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Evaluation of the sustainability of hemp fiber reinforced wheat gluten plastics

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FOREWORD

Before coming to SLU, Alnarp, I completed 4 year bachelor's degree in agriculture in Pakistan. My previous education was based on knowledge which mostly emphasized a conventional system of agriculture. In 2009, I came to Sweden and started master's programme in agroecology in 2010. When I started the master's programme in agroecology, it had opened new areas for me to think about sustainability and how we should look at the system on global level. I didn't really think that the organic agriculture is practically possible but after this programme I definitely think that there are ways to deal with that. The whole programme was well designed and focused on different aspects of agriculture which gave me an insight to the production process, the big picture of the system, eco-friendly approaches farmer's perspective, sustainable food systems, socio-economic and environmental issues, and training to deal with problems. The course about thesis writing gave me an insight about the quantitative and qualitative learning processes which was very useful during thesis writing process. The project based training course was an opportunity to work with research groups in the university, which was a great learning experience as I have learned to independently work with problems, giving presentations, writing peer reviewed article and prepared a poster in an international conference. Thesis topic is a continuation of the whole learning process as it is about using plant resources for making plastics which are more sustainable than the petro-chemical based plastics. In a nutshell the whole programme was very useful for my career and it has opened new areas for me to think, learn and to perform practically.

Faraz Muneer

ABSTRACT

Bio-based plastics and composites are getting attention as an alternative to unsustainable petro-chemical based plastics. Hemp fiber reinforced wheat gluten (WG) composites can be an alternative to petro-chemical based plastics in many applications, because of their interesting tensile properties and environmental friendliness. However, the evaluation of sustainability is important before efforts can be made for their commercial production process. In this study three hemp farmers were interviewed for their opinion about hemp fiber reinforced WG composites and future cropping plans. Consumer analysis was done for people's willingness to choose and pay for hemp fiber reinforced WG composites (80 respondents). The produced composites were subjected to biodegradability test using the ASTM D5988-03 standard. Life cycle assessment analysis (LCA) was also conducted for hemp fiber reinforced WG composites. Farmers have shown a positive response to hemp fiber reinforced WG composites and showed willingness to increase the production of hemp. In consumer analysis 75.3% people said that they will choose hemp fiber reinforced WG plastics, whereas 4.9% said that they will choose synthetic plastics. Forty six percent said that they will pay 10% more whereas 30.6% people said that they will pay 20% more, and the percentage of people who can pay 30% more was 15.8%. Biodegradability analysis shows that the hemp fiber reinforced WG composites are biodegradable with 37% for WG, 29% for glutenin and 34% for gliadin based composites (conversion of carbon into CO_2 after 90 days period). Life cycle assessment analysis showed that the hemp fiber reinforced WG composites consume less energy and emit less greenhouse gases compared to synthetic plastics. Hemp fiber reinforced WG composites are sustainable compared to synthetic plastics and are of interest in the future.

1. INTRODUCTION

1.1 Plant based plastics

In recent years, there has been a shift to making environmentally friendly bio-plastics from plant resources for applications like packaging, automobile parts, agriculture, medicine and construction materials (Kolybaba et al., 2003). Biodegradable polymers which are based on feedstock sources from annually grown crops like wheat (wheat gluten), soy (soy proteins), corn and potatoes (starch), make the basis of a platform for sustainable and eco-efficient products which can compete with plastics and composites made solely from petroleum based feedstock (Mohanty et al., 2002). Natural fibers which are obtained from hemp, jute, flax, wheat straw etc. are an important source for reinforcing material for making composites, which are biodegradable and have market attraction (Taj et al., 2007). Hemp fibers are currently used for making composites together with synthetic polymers like polypropylene, epoxy resin and acrylonitrile-butadiene-styrene copolymer (ABS) for automobile applications (Schmidt and Beyer, 1998, Wötzel et al., 1999). However, combining plant based fibers with plant based polymers for making environmentally friendly and biodegradable bio-composites can improve sustainability.

1.2 Bio-plastics

Biopolymers are different from petro-chemical based polymers, as the monomers of a biopolymer are mainly derived from biological sources. Biopolymers are derived from plant resources and as well produced in organisms. An example of protein based commercial bio-plastic produced in microorganisms (bacteria) is poly-3-hydroxybutyrate (PHB) (Vink et al., 2003, US Congress, 1993).

Commercial bio-plastics derived from plant resources, e.g. starch based bio-plastics (which account for 80% of all bio-plastics produced today) are usually made from wheat, barley, corn

(Polylactic acid), rice, potatoes, or sorghum. The examples of protein based bioplastics are wheat gluten and soy protein derived from wheat grain and soy respectively. Cellulose-based bio-plastics are made from wood, and plant oil-based bio-plastics made from soy and palm (Momani, 2009).

Composites are materials that consist of a matrix mixed with a reinforcement material. The matrix is the part of the composite that bind the reinforcements so that a composite is formed. Natural or synthetic fibers or the particulates from plants or minerals can be used as materials for reinforcement and these reinforcements contribute with strength and rigidity to the structure of the composite. These composites may have some unique qualities which are different from those of their raw materials (Taj et al., 2007).

Efforts have been made to develop partially biodegradable composites where either the reinforcing fibers or the matrix are biodegradable and totally biodegradable composites where both reinforcing fibers and matrix are biodegradable (Reddy and Yang, 2011a-b , Wretfors et al., 2009, Kunanopparat et al., 2008). The purpose of using plant fibers in bio-composites is to increase the strength, elasticity, they are non-abrasive, light weight and biodegradable (Kohler and Wedler, 1994).

This study is based on hemp fiber reinforced wheat gluten (WG) composites, which are an example of fully plant based composites using less fossil resources than synthetic plastics, and are potentially biodegradable. The reason why bio-composites are receiving attention are problems with petro-chemical based plastics that are creating environmental and health concerns and, increased focus on sustainability.

1.3 Petro-chemical based plastics

Petro-chemical based plastic production is constantly increasing with the demand for packaging materials, automobile applications and construction materials (Winandy, 2007). Petro-chemical plastics have brought many benefits in applications such as, packaging, construction, automobile and medical applications (Thompson et al., 2009). Due to massive use of plastics in everyday life, their production has increased from 0.5 million tons in 1950 to 260 million tons in 2010. The turnover of the plastic industry in Europe is about 300 million € (Bioplastics, 2008).

Production of petro-chemical based plastics, e.g. polystyrene, polyethylene and polypropylene is consuming limited petroleum resources (Gervet, 2007). In 2009, the world's average use of petroleum resources was 98.3 million barrels per day (Momani, 2009). The use of petroleum resources for making plastics is about 4% of the total production (Hopewell et al., 2009). Prolific use of petroleum based energy resources can lead to expensive and less environmental friendly end products. Problems associated with the unsustainable source of materials and energy consumption during petro-chemical based plastics production can lead to the problems of greenhouse gas emissions and disposal.

1.4 Problems associated with petro-chemical based plastics

The biodegradability of most of the synthetic or petro-chemical based plastics are low, contributing to the major problem of these plastics at disposal, where they accumulate in large quantities in the landfills and in the environment (Thompson et al., 2009, Barnes et al., 2009, Domenek et al., 2004) . A large quantity of such waste also ends up in fresh water streams, lakes, rivers and oceans creating numerous environmental problems (Thompson et al., 2009). It has been reported that more than 260 species of mammals, birds, reptiles and insects have been affected either by toxicity of the plastics or they have been entwined by them (Gregory, 2009).

Countries such as China, Australia, USA (e.g. city of San Francisco), and European Union banned the use of plastic bags on local level (Mooney, 2009).

Health risks to humans and animals are one of the major issues regarding the use of plastics. The health risks associated to plastics are related to the monomers present in the structure polymers which can be released during their processing. One such example is polystyrene; from which styrene is a monomer which can be leaked from its polymeric structure during processing and can cause endocrine diseases and cancer (Momani, 2009). Another main problem comes not directly from the polymer but from plasticizers used for making petro-chemical based plastics. Di (2-ethylhexyl) phthalate (DEHP), a plasticizer used in PVC has been found to be carcinogenic and harmful to the reproductive system. DEHP is banned in Europe and it is also of concern because it is used in some medical equipment (European Commission, 2008).

The processing of plastics not only produces a lot of heat but a huge amount of carbon dioxide of fossil origin. Global CO_2 emissions due to petro-chemicals production have increased by 160%, from 1971 to 2004 resulting in a release of 1 Gt. CO_2 /year (Gielen et al., 2008).

1.5 Wheat gluten plastics

Wheat gluten (WG) plastics are an alternative to synthetic or petro-chemical based plastics because these plastics have interesting properties including film forming properties, good oxygen barrier, relatively high mechanical strength and they are also renewable (Olabarrieta et al., 2006). WG is a by-product of the bio-ethanol industry, with a rather low cost of approximately 1 US $/kg (Ye et al., 2006). Cornstover, cotton stalks and hemp fibers are examples of cellulose and lignin containing agricultural by-products which have been combined together with WG to form composites (Reddy and Yang, 2011a-b, Huda and Yang 2008). WG is itself a protein composite, containing numerous types of protein components with different molecular weights e.g. high molecular weight (HMW) polymeric glutenin, HMW oligomeric glutenin and monomeric gliadin (Wrigley et al., 1988). Cysteine is one of the important amino acids present in WG, responsible for formation of inter-protein disulphide linkages, these linkages play an important role in binding the proteins together (Morel et al., 2002). Cysteine also plays an important role in the functionality of the WG even though it is one of the minor amino acids (≈2%) (Diener and Siehler, 1999).

1.6 Natural Fibers

Natural fibers have very interesting properties e.g. they are environmental friendly, fully biodegradable, low cost and abundantly available (Taj et al., 2007). Examples of fibers for composites from plant sources include bamboo, cotton, flax, hemp, jute, kenaf, rice, reed, straw, and wood (Taj et al., 2007, Bismarck et al., 2002). Hemp fiber is a lignocellulosic fiber obtained from industrial hemp (*Cannabis sativa*) and has been used for reinforcing plastics materials (Mwaikambo and Ansell, 2003). When natural fiber are evaluated at the end of their life cycle they tend to have neutral CO_2 balance, i.e. they release as much CO_2 as they have taken up during growth (Wambua et al, 2003).

1.7 Hemp fiber reinforced wheat gluten plastics

Hemp fiber reinforced WG plastics can be produced through extrusion and compression molding. Different factors chosen for making the composite material, including pressure, temperature, pH, matrix and reinforcement material, can affect the polymerization behavior of the matrix (WG) during the compression molding process (Reddy and Yang, 2011a). Materials from WG reinforced with hemp, jute and bamboo fibers, have been developed and tested for their mechanical properties (Reddy and Yang, 2011a-b, Wretfors et al., 2009, Kunanopparat et al., 2008). Presence of hemp fiber in WG plastics gives better stiffness and makes the materials stronger as compared to materials without hemp fibers (Wretfors et al., 2009). Mechanical properties (stiffness, elasticity and tensile strength) of the composite depend not only on the presence of the fibers in the structure but also on aggregation and crosslinking of the protein during processing (Kunanopparat et al., 2008, Domenek et al., 2002). Other factors affecting the mechanical properties, i.e. compression molding temperature and pressure, are of utmost importance following the protein aggregation and quality of the fibers (Kunanopparat et al., 2008). Unfortunately there is no data available in literature for glutenin and gliadin based composites reinforced with natural fibers, however gliadin and glutenin have also been used for the processing of thermoplastic films without the use of natural fibers for studying their tensile properties. The results shows that glutenin has higher strength and modulus but lower elongation properties whereas gliadin showed lower strength and increased elongation properties (Chen et al., 2011).

1.8 Sustainability of bio-based plastics

Petro-chemical based plastics do not fulfill the definition of sustainability, as they pose social, economic and environmental problems, and more importantly their feedstock source is not sustainable (Poole et al., 2008). Alternatively, bio-based plastics are an interesting substitution for synthetic based plastics as they will reduce our dependency on fossil resources and as well reduce the amount of solid wastes (Álvarez-Chávez et al., 2012). Geiser stated that sustainable materials are those which reduce the impacts to occupational and human health as well as to the environment throughout their lifecycles (Geