all processes involved in resource extraction, processing, and utilization. Natural gas production entailed extraction, transportation, compression, processing, and finally distribution to the consumer. Natural gas was assumed to be extracted in Norway and Russia and distributed throughout France. The crude oil was extracted in OPEC countries and transported to Europe with transport costs calculated using average distances (IFEU, 2000). These choices are based on expert opinion and current technology (IFEU, 2000). The IFEU report provided an assessment of the relative reliability of environ-

mental impacts. Since empirical data were very limited or nonexistent for miscanthus, values were extrapolated from other crop production systems and qualified by in-country experience (Benoit et al., 2001). We decided to analyze only those environmental impacts whose estimates and data sources were considered by IFEU (2000) to be reliable. Impacts excluded from this analysis included stratospheric ozone depletion, human toxicity (e.g. carcinogens, heavy metals, particulates), and ecotoxicity agents (e.g. heavy metals and recalcitrant organics).

For the life-cycle inventory assessment, sums of impacts for all processes were converted into functional units of MJ/ha or g emissions/ha to calculate total impacts for the entire production chain. We subtracted these sums from the reference system for miscanthus. A normalization step, or ranking, was carried out to compare the results over a range of variables and impact categories, including conversion to percentage of total impacts to simplify the presentation and interpretation of data. Calculations and graphing were carried out using Microsoft Excel® spreadsheets.

RESULTS AND DISCUSSION

Standardized outputs of primary energy depletion and environmental pollutants for simulated miscanthus production are illustrated in Fig. 2. All impacts were small in comparison to global warming potential resulting from fertilization, harvest, and transport. Fertilization impact is relatively large because the process of converting atmospheric nitrogen gas (N₂) into ammonia is energy intensive and consumes natural gas as a source of hydrogen. Thus, any energy-efficient, plant-derived biofuel system must be one which has very low nitrogen fertilizer requirements. Miscanthus is a crop which is relatively efficient in nitrogen use and conversion to biomass yield (Lewandowski and Schmidt, 2006). Harvest and transport also consume significant amounts of fossil fuel and thus emit measurable amounts of GHG, suggesting the importance of developing improved methods of handling bulky feedstocks such as plant biomass.

The wide range of orders of magnitude of the output values necessitates comparing the two fuels on a percentage basis to more easily visualize their relative impacts. Figure 3 illustrates relative contributions to each impact category of each production process, ranging from seedstock production to ash disposal. The entire value of an impact, be it in MJ of primary energy depletion or g of emissions, is represented by 100%. Combustion contributed the large majority of emissions resulting in ozone creation (photochemical ozone creation potential, POCP, or smog), eutrophication, acidification, global warming potential, and primary energy depletion. The

latter category essentially represents fossil-fuel depletion involved in all nonrenewable energy consumption processes. Eutrophication, acidification, and ozone creation are explained by release of nitrogenous, sulfurous, and phosphatic compounds to the soil, water, and atmosphere resulting from fertilization of the crop and from combustion and release of gases (Table 1). Harvest and biomass transport impacted the environment less adversely than fertilization (Fig. 3), whereas seedstock production, field preparation, planting, and pest control contributed negligible amounts to environmental impacts.

Values for comparing miscanthus vs. natural gas are summarized in Table 2. Natural gas had substantially greater resource depletion (3.6-fold) and global warming potential (2.0-fold) than miscanthus. Photochemical ozone creation potential was essentially the same between the two energy sources. In contrast, acidification and eutrophication impact values were lower and thus more favorable for natural gas than miscanthus, based on our analyzed system. The calculated differences between the fuel types indicate which had a more favorable environmental impact. The negative values represent an advantage for the bioenergy when compared to its fossil fuel counterpart. Likewise, positive values show a disadvantage for the biofuel. Results are also presented as relative percentages of the sum of the two energy types (Fig. 4). This presentation normalizes the data and places the impact categories on the same scale. The advantage of miscanthus over natural gas in reducing nonrenewable resource depletion and global warming potential is again clear, as is the relative advantage of natural gas in reducing acidification and eutrophication.

It is clear that replacing a nonrenewable fossil fuel such as natural gas with a renewable, perennial biofuel crop would greatly reduce depletion of fossil fuel reserves, even though some fossil energy consumption occurs with production, harvest, and transport of the crop. The annual photosynthetic ability of miscanthus greatly reduces net CO₂ emissions and thus reduces GHGs and the global warming potential. Lewandowski et al. (1995) concluded that combusting 20 metric tons/ha miscanthus emits a net 2.2 tons CO₂, whereas combusting the same energy equivalent of hard coal emits 34 tons CO₂. Therefore each hectare of miscanthus would directly reduce emission of 31 tons CO₂ per year (90% reduction) when compared with hard coal. In addition to CO₂, emissions include other GHGs such as CO, CH₄, and N₂O (Kaltschmitt et al., 1997). Use of low-net-emission biofuels combined with minimal fossil energy consumption during conversion would have more favorable effects on atmospheric conditions, particularly global warming reduction, than any fossil fuel.

The disadvantage of miscanthus in terms of acidification and eutrophication demonstrates that biofuel crops are not completely benign in their potential environmental impact when used in combustion. Sources of emissions in these categories are mainly from the combustion process itself (Fig. 3), which oxidizes organic S and N in plant biomass to SO₂, NO_x, and other trace compounds, which convert to acids in the atmospheric water and return to soil and surface waters as precipitation or dry fallout. Natural gas is a relatively clean-burning fossil fuel, especially in relation to coal. Soil acidification from nitrogen fertilizer was assumed to occur in this LCA, and fertilization of the biofuel crop to produce high yields results in some degree of leakage of nutrients off-site. The ability of miscanthus to retain and internally recycle environmentally sensitive macronutrients such as N, P, and S is poorly understood. Efficient nutrient recycling of such nutrients would be expected to minimize the eutrophication impact of producing perennial biofuel crops.

Conclusions

We conclude that the lignocellulosic feedstock, miscanthus, is a more environmentally beneficial fuel source than natural gas in terms of global warming potential when comparing their use for combustion for district heating. Miscanthus production would theoretically involve zero net carbon emissions when only considering the re-assimilation of CO₂ via photosynthesis that had been previously emitted through combustion; however, use of fossil fuels in nitrogen fertilizer synthesis, delivery, and application and the harvest and transport of biomass consume some fossil energy. Site conditions, nitrogen fertilizer-use efficiencies by different feedstocks, and local economic factors must be taken into account when selecting a fuel source that will create the most environmentally benign system. The agronomic properties of miscanthus make it a promising plant species for bioenergy in France and potentially the U.S. because it produces high biomass yields with a low level of industrial inputs, such as fertilizers and pesticides. The favorable CO₂ balance of this feedstock emphasizes its efficiency as a fuel source, especially considering current global climate change. It is important to note that other biomass species, such as switchgrass (*Panicum virgatum*), may lead to different results if our assumptions do not apply. The comparison of biogenic and fossil fuels shows clear advantages and disadvantages with both fuel options, and decision-makers must consider the trade-offs based on the acceptance of the various ecological impacts on a worldwide basis.

Further research should include field trials and comparative analyses with other biofuel feedstocks in multi-

ple sites in Europe and the U.S. to more accurately quantify the net energy balances and environmental impacts than just those estimated in this simulation model. Life-cycle analyses are useful complements to field trials to estimate environmental advantages of alternative biofeedstocks that could replace nonrenewable fossil fuels.

ACKNOWLEDGMENTS

The support of the Dale Bumpers College of Agricultural, Food and Life Sciences and the University of Arkansas Division of Agriculture is gratefully acknowledged.

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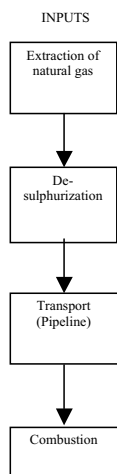
Table 1. Impact classification of pollutants indexed in the life cycle inventory.

| Impact categories | Pollutants inventory |
|---|---|
| Primary energy depletion | Primary energy inputs: natural gas, petroleum, coal, and uranium |
| Global warming potential (GWP) | Volatile organic compounds (VOCs) CO ₂ , CO N ₂ O, CH ₄ |
| Ozone depletion | N ₂ O |
| Photochemical ozone creation potential (POCP, smog) | Benzene (C ₆ H ₆), Methane (CH ₄), VOCs CO, Hexane |
| Acidification | NH ₃ , HCl, NO _x , SO ₂ |
| Eutrophication | NO _x , NO ₃ ⁻ , NH ₃ , NH ₄ ⁺ , PO ₄ ⁻³ |

Table 2. Resource depletion and emission values for miscanthus and natural gas. Negative values for the difference between the energy types indicate an environmental benefit from using the bioenergy crop over the fossil fuel.

| Environmental impact | Balance parameter | Unit (per hectare, per year, per MJ of heat) | Bioenergy life cycle (miscanthus) | Fossil fuel life cycle (natural gas) | Difference (bioenergy-fossil fuel) |
|----------------------|-----------------------------|--|-----------------------------------|--------------------------------------|------------------------------------|
| Resource depletion | Primary energy | MJ | 0.3415 | 1.2336 | -0.8921 |
| GWP500 | CO ₂ equivalents | g | 35.128 | 69.814 | -34.685 |
| POCP | Ethylene equivalents | g | 0.0182 | 0.0199 | -0.0017 |
| Acidification | SO ₂ equivalents | g | 0.2910 | 0.0601 | 0.23090 |
| Eutrophication | NO ₃ equivalents | g | 0.3092 | 0.0785 | 0.2306 |

Natural Gas Production



Miscanthus Biomass Production

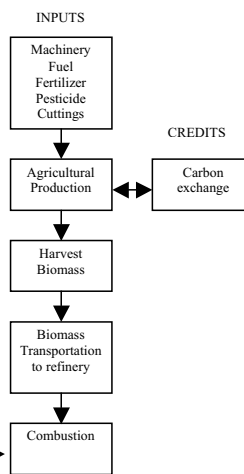


Fig. 1. Standard life cycle comparison of natural gas and miscanthus production

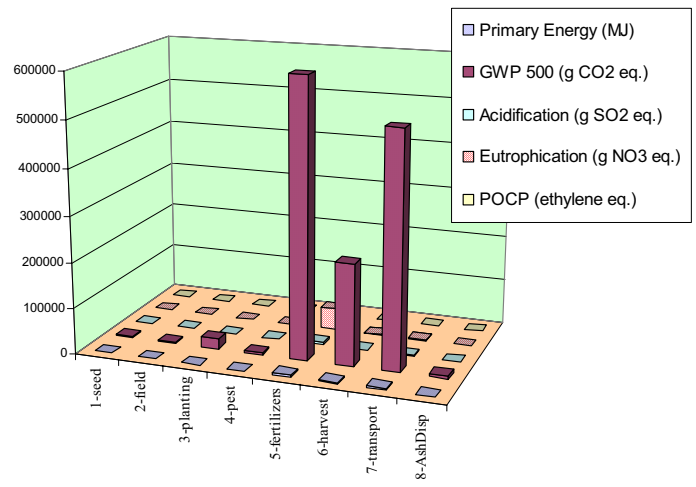


Fig. 2. Impacts of miscanthus production steps on environmental impact categories expressed as standardized functional units, megajoules (MJ) or grams (g) per hectare, as appropriate.

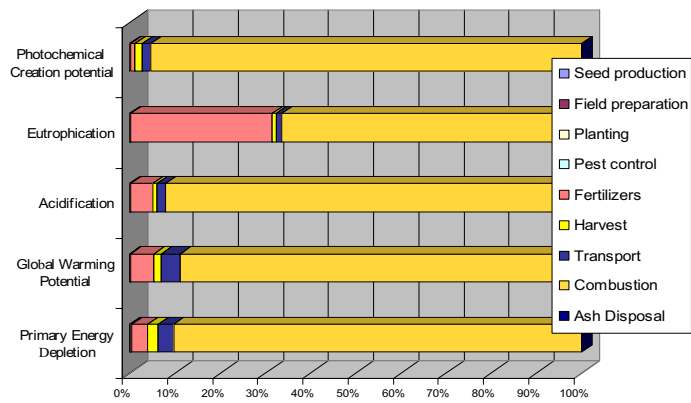


Fig. 3. Relative contributions of miscanthus biofuel production and combustion processes to each environmental impact classification.

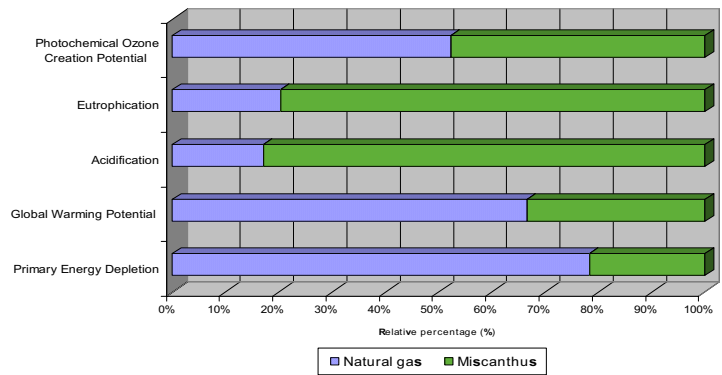


FIG. 4. Comparisons of miscanthus vs. natural gas for their environmental impacts. Fuel type with a horizontal bar greater than 50% indicates more negative environmental impact.

An acreage response model for Arkansas rice farms

J. Grant Ballard^{*} and *Michael R. Thomsen*[†]

ABSTRACT

In recent years, market forces have signaled a strong demand for rice as well as other Arkansas crops. However, high fuel, fertilizer, and chemical costs have negatively impacted farm income, and these input costs are widely known to impact planting decisions of farmers. The goal of this study is to develop and estimate an acreage response model for rice. The model is used to compute acreage response elasticities and provides insight into roles that input costs and crop prices play in acreage decisions made by producers. Economic theory predicts that prices for important inputs such as fuels and fertilizers as well as the relative prices of rice and soybeans will impact acreage decisions. Soybean prices are expected to be important because most of the machinery needed to produce rice and soybeans is the same and these crops are already used commonly in rotation. Results of the study show that crop price variables do indeed play a significant role in producer planning. Short- and long-run own-price acreage response elasticities are estimated to be 0.69 and 1.19, respectively. Soybean prices have the expected negative impact on rice acreage with a cross-price elasticity of -0.33 in the short run and -0.57 in the long run. On the other hand, the expected economic impacts of input prices on rice acreage were not supported by the results. Estimated relationships were negative, as would be predicted by economic theory, but were not statistically significant.

^{*} J. Grant Ballard completed his BSA in agricultural business in December 2007 and is entering the University of Arkansas School of Law in August 2008. This paper is based on his honors research project that he completed while a senior in the Dale Bumpers College studying in the Department of Agricultural Economics and Agribusiness.

[†] Michael R. Thomsen is an associate professor in the Department of Agricultural Economics and Agribusiness.

MEET THE STUDENT-AUTHOR



J. Grant Ballard

I am a native of Roland, Ark., and a 2004 graduate of Little Rock Central High School. Upon graduation from high school, I enrolled at the University of Arkansas in the Department of Agricultural Economics and Agribusiness. I completed my B.S. degree in December 2007 with a major in agribusiness and a minor in environmental, soil, and water science. While an undergraduate at the University of Arkansas, I was a member of the Alpha Gamma Rho Fraternity, Agribusiness Club, Collegiate Farm Bureau, Order of Omega, and Alpha Zeta. I also had the honor of serving the Bumpers College as a student ambassador. I was Vice Noble Ruler of Alpha Gamma Rho in 2006, and I was president of the University of Arkansas chapter of Collegiate Farm Bureau in 2007. I will begin law school in fall 2008 at the University of Arkansas at Fayetteville.

This field of research was selected because of my personal interest in agricultural economics and rice production as well as the economic importance of rice production and milling to the study region and the state. I would like to thank Dr. Michael Thomsen for his guidance, time, and commitment to this study.

INTRODUCTION

In recent years, market forces have signaled a strong demand for rice and other Arkansas crops. This demand fueled a growth in Arkansas crop sales. However, high fuel, fertilizer, and chemical costs have negatively impacted farm income (Childs and Livezey, 2006), and these input costs are widely known to impact planting decisions of farmers. In eastern Arkansas, rice and soybeans are commonly grown in rotation in order to control weed populations in rice fields. Most eastern Arkansas soils that are suited for rice are also well suited for soybean production, and that makes this arrangement economically sound. Growers clearly have the option to grow rice, soybeans, or other possible crops. Aside from agronomic considerations, producers will base their planting decisions on expected profitability (Kay, Edwards, and Duffy, 2004). For a variety of reasons, a producer could decide to dedicate more of his/her acreage to soybeans or other crops and less to rice. Rice is more capital intensive than soybeans (Childs and Livezey, 2006), and in years with higher input costs or lower average rice prices, it would be expected that a lower than average acreage would be planted in rice.

The objective of this study is to develop and estimate an acreage response model for rice. The model will be used to compute acreage response elasticities and will provide insight on the role that input costs and crop prices play in acreage decisions made by producers in the selected study region. It is expected that prices for important inputs such as fuels and fertilizers as well as relative prices of rice and soybeans will impact acreage decisions. Soybean prices are expected to be important because most machinery needed to produce rice and soybeans is the same and these two crops are already used commonly in rotation.

MATERIALS AND METHODS

Acreage Response Model

Shumway (1986) summarizes supply relationships for several southern US crops and provides an overview of empirical methods of supply estimation. Economic theory indicates that supply depends on the price the producer expects to receive at harvest along with the prices of inputs and the expected profitability of other competing crops (Hudson, 2007). Several approaches are available for specifying an expected price. Nerlove (1958) championed the use of the adaptive expectations model for the analysis of agricultural supply functions. This is a very common approach and many textbooks on

the subject of econometrics discuss this model and present issues involved in its estimation (Maddala, 1992; Kmenta, 1986). The adaptive expectations model provides one way to address price expectations even though such expectations are not observed. Producers cannot always accurately predict price they will receive but it is reasonable to assume that producers' expectations of price are expressed as a weighted average of past prices (Nerlove, 1958). The weights of past prices are functions of λ , where λ is a coefficient between zero and one. Specifically, expected prices are expressed as:

(1)

$$P_{t+1}^* = (1-\lambda)P_t + (1-\lambda)\lambda P_{t-1} + (1-\lambda)\lambda^2 P_{t-2} + (1-\lambda)\lambda^3 P_{t-3} + \dots$$

According to equation (1) the expected price in any given period depends on prices that have been observed in the past. The influence of observed prices on this expectation will decline as one goes back in time, since λ is between zero and one. The goal is to represent expected price in some manner that does not require an infinite number of observations on past prices. This can be accomplished by lagging equation 1 by one period and multiplying through by λ to get:

(2)

$$\lambda P_t^* = (1-\lambda)\lambda P_{t-1} + (1-\lambda)\lambda^2 P_{t-2} + (1-\lambda)\lambda^3 P_{t-3} + \dots$$

Subtracting equation (2) from equation (1) provides:

(3)

$$P_{t+1}^* - \lambda P_t^* = (1-\lambda)P_t$$

The usefulness of equation (3) will be clear momentarily.

A linear econometric model for the acreage response function for rice is given by:

(4)

$$Q_t = \alpha + \beta P_t^* + \sum_{i=1}^N \gamma_i Z_{it} + U_t$$

Where Q_t is acreage, P_t^* is expected rice price, and the Z_{it} are exogenous variables reflecting the profitability of soybeans (a competing crop) and prices of inputs. Lagging equation 4 by one period and multiplying through by the partial adjustment coefficient, λ , provides:

(5)

$$\lambda Q_{t-1} = \lambda\alpha + \lambda\beta P_{t-1}^* + \lambda \sum_{i=1}^N \gamma_i Z_{it-1} + \lambda U_{t-1}$$

Subtracting equation 5 from equation 4 provides:

(6)

$$Q_t = (1-\lambda)\alpha + \lambda Q_{t-1} + \beta(P_t^* - \lambda P_{t-1}^*) + \sum_{i=1}^N \gamma_i (Z_{it} - \lambda Z_{it-1}) + U_t - \lambda U_{t-1}$$

which, by equation 3, can be expressed in terms of observed variables as:

(7)

$$Q_t = (1-\lambda)\alpha + \lambda Q_{t-1} + \beta(1-\lambda)P_{t-1} + \sum_{i=1}^N \gamma_i (Z_{it} - \lambda Z_{it-1}) + U_t - \lambda U_{t-1}$$

Equation 7 is a function of observed variables and can be used to uncover estimates of the parameters from the theoretical model in equation 4. There is one problem that complicates the estimation of equation 7 in that the error term is correlated with Q_{t-1} , one of the regressors.

As a result, the method of ordinary least squares will provide inconsistent parameter estimates. For this reason, Maddala (1992) discusses the use of non-linear least squares to estimate equation 7.

Computation of Elasticities

The parameter estimates observed from equation 7 make it possible to calculate point estimates for acreage response elasticities. The estimated own-price coefficient (β) and estimates for coefficients on exogenous variables (γ_i) are used to determine point estimates for acreage response elasticities. Specifically, the own-price elasticity of supply is given as:

(8)

$$\beta \frac{P}{Q}$$

and the elasticity of supply with respect to the i th exogenous variable is given by:

(9)

$$\gamma_i \frac{Z_i}{Q}$$

Long-run acreage response elasticities can be computed by dividing the short-run elasticity computed from either equation 8 or 9 by $(1-\lambda)$ (Nerlove and Addison, 1958).

Data

Data for this study were collected from the United States Department of Agriculture National Agricultural Statistics Service (NASS, 2007) and the United States Department of Labor Bureau of Labor Statistics (BLS) (2007a; 2007b). NASS provided average yearly prices for rice and soybeans as well as county-level information on acres planted, acres harvested, and average yield. Producer Price indexes (PPI's) for petroleum products and for fertilizer products were collected from BLS (2007a) in order to demonstrate changes in prices paid

by producers for inputs. The producer price index measures average change over time in selling prices received by domestic producers for their output. The BLS's (2007b) Consumer Price Index (CPI), which measures general inflation in the US economy, was used to adjust all prices and PPI measures for inflation.

The study region consists of 55 counties and parishes in the states of Arkansas, Mississippi, Missouri, and Louisiana. The selected counties and parishes are all found in what NASS classifies as the Mississippi Delta region and in the East Arkansas Non-Delta region (Livezey and Foreman, 2004). Production practices throughout the region are similar, and costs of production as well as returns should be fairly standard across the region. In order to accurately assess impacts of input costs and crop prices upon acreage decisions of farmers, only those counties with a regular history of rice production were included. The criterion used to include or exclude counties from the study region was for the county to have reported rice production in each of the past 10 years. A graphic of the study region used for this study is presented in Figure 1.

Rice acreage, the dependent variable for the acreage response model, was obtained by summing acres harvested over all counties and parishes in the study region for each year. Based on 2000 to 2006 production data from NASS, the 55 counties and parishes in the study region accounted for 62% of all US rice production and approximately 80% of US long grain rice production. Soybean price was considered exogenous for the purposes of this study. In terms of national production, the study region was responsible for a small portion (approximately six percent) of the total US soybean production. The implicit assumption here was that producers in the study region can sell all the soybeans they want at prevailing prices.

In developing the dataset it was important to account for the impact of policy on producer behavior. Beckman (2005) provides a good summary of US farm policy that affects rice production. Supply controls such as acreage adjustments, marketing quotas, price supports, and storage of excessive supplies under loan were a part of the government policy toward basic US commodities for much of the twentieth century. The rice acreage allotment system was eliminated with the Farm Bill of 1981. The Marketing Loan Program allows producers to obtain a loan from the Commodity Credit Corporation (CCC). The producer uses his current year production as collateral. The loan rate creates a price floor, and producers are eligible for a marketing loan gain (MLG) when world price falls below the loan rate. Loan Deficiency Payments (LDPs) are also available to producers under the Marketing Loan Program. Again, these

payments are available when world price falls below the loan rate. Producers can take this direct payment instead of securing a Marketing Assistance loan. Because the loan rate acts as a price floor that maintains a certain level of production, the price of rice was modified to reflect the larger of (a) the loan rate or (b) the price reported by NASS (2007). Loan rate data were gathered from the USDA's Economic Research Service.

The period chosen for this study reflects 30 years beginning with 1977 and extending through 2006. Although the earliest years in the dataset reflect conditions under the acreage allotment system, which limited producer responses to price signals, the goal here is to obtain a dataset that reasonably reflected recent production practices but still contained enough observations for the statistical methods to be reasonably powerful. Descriptive statistics for variables used in the acreage response model are reported in Table 1.

RESULTS AND DISCUSSION

Table 2 presents results of the estimated acreage-response model. The estimate column displays the parameter estimates of the model. These estimates demonstrate the impact of an increase in rice price, soybean price, fuel price, and fertilizer price. These estimated impacts can be used to determine how producers respond to changes in these variables. For example, if rice price were to increase by \$1 per cwt., then according to the results rice acres harvested would increase by 173,643 acres. If soybean price was to increase by \$1 a bushel, then rice acreage would drop by 108,915 acres. Continuing with this analysis, if fuel price and fertilizer price were to increase by the same amount per unit, acreage would shift down 125 acres and down 5,107 acres, respectively. However, one must also consider the magnitude of the t-values reported in Table 2. The t-values for fuel and fertilizer prices are small in magnitude and indicate a lack of statistical evidence for these variables having an effect on acreage decisions.

The conclusion to be drawn from Table 2 is that rice and soybean prices have the most significant impact upon acreage devoted to rice while fuel and fertilizer prices seem insignificant. The insignificant impacts of fuel and fertilizer prices are perplexing because economic theory would suggest acreage should be reduced as input prices increase. To explore the issue further the model was re-estimated without the fertilizer price because fuel and fertilizer prices are highly correlated. This alternative specification did not meaningfully change the results. After fertilizer was dropped, the fuel coefficient was still positive and insignificant.

Acreage response elasticities (Table 3) are computed

at the sample means. Again, it is important to keep in mind that the coefficients on fuel and fertilizer price variables were insignificant and so the fuel and fertilizer elasticities are suspect. The short-run own-price elasticity is 0.69 and can be interpreted as indicating that all else equal, a one percent increase in the price of rice will result in 0.69 percent increase in acreage devoted to rice production. The long-run own-price elasticity of 1.19 is larger in magnitude and is consistent with the idea that production decisions are more flexible over a longer planning horizon. Other elasticity estimates reported in Table 3 can be interpreted in the same fashion.

Discussion

The objective of this study was to determine acreage response of rice to changes in crop price and increasing costs of inputs. The goal was to identify the impact of these factors upon planting decisions of rice producers in the study region. Economic theory predicts that expected returns motivate planting decisions, and results presented here provide clear evidence that crop price variables play an important role in producer planning. All else equal, when price of a crop increases, supply will follow. Similarly, the model showed that as soybean prices increase, acreage shifts out of rice. This is again a basic economic principle that makes good sense for business application.

The expected economic impacts of input prices, on the other hand, were not supported by the results. Rice acreage was not found to be significantly responsive to fuel costs or fertilizer costs. This may suggest that input costs are not as significant as expected price when producers make their planting decisions. However, it is more likely that the lack of significance is a feature of the problem being analyzed. Specifically, inputs such as fuel make up about the same percentage of total cost for production with irrigated soybeans as with rice. Fuel costs average approximately 15 to 20 percent of cost for production with both crops (Watkins, 2006). Producers will spend less to make a crop of soybeans because the crop is not as input-intensive, but the returns will generally be higher for rice if the price is competitive due to rice being a higher yielding crop than soybeans.

Agriculture is changing rapidly in the present day. The 2006 crop year was the last year analyzed in this study. Since then, many new issues have arisen that could bring attention to the questions addressed in this study. Basis has reached record highs in many regions and the ethanol boom has shifted much acreage into corn and out of soybeans in the past year. In future research, a market equilibrium model could be useful for a study of the Midwest corn and soybean crops. In the Midwest, where corn and soybean prices would not be considered

exogenous, it may be easier to estimate the impact that fuel prices have on equilibrium prices of these crops and then to examine how the impact of those price changes indirectly impact rice prices and consequently rice acreage.

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Table 1. Descriptive statistics for the study region 1977-2006.^A

| Variable | Description | N | Mean | Std Dev | Minimum | Maximum |
|----------|------------------------|----|-----------|---------|---------|-----------|
| Rharv | Rice Acres Harvested | 30 | 1,694,145 | 316,640 | 985,490 | 2,227,400 |
| Rprice | Rice Price (\$/cwt.) | 30 | 6.88 | 3.46 | 3.61 | 15.66 |
| Sprice | Soybean Price (\$/bu.) | 30 | 4.99 | 2.18 | 2.47 | 10.21 |
| Fert | Fertilizer Price (PPI) | 30 | 81.05 | 15.41 | 57.70 | 111.33 |
| Petro | Petroleum Price (PPI) | 30 | 61.92 | 23.33 | 31.47 | 116.50 |

A. All prices and price indexes are adjusted for inflation and are in constant 1982-1984 dollars.

Table 2: Parameter estimates for the acreage response model

| Parameter | Variable | Estimate | Std Err | t Value |
|------------|--------------------------------|-----------|---------|---------|
| λ | Partial adjustment coefficient | 0.42 | 0.16 | 2.66 |
| α | Intercept | 2,843,321 | 645,278 | 4.41 |
| β | Rice price (\$/cwt.) | 173,643 | 71,069 | 2.44 |
| γ_1 | Soybean price (\$/bu.) | -108,915 | 38,729 | -2.81 |
| γ_2 | Fuel price (PPI) | -126 | 2,499 | -0.05 |
| γ_3 | Fertilizer price (PPI) | -5,107 | 6,703 | -0.76 |

Table 3: Elasticities of rice acreage

| Variable | Short-run elasticity | Long-run elasticity |
|------------------|----------------------|---------------------|
| Rice price | 0.69 | 1.19 |
| Soybean price | -0.33 | -0.57 |
| Fuel price | -0.006 | -0.01 |
| Fertilizer price | -0.19 | -0.33 |

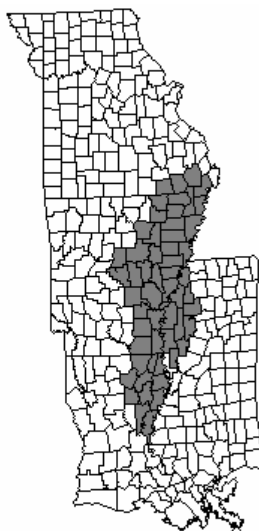


Fig. 1. Counties and parishes included in the Study Region

Investigating the effectiveness of malic acid, nisin, and grape seed extract incorporated into whey-protein coatings to inhibit the growth of *Listeria monocytogenes* on ready-to-eat poultry

Amanda Bettasso*, Navam Hettiarachchy†, Vidya Chitturi§, and Michael Johnson‡

ABSTRACT

The ability to control growth of *Listeria monocytogenes* on ready-to-eat poultry products with the antimicrobials nisin, malic acid, and grape seed extract incorporated into whey-protein coatings was evaluated. The antimicrobials were incorporated into the coating solution alone and in combinations. One gram pieces of turkey frankfurters were coated with the coating solutions and then inoculated with *L. monocytogenes* and stored at 4°C for 28 days. The inhibitory effect of the coatings on turkey frankfurter pieces was evaluated on d 0, 7, 14, 21, and 28. Coatings containing 2% malic acid, 3% malic acid, and the combination of nisin (6,000 IU/g) and malic acid (1%) were the most effective in inhibiting the growth of *L. monocytogenes*. Malic acid at 2 and 3% concentrations reduced *L. monocytogenes* population by 2.0 log cycles compared to the control after 28 d. Combination of 1% nisin and 1% malic acid reduced the population of *L. monocytogenes* by 2.7 log cycles compared to the control after 28 d of storage at 4°C. Grape seed extract did not inhibit the pathogen effectively when used alone or in combination with malic acid or nisin. Results of this investigation demonstrate synergistic effects of nisin and malic acid, which can be effectively incorporated into whey-protein coatings to control the post-processing contamination of *L. monocytogenes* in ready-to-eat poultry products.

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† N. Hettiarachchy, faculty mentor, is a university professor in the Department of Food Science.

§ V. Chitturi, technical advisor, recently completed a doctorate at the University of Arkansas.

‡ M. Johnson, a committee member, is a professor in the Department of Food Science.

MEET THE STUDENT-AUTHOR



Amanda Bettasso

After I graduated from Joplin High School in Joplin, Mo., in 2004, I began my studies at the University of Arkansas. I am a senior food science major and have recently completed the AFLS honors program. I have been the recipient of various scholarships while attending the UofA, such as: University Scholarship, Food Science Scholarship, and the OFPA scholarship. I have been a resident assistant for University Housing for the past two years. I am an active member of the Food Science Club and am currently serving as the treasurer. I am a member of the Institute of Food Technology and the Research Chefs Association. I began doing research under Dr. Navam Hettiarachchy during my junior year in the area of food safety. I plan to get my master's degree in food science and eventually obtain a job in research and development.

INTRODUCTION

Listeria monocytogenes is a psychrotrophic, Gram-positive, facultative intracellular organism widely distributed in the environment. It affects pregnant women, immunocompromised patients, newborns, and very old people. *L. monocytogenes* specifically causes listeriosis, which can give rise to meningitis, encephalitis, septicaemia, endocarditis and cause spontaneous abortion, premature birth, stillbirth, abscesses, and lymphadenitis (Kiss et al., 2004). *L. monocytogenes* can survive at temperatures ranging from 2–45°C and in low pH and high osmotic stress, resulting in many challenges for its control in the food industry (Gandhi and Chikindas, 2007). On an average there are 2500 reported cases of listeriosis annually, resulting in about 500 deaths according to the Center for Disease Control (CDC, 2005). *L. monocytogenes* contamination is especially a problem in the ready-to-eat (RTE) meat industry, often causing massive recalls. In February 2007 approximately 52,650 pounds of RTE chicken, processed in South Carolina, was recalled (FSIS, 2007a). There was an outbreak in May 2007 in ready-to-eat turkey products from a poultry ranch in California (FSIS, 2007b). These outbreaks, along with many others, have lead to increased regulations in RTE meats and increased interest in improving

the current preservation techniques to inhibit the growth of *L. monocytogenes*.

There are several existing hurdle technologies that attempt to inhibit the growth of *L. monocytogenes* in RTE meats. Thermal processing techniques, although effective, pose the problem of decreasing product quality due to an edge-heating effect that is typically associated with microwave heating (Huang and Sites, 2007). Organic acids are often used in conjunction with other antimicrobials to prevent contamination in food products and have proven to be effective in bacterial inhibition (Palumbo and Williams, 1994; Murphy et al., 2006). Antimicrobial peptides, such as nisin, are used as food preservatives to inhibit growth of several foodborne pathogens and spoilage bacteria in various food products (Zuoxing et al., 2006). Recently, increased interest in plant extracts has grown due to their antioxidant and antimicrobial activities. In addition, there is increasing evidence of antimicrobial properties of phenolic constituents of grape seed extract. Grape seed extract is effective in inhibiting *Escherichia coli* O157:H7, *Salmonella typhimurium*, and *Listeria* (Ahn et al., 2004). Dr. Hettiarachchy's research team focuses on developing protein-based antimicrobial edible films and coatings. This research team showed that the combination of nisin with the natural extracts in edible films could help

increase protections against *L. monocytogenes*, specifically at refrigerated storage temperatures (Theivendran et al., 2006). Heat-denatured whey protein produces bland, flexible, water-based edible films with excellent oxygen, aroma and oil-barrier properties (Perez-Gago and Krotcha, 2001).

With outbreaks occurring as recently as June 2007, resulting in recall of 2,768 pounds of contaminated RTE chicken products out of Tennessee, there is still a call for effective pathogen hurdle technologies (FSIS, 2007c). Hence the objectives of this study are to 1) develop whey-protein edible films incorporated with natural antimicrobials such as grape seed extract, nisin, and malic acid and 2) evaluate their effectiveness in inhibiting *Listeria monocytogenes* in turkey frankfurter systems.

MATERIALS AND METHODS

Listeria monocytogenes was obtained from the Food Microbiology Research Laboratory at the University of Arkansas, Food Science Department. Nisin (N) was purchased from Aplin and Barret Ltd., Dorset, United Kingdom. Grape seed extract (GSE) powder was obtained from Mega Natural Inc., Madera, California. Malic acid (MA) was purchased from Baker, Phillipsburg, N.J. Whey protein was purchased from Land O'Lakes Food Ingredients Division, Arden Hills, Minn., and glycerol plasticizer was purchased from the Sigma Chemical Company, St. Louis, Mo. Turkey frankfurters were obtained from Hettiarachchy's lab, previously made by her team at the University of Arkansas.

Determination of nisin activity. During refrigerated storage nisin loses its activity, hence the activity was determined. *Lactobacillus plantarum* NCDO 955, a standard indicator organism, was used to determine the activity of nisin. Activity was considered as a measure of inhibitory effect of nisin against *L. plantarum* on MRS soft agar plates. Frozen culture of *L. plantarum* was activated by inoculating 10 µl of the culture in MRS medium and incubating at 30°C for 24 h. Approximately 6 ml of MRS soft agar (preboiled at 45°C and cooled) were inoculated with 10 µl of *L. plantarum* and mixed gently. Inoculated soft agar was then poured onto MRS agar plates and allowed to solidify for 30 min under laminar flowing conditions. Stock solution of 0.01 g/ml nisin was prepared in sterilized de-ionized water. Serial dilutions from 1:2 to 1:256 were prepared from the stock and 5 µl of serial dilution were transferred into the surface of the agar by a micropipette tip. The spotted plates were dried for 30 min under the laminar hood and then incubated at 30°C for 24 hours. The activity of nisin was determined using the inverse value of the highest dilution (D) that produced at least a 2mm zone of inhibition. Nisin

activity was calculated using the formula:

$$\frac{\text{Amount of sample (5 } \mu\text{l) spotted}}{\text{Inverse of the highest dilution (D)}}$$

Whey-protein film preparation. Nine grams of whey protein were added to 91 grams of water and stirred on a magnetic stirrer continuously until the protein dissolved. Then, 45% glycerol (w/w of protein) was added during continuous stirring for 30 min. The solution was heated at 85°C to denature the protein and to cross link glycerol with the denatured protein to form a polymer. Solutions were cooled to ambient temperature. Nisin (N) was added at 6000, 12,000, and 18,000 IU/g; malic acid (MA) or grape seed extract (GSE) was added at 1%, 2%, and 3% concentrations alone. Concentration of these treatments below 1.0% was not effective in inhibiting the pathogen (Theivendran et al., 2006). Concentrations more than 3.0% resulted in formation of gels in the solution, which is not desirable for coating the food products. Hence the concentrations selected in this study reflect optimum levels for film formation. The combinations of nisin (6000 IU/g), MA (1%), and GSE (1%) were incorporated and stirred until the ingredients were completely solublized. The coating solutions were then stored at 4°C until the meat samples were ready to be coated.

Activation of frozen *L. monocytogenes* for inoculation of meat samples. The strain V7 serotype 1/2a of *L. monocytogenes* was used in this project. A loopful of *L. monocytogenes* from stock frozen to -70°C was placed in 10 mL of BHI broth and incubated at 37°C for 24 h. A subculture was prepared with 10µL from the first culture in 10mL of BHI and incubated at 37°C for 18 h. Then 1000 µL of this culture were centrifuged for 10 minutes at 7000 xg. Serial dilutions of the cell suspensions were made to obtain an inoculum size of 10⁷ (CFU/ml).

Turkey frankfurter preparation. Turkey breast halves were obtained from Cargill Inc. Minneapolis, Minn. Composition of the turkey frankfurters was as follows: Meat (52.35%), fat (21%), salt (1.25%), phosphate (0.4%), and water (25%). All the dry ingredients, meat and water were blended under vacuum for 30 min at 45 rpm with a 220-kg Keebler mixer (Keebler Engineering, Inc., Chicago, Ill.) to form a meat emulsion batter. The meat batters were subsequently stuffed into non-permeable casings (4.6 cm in diameter) and cooked in water tanks for 2 h at 85°C until products reached an internal temperature of 74°C. The frankfurters were chilled in a 4°C cooler. After chilling, the frankfurters were stripped of their casings and sliced into 1-gram pieces (1x1x1cm cubes), packed in sterile Whirl-Pak® bags, and stored at -20°C until used.

Preparation of meat samples. To initiate the studies, the turkey frankfurters were thawed, then dipped in the whey-protein coating (WPI) solutions and dried under laminar flow conditions. A control sample without WPI coating and a control sample with WPI coating with no added antimicrobials were also included. A total of 225 samples were prepared (15 treatments X 3 replications X 5 sampling days). The concentrations and treatments are given in Table 1. After the protein-coated meat pieces were completely drip-dried, they were inoculated with *L. monocytogenes* by dipping them into the cell suspensions in phosphate-buffered saline (PBS) (approximately 10^7 CFU/ml) for one min and dried under laminar flow conditions. Then the meat pieces were packed in sterile Whirl-Pak® bags and incubated for 28 d at 4°C.

L. monocytogenes count determinations in turkey frankfurter samples. The samples were analyzed for survivors of *L. monocytogenes* on d 0, 7, 14, 21, and 28. Samples were crushed in a stomacher with 9.0 ml of PBS. Serial dilutions of the stomached samples were spread-plated on *Listeria*-selective agar. The plates were incubated at 37°C for 48 h and colony-forming units were counted. The plate counts were then analyzed to determine if there were log reductions in *L. monocytogenes* growth.

RESULTS AND DISCUSSION

Inhibitory effect of whey-protein films. At zero hour, mean population of *Listeria* on the frankfurter samples was 5.0 log CFU/g. As shown in Figure 1, microbial counts, in the control without whey-protein coating (C) and in the control with whey protein coating without antimicrobials (C1), increased over the 28 d study. The control sample started with a listerial level of approximately 5.0 log CFU/g at zero hour and increased to 7.85 log CFU/g on d 28. Control 1 had the same initial listerial level as C and grew to 8.12 log CFU/g after 28 d.

WPI coatings with nisin (6000 IU/g, N1) on frankfurter pieces did not inhibit the pathogen effectively when compared to the controls. As shown in Figure 1, the listerial count started at the same level as the control (C) and increased to 7.9 log CFU/g after 28 d. WPI coating with nisin (12,000 IU/g, N2) on frankfurter pieces lowered the *Listeria* population to 4.7 log CFU/g on d 14. This was a 3.7 log reduction compared to the control (C). However, after d 14 the *L. monocytogenes* counts steadily increased to 7.0 log CFU/g after storage for 28 d at 4°C. This can be explained as the development of resistance to the nisin by the *L. monocytogenes* population. The WPI coating with nisin (18,000 IU/g, N3) had a similar pattern to N2, but was more effective in inhibit-

ing the pathogen. The population of *L. monocytogenes* in N3 samples increased over the first 7 d to 7.1 log CFU/g, and then decreased over the next 14 d (from d 7 to d 21) to 4.3 log CFU/g. The *L. monocytogenes* population developed resistance to the nisin at this concentration and increased to 5.8 log CFU/g at 28 d. The N2 (12,000 IU/g) and N3 (18,000 IU/g) treatments lowered the *Listeria* population by 0.8 and 2 log CFU/g, respectively, compared to the control (C) after 28 d of storage.

Figure 2 shows the response of *L. monocytogenes* in turkey frankfurters coated with WPI films containing malic acid at 1.0% (MA1), 2.0% (MA2), and 3.0% (MA3) concentrations. Listerial counts on frankfurter samples with MA1 steadily increased over the 28 d period to 7.7 log CFU/g. Listerial counts on frankfurter samples containing MA2 and MA3 increased to 7.1 log CFU/ml on d 7 and then decreased over the next 21 d to 5.5 and 5.3 log CFU/g in MA2 and MA3, respectively. There was approximately a 2.0 log CFU/g reduction after 28 d in comparison to the control (C) in frankfurter samples coated with WPI containing 2% and 3% malic acid.

In contrast to nisin and malic acid, the samples containing grape seed extract (GSE) did not inhibit the pathogen. All the GSE treatments at 1.0, 2.0, and 3.0% concentrations (GSE1, GSE2, and GSE3, respectively) had similar growth patterns as the control. The population of *L. monocytogenes* on turkey frankfurter samples coated with WPI containing GSE at 1.0, 2.0, and 3.0% concentrations increased to 8.53, 8.58, and 8.61 log CFU/g, respectively, as shown in Figure 3. These results suggest that grape seed extract is not effective in inhibiting *L. monocytogenes* on turkey frankfurters coated with the WPI films. This can be explained as the availability of protein molecules as nutrients and availability of oxygen conditions, which provide a conducive environment for the growth of *L. monocytogenes*. Previous studies by Dr. Hettiarachchy's team have demonstrated inhibitory effects of grape seed extract incorporated edible films in pre-processing contamination conditions (inoculation of the pathogen on meat samples and then coating the samples with antimicrobial edible films) (Theivendran et al 2006; Chitturi, 2008). However, grape seed extract incorporated WPI films are not effective in controlling post-processing contamination of *L. monocytogenes* on turkey frankfurters.

Figure 4 shows growth of *L. monocytogenes* in turkey frankfurters coated with WPI films containing the combination of N, MA, and GSE. Treatments GSE+MA and N+GSE had similar listerial counts as the controls, C and C1. Both these treatments had listerial counts starting at 5.0 log CFU/g at zero hour and grew to 8.0 and 8.1 log

CFU/g in samples containing GSE+MA and N+GSE, respectively, after 28 d of storage. Listerial levels in the samples containing N+MA increased from 5.0 log CFU/g at zero hour to 6.3 log CFU/g on d 21. After d 21, the listerial level decreased to approximately 5.2 log CFU/g. There was a 2.7 log CFU/g reduction compared to the controls after 28 days of storage. The WPI coatings containing a combination of N and MA were more effective in inhibiting the pathogen than when either was used alone. This can be explained due to the improved stability of nisin at acidic pH. Similar observations were made by Ko et al. (2001), who demonstrated that nisin-incorporated edible films have more potency at lower pH conditions. Moreover, pore formation by nisin on the membrane of *L. monocytogenes* facilitates the lower molecular-weight compound malic acid in penetrating inside the cell and lowering the pH of the cell. This leads to a reduction in listerial levels.

The combination of all three antimicrobials, N+MA+GSE, resulted in a decrease in listerial levels over the first 7 d from 5.0 log CFU/g to 3.7 log CFU/g. The listerial levels then steadily increased over the 28 d storage to 6.8 log CFU/g. There was a 1.0 log CFU/g reduction in the *Listeria* population in comparison to the control after 28 d of storage. Incorporation of grape seed extract with N and MA did not further enhance antimicrobial activities. This could be explained due to the lack of inhibition from the grape seed extract.

In summary, nisin (12000 IU and 18000 IU) and malic acid (2.0 and 3.0%) reduced the *L. monocytogenes* population by 2.0 log CFU/g in turkey frankfurters after 28 d of storage as compared to the controls. Grape seed extract did not inhibit the pathogen at all when used alone or in combination with nisin and malic acid and compared to the control. The most effective treatment in the study was the nisin and malic acid combination (N+MA), which lowered the population of *L. monocytogenes* by 2.7 log CFU/g, compared to the control, after 28 d of storage. Edible films can be an effective hurdle technology against foodborne pathogens and could be used in the ready-to-eat poultry and meat industry.

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Table 1. Composition and concentrations of treatments used in whey protein edible films

| # | Treatment | Abbreviation | Concentration (%) | | |
|----|--|--------------|-------------------|-----|-----|
| | | | N | MA | GSE |
| 1 | Control with no WPI film, no antimicrobial additives | C | - | - | - |
| 2 | Control with WPI film, no antimicrobial additives | C1 | - | - | - |
| 3 | WPI film + nisin | N1 | 6,000 IU/g | - | - |
| 4 | WPI film + nisin | N2 | 12,000 IU/g | - | - |
| 5 | WPI film + nisin | N3 | 18,000 IU/g | - | - |
| 6 | WPI film + grape seed extract | GSE1 | - | - | 1.0 |
| 7 | WPI film + grape seed extract | GSE2 | - | - | 2.0 |
| 8 | WPI film + grape seed extract | GSE3 | - | - | 3.0 |
| 9 | WPI + malic acid | MA1 | - | 1.0 | - |
| 10 | WPI + malic acid | MA2 | - | 2.0 | - |
| 11 | WPI + malic acid | MA3 | - | 3.0 | - |
| 12 | WPI + Malic acid + grape seed extract | MA+ GSE | - | 1.0 | 1.0 |
| 13 | WPI + nisin + malic acid | N + MA | 6000 IU/g | 1.0 | - |
| 14 | WPI + nisin + grape seed extract | N + GSE | 6000 IU/g | - | 1.0 |
| 15 | WPI + nisin + grape seed extract + malic acid | N + GSE + MA | 6000 IU/g | 1.0 | 1.0 |

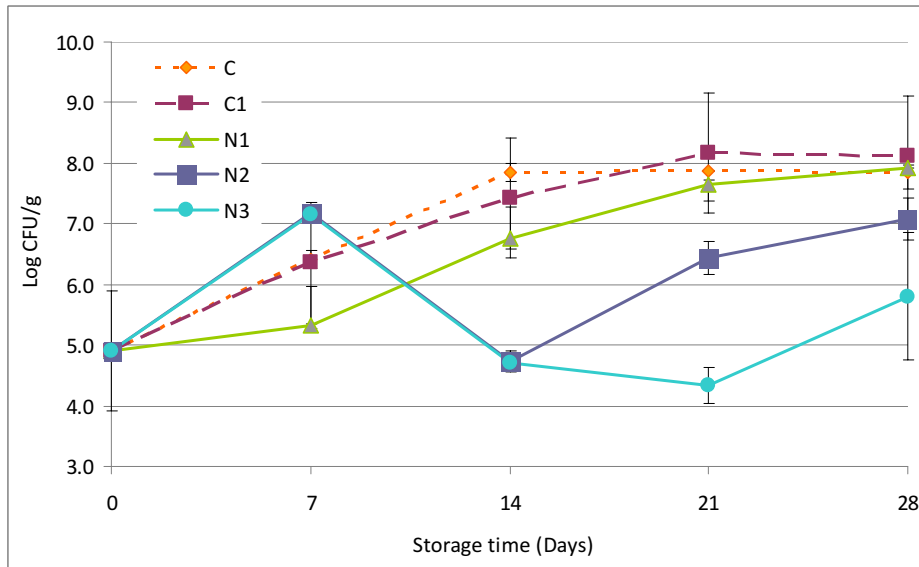


Fig. 1. Inhibitory activity of N-incorporated whey-protein coatings on turkey frankfurters, inoculated with *L. monocytogenes* stored at 4 °C for 28 d. C: Control without WPI films, C1: control with WPI film and without antimicrobials, N: WPI film with nisin at 6,000 IU/g = N1, 12,000 IU/g = N2, and 18,000 IU/g = N3. Values in figure are means of three different replications, error bars represent standard error.

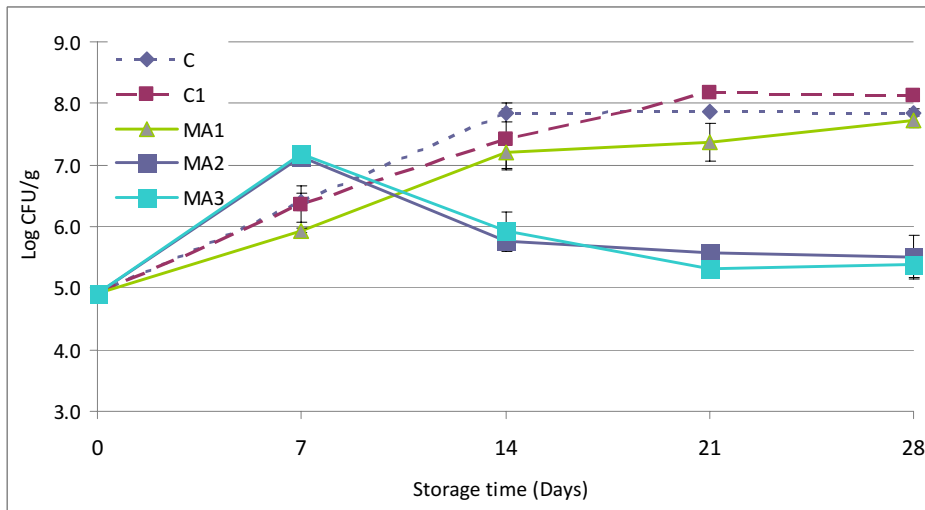


Fig. 2. Inhibitory activity of MA-incorporated whey protein coatings on turkey frankfurters, inoculated with *L. monocytogenes* stored at 4 °C for 28 d. C: Control without WPI films, C1: control with WPI film and without antimicrobials, MA: WPI film with malic acid at 1% = MA1, 2% = MA2, and 3% MA3. Values in figure are means of three different replications, error bars represent standard error.

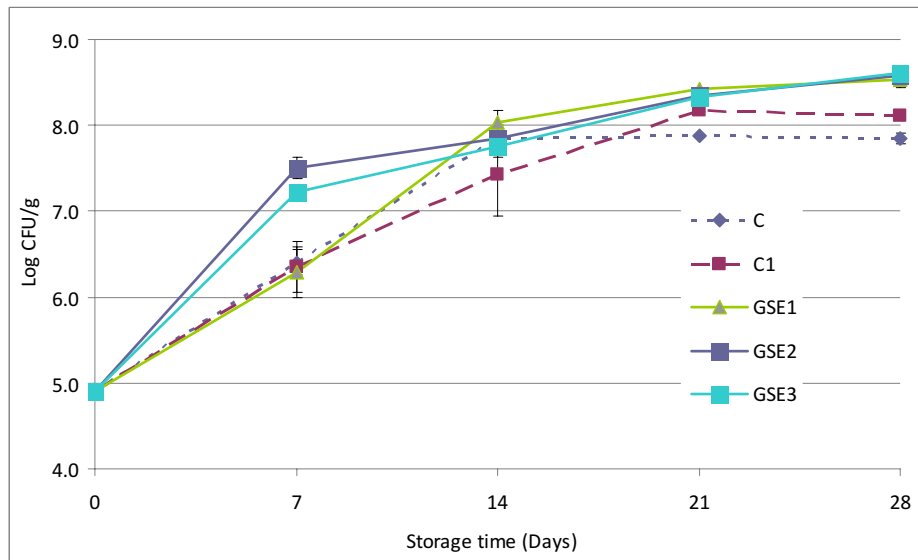


Fig. 3. Influence of GSE incorporated into whey protein coatings on turkey frankfurters, inoculated with *L. monocytogenes* stored at 4 °C for 28 days. C: Control without WPI films, C1: control with WPI film and with out antimicrobials, GSE: WPI film with grape seed extract at 1% = GSE1, 2% GSE2, and 3% GSE3. Values in figure are means of three different replications, error bars represent standard error

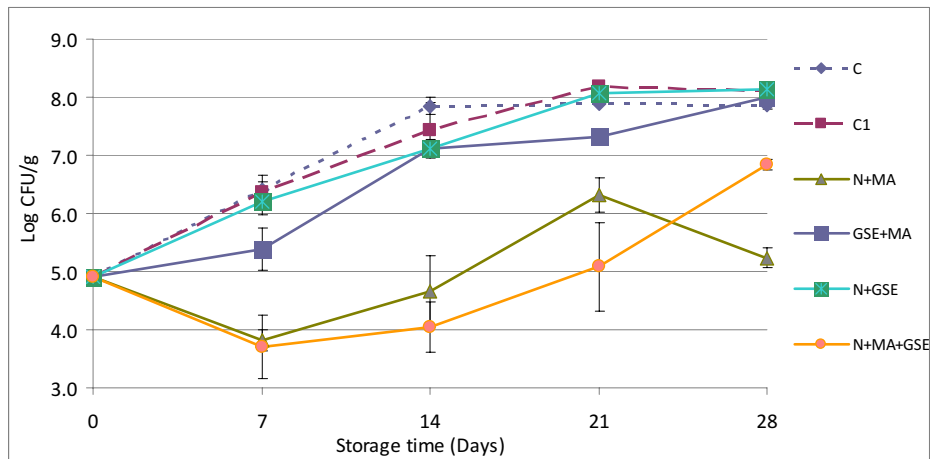


Fig. 4. Inhibitory activity of combinations of GSE, N, and MA into whey protein coatings on turkey frankfurters, inoculated with *L. monocytogenes* stored at 4 °C for 28 d. C: Control without WPI films, C1: control with WPI film and without antimicrobials, GSE: grape seed extract, MA: malic acid, N: nisin. Values in figure are means of three different replications, error bars represent standard error.

Psycho-social effects of a brain-training program among healthy older adults

Desma J. Hurley^{}, M. Jean Turner[†], and William C. Bailey[§]*

ABSTRACT

Grounded in cognitive neuroscience and social exchange theory, this research evaluated the relationship between changes in cognitive functioning and two psycho-social dimensions of life among healthy adults over the age of 70 (N=12). Specific psycho-social dimensions examined were social interaction and depression. Six females and six males participated in the study. All were white, college-educated individuals residing in a life-care residential retirement community. The participants used the Posit Science® Brain Fitness Program™, an auditory-based computer training program that improves memory and speed of processing, for forty hours over an eight-week period. Pre- and post-tests related to social interaction and depressive symptoms indicated that improvement in cognitive functioning was related to improvement in psychosocial dimensions in later life.

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MEET THE STUDENT-AUTHOR



Desma Hurley

After graduating from Flippin High School in Marion County, Ark., I enrolled at Arkansas State University of Mountain Home, Ark. From this institution, I earned an associate degree in business with an emphasis in computer applications. After graduating, I became Montessori-certified and a lead teacher at the Fayetteville Montessori School, supervising 18 two-year-olds and six teacher assistants. After working with children for several years, I made the decision to earn my bachelor's degree in Human Development, Family Sciences and Rural Sociology with a Lifespan / Family Sciences concentration. Late in my undergraduate work I became fascinated with research focused on improving the overall quality of life of older individuals. This interest afforded me the opportunity to study cognitive functioning as it correlates with psychosocial effects of mature adults. I am now a first-year master's student majoring in Human Development, Family Sciences, and Rural Sociology with an emphasis in Gerontology. I am currently a graduate research assistant working with M. Jean Turner, Ph.D. I would like to give a very special thank

you to my research mentor, Dr. Turner, for her support, motivation, and guidance. Her constant positive support has led me to continue my pursuit of academic achievement.

INTRODUCTION

This study examines how changes in age-related cognitive functioning associated with a brain training program affect depressive symptoms and social interaction among older adults. The purpose of the research is to assess the effects of a brain training program on improved psychosocial functioning of healthy aging adults. This study examines how healthy, mature adults' improvements in cognitive functioning, resulting from use of a computer program, relate to psycho-social dimensions of older adults' lives.

Aging adults often experience "age-related cognitive decline" (ARCD) (Park, O'Connell, and Thomson, 2003). According to researchers, an aging individual experiencing ARCD is also susceptible to decline in his or her psycho-social functioning (Biringer et al., 2005; Cumijs, Jonker, Beekman, and Deeg, 2001; Park et al., 2003). These declines can impact an older adult's level of depression, social interactions, and overall well-being. Research has also shown that ARCD decreases one's short-term memory skills, impacting mental and physi-

cal health (Park et al., 2003). ARCD can be a contributing factor to increased levels of depression leading to less social activity for older adults (Biringer et al., 2005; Cumijs et al., 2001).

A computer-based software program called the Brain Fitness Program™ (BFP) by Posit Science® Corporation (San Francisco, California) is designed to stop or even reverse ARCD. This program is a computer-based auditory training software program. The BFP was designed by leading scientists to provide the brain with six specific exercises to improve cognitive ability. The goal of the targeted brain exercises is to drive learning, focus on certain areas of ARCD, and stimulate analytical pathways for an overall increase in cognitive ability. Past research has focused only on cognitive gains related to the BFP's training designs and its core applications for older adults (Mahncke, et al., 2006). The current study explores implications of BFP on the number of depressive symptoms and social interaction.

Social exchange theory provides a possible explanation for the decline in social interaction and activity sometimes seen in elders in later life. This theory sug-

gests that decline of social interaction does not result from one's personal choice or social system needs, but rather from an unequal communication process between older adults and other members of society (Hooymann and Kiyak, 2008). The equal balance of social exchange experienced between an older adult and other individuals establishes the older adult's level of personal satisfaction. Because of the changes in social arrangements, roles, and skills that usually accompany aging, an older individual may have fewer commonalities with his or her social environment. This circumstance may lead to a decline in social interaction experiences. With fewer opportunities to exert power in social interactions, mature adults may remove themselves from interactions and thus be forced to accept a decline in their level of social interaction (Hooymann and Kiyak, 2008).

Older adults who feel a sense of declining cognitive functioning often become less confident during social situations (Plehn, Marcopulos, and McLain, 2003). Those who suffer from ARCD often experience less personal independence and a decline in overall quality of life (Plehn et al., 2003). The BFP used in this research may provide gains in cognitive functioning that lead to improvements in social interaction as well as decreases in the number of depressive symptoms participants experience.

Cognitive Functioning. ARCD is the normal progression of memory and cognitive decline among older adults, affecting more than 36% of adults 85 years of age and older (Black and Rush, 2002). The greatest amount of cognitive decline occurs among the oldest-old cohort, the fastest growing population in the United States (Park, et al., 2003). A study of 15,000 participants conducted by Cutler and Grams (1988) found that 40% of individuals over 55 years of age experienced a decline in memory skills.

An individual experiencing ARCD requires more time to learn information than his or her counterpart. While conversing, one may have difficulty conjugating words and may often repeat sentences because he or she can recall thinking a statement but not recall expressing it (Insel and Badger, 2002). Mature adults who suffer from ARCD often experience a loss of independence and a decrease in overall quality of life (Plehn, et al., 2003). Cognitive decline is a predictor of functional disability (Doge, Du, Sazton, and Ganguli, 2006). Also, those who suffer from ARCD are more likely to be institutionalized and require more medical services than other individuals (Black and Rush, 2002). Doge et al., (2006) expressed that cognitive decline is coupled with a decrease in instrumental activities of daily life (IADLs). IADLs include money management, cooking, laundry, and simple household cleaning (Plehn, et al., 2003).

Depression. Research suggests that ARCD leads to a decline in mental health and social interaction (Mahncke, et al., 2006). Depression and ARCD are directly correlated with one another. Hofman, et al. (2000) found an inverse association between levels of depression and cognitive functioning. Intervention programs that increase cognitive functioning may also prevent the development of mental illnesses like depression among older adults (Blazer, 2002).

Depressive symptoms include: feelings of sadness and loneliness, sleep disturbance, lack of interest, energy reduction, changes in appetite, and concentration difficulties (Blazer, 2002; Insel and Badger, 2002). Older adults with symptoms of depression often experience a drop in cognitive functioning, a decrease in information processing speed, and declines in memory, abstract reasoning, flexible thinking, and word creation (Biringer, et al., 2005; Blazer, 2002). Depression can be compounded with the onset of ARCD because of a decline in overall self-efficacy (Biringer, et al., 2005).

Social Interaction. ARCD has been reported to be negatively related to social interaction (Nezlek, Richardson, Green, and Schatten-Jones, 2002). A persistent and healthy social life is more beneficial to older adults than it is to any other age group (Caprara and Steca, 2005). It greatly increases the overall life satisfaction of elders (Caprara and Steca, 2005). Adults in late life who report a rewarding, active, high-quality social life also report greater psychological well-being than other individuals. In return, healthy psychological well-being is positively related to the quantity and quality of social interaction (Nezlek, et al., 2002). Engaging in social activity is likely related to better physical and mental health, and may also be a predictor of fewer disabilities and a decrease in overall ARCD (Doge et al., 2006).

A common denominator of social interaction is loneliness. Older adults spend more time alone than individuals of other age groups (Adams, Sanders, and Auth, 2004). Loneliness is defined as a reaction to a difference between desired and achieved social activity (Blazer, 2002). Some characteristics of loneliness include shyness, low self-esteem, self-depreciation, and poor social skills, some or all of which may stem from childhood (Blazer, 2002). A decline in social activity is associated with depression. Further, depressive symptoms may lead to lower levels of overall social activity. Loneliness is not a symptom of depression. However, it may contribute to depression (Adams et al., 2004). Mature adults can relieve or prevent loneliness by enhancing their cognitive functioning (Blazer, 2002).

Brain Fitness Program. The BFP was designed to strengthen brain health and quality of life for older individuals. As people improve their abilities to hear and

process language, they also improve their abilities to remember information and act on what they hear. The BFP guides users away from learned negative behaviors that diminish brain health into new behaviors that positively reinforce improved brain-functioning skills. Each BFP exercise targets specific aspects of cognitive decline, aiming to reduce or even reverse ARCD. Participants who have completed the BFP report improved communication skills, memory, self-confidence, attention, and optimism (Posit Science, 2006).

Components of the Brain Fitness Program. The BFP is composed of six basic exercises that build cognitively on each other. For example, the first exercise, High or Low, is a time-order judgment exercise. The goal of this exercise is to gradually improve one's ability to identify sweeps and bursts that are shorter and close together in time, training the brain to react faster and more accurately to sounds. The fourth exercise, Sound Replay, is a serial memory-span exercise. This exercise is designed to improve the brain's ability to differentiate sounds, store them, and recall increasingly longer series of sounds or syllables in their correct sequence (Posit Science, 2006).

The BFP has been shown to decrease and sometimes reverse the effects of ARCD. As stated previously, ARCD can negatively affect the overall quality of life and sense of well-being for older adults. Recovering from ARCD may lead to an increase in social interactions, mental health, and self-efficacy, and may reduce depressive symptoms. Mahnke, et al. (2006) found the BFP to be effective with adults over 60 years of age. Test results for those scoring below 85% on the initial neurological assessments indicated that the test group experienced increases in the areas measured, showing that the brain plasticity-based program improved cognitive functioning (Mahnke, et al., 2006).

MATERIALS AND METHODS

The objective of this research project was to determine psycho-social changes associated with the use of the BFP among healthy, community-dwelling, mature adults. The relationship between changes in cognitive functioning, depressive symptoms, and sociability is examined using pre- and post-test measures. The Repeatable Battery for the Assessment of Neuropsychological Status (RBANS; Randolph, 1998) was used for cognitive evaluation. Dr. Stephen Gemmell, a neuropsychologist, and Ms. Nakia Richter, a testing and measurement technician, conducted the pre- and post-test assessments using the RBANDS to assure consistency and accuracy in cognitive evaluations for the study. Social interaction and depressive symptoms were assessed using the Form 36 HARQoL (Brazier et al.,

1992). Participants were also asked about the frequency and extent to which health problems interfered with social interaction.

Older adults (N=12) living in a multi-level retirement community were recruited and trained on the BFP. All potential participants were determined to be free of diagnosable cognitive decline and depression. Participants were instructed to use the BFP once a day for one hour, five days a week, for eight weeks for a total of 40 hours. The student researcher loaded the program onto the study group's personal computers and demonstrated how to use the software. The researcher then remained in contact with the participants as frequently and in the manner each individual chose in order to resolve any problems with the BFP. Some participants requested regular weekly visits, others wanted phone calls on a regular basis, and still others requested e-mail contact as they needed it.

RESULTS AND DISCUSSION

A one-tailed t-test was used to assess positive change between time one and time two. Due to the small sample size and the fact that this project is exploratory research, the acceptable level of significance was set at $p < .10$. Although changes in the participants' levels of cognitive functioning were not statistically significant, the post-test results indicated improvement in several cognitive dimensions measured (see Table 1), as predicted by previous research (Mahnke, et al., 2006). Results also indicated a significant reduction in the participants' perceptions of the extent to which health problems interfered with social activities between time one and time two (see Table 2). However, no significant reduction in their perception of the frequency with which health problems interfered with social activities was found. Only one indicator of depressive symptoms approached significance. Respondents reported fewer instances of feeling down in the dumps following their experience with the BFP (see Table 3).

This study provides important insight into a previously unexplored area of research. However, it does have some limitations. The biggest limitation is the sample size. Because it serves as an exploratory study, the sample was limited to a manageable and conveniently available group. The sample was primarily obtained from a local multi-level living facility by asking for volunteers. The self-selection process combined with the high level of education and SES of the residents and numerous available activities provided by the center make it difficult to generalize the findings of this study to a broader population of older adults. To further explore the issues of the study, future research needs larger, more diverse

samples reflecting both community dwelling and residential elders.

The findings of this study provide a beginning for understanding the relationship between improving cognitive functioning and social interaction and the number of depressive symptoms experienced by older adults. Future research is required if we are to fully understand associations between improved brain fitness and overall well-being for aging individuals.

Individual reports from participants indicated that they perceived more of an increase in cognitive functioning and social interaction as well as a greater decrease in depressive symptoms than the statistical analysis indicated. Anecdotal comments of participants include "I do not have to write down telephone numbers from the phonebook anymore. I can remember the numbers as I walk from the phonebook to the telephone." "Installing the BFP onto my computer early this summer allowed me time to gain the needed confidence to participate in the play at the end of the summer. Both my wife and I are impressed that I remembered 40 lines." Participating in the BFP gave this 92 year-old individual the confidence to pursue being in a play, which he very much wanted to do. However, before participating in this study he had doubted his ability to memorize lines should he join the cast.

This project examines a modern-day application for enhancing older adults' cognitive abilities. The positive effects on cognitive functioning are well documented in previous research (Mahncke, et al., 2006). However, previously only anecdotal evidence supported the expectations of this study—that cognitive improvements would also improve various psycho-social dimensions. Increasing social interaction and reducing the number of depressive symptoms experienced combine for an overall effect of enhancing quality of life among older adults. Combining new technology with the potential to enrich overall well-being for the rapidly growing older adult population will create greater health and fitness opportunities for many future generations. Discovering methods to maintain cognitive ability leading to the reduction of depressive symptoms and loneliness while increasing social interactions and adaptability will improve quality of life for mature adults as well as for the loved ones who care for them.

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Table 1. Cognitive Functioning

| BFP Factors | Pre-test mean(SD) | Post-test mean(SD) | t | p-value |
|------------------|----------------------|-----------------------|--------|---------|
| List recall | 4.83(1.56) | 5.25(.329) | -0.959 | 0.179 |
| Delayed memory | 98.25(17.062) | 102.33(11.139) | -0.867 | 0.203 |
| Figure recall | 11.33(2.807) | 10.92(3.872) | 0.302 | 0.384 |
| Semantic fluency | 17.75(2.989) | 18.83(3.010) | -1.193 | 0.129 |

Table 2. Social Interaction

| Perceived Health Interference | Pre-test mean(SD) | Post-test mean(SD) | t | p-value |
|---|----------------------|-----------------------|--------|---------|
| Extent health problems interfered with social activities | 4.58(.669) | 4.00(1.044) | 2.028 | 0.034* |
| Frequency health problems interfered with social activities | 4.18(1.25) | 4.55(.688) | -0.938 | 0.186 |

*Significance level $p < .10$.

Table 3. Depression

| Depressive Symptoms | Pre-test mean(SD) | Post-test mean(SD) | t | p-value |
|---|----------------------|-----------------------|--------|---------|
| Been very nervous | 4.36(.674) | 4.27(.647) | 0.363 | 0.362 |
| Felt so down in the dumps that nothing could cheer you up | 4.64(.674) | 4.82(.182) | -1.491 | 0.084* |
| Felt calm and peaceful | 3.82(.982) | 3.73(1.009) | 0.209 | 0.420 |
| Felt downhearted and depressed | 4.45(.522) | 4.55(.522) | -0.559 | 0.294 |
| Been happy | 4.00(.447) | 3.91(1.044) | 0.219 | 0.416 |

*Significant level $p < .10$.

Using combined prediction models to quantify and visualize stormwater runoff in an urban watershed

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ABSTRACT

Stormwater runoff can transport nutrients, sediments, chemicals, and pathogens to surface waterbodies. Managing runoff is crucial to preserving water quality in rapidly developing urban watersheds like those in Northwest Arkansas. A watershed containing the majority of the University of Arkansas campus was designated as the study area because stormwater from it drains into the West Fork of the White River, designated as an impaired waterbody due to siltation. The project objective was to develop methodology to test existing stormwater drainage infrastructure, identify potential areas of improvement, and estimate potentially contaminated runoff by combining two widely used prediction models. The U.S. Department of Agriculture's Natural Resource Conservation Service's curve number (CN) method was used to estimate runoff depths and volumes, while a flow-direction model was created that integrated topography, land use, and stormwater drainage infrastructure in a geographic information system. This study combined the CN and flow-direction models in a single geodatabase to develop flow direction/quantity models. Models were developed for 5-, 10-, 25-, 50-, and 100-year floods and varied by the antecedent moisture content. These models predicted flow directions within existing drainage infrastructure and runoff volumes for each flood, and served as a hypothetical flood analysis model. Results showed that between 24,000 m³ (5-year flood) and 60,000 m³ (100-year flood) of runoff would be transported to the West Fork of the White River. The methodology developed and results generated will help stormwater planners visualize localized runoff, and potentially adapt existing drainage networks to accommodate runoff, prevent flooding and erosion, and improve the quality of runoff entering nearby surface waterbodies.

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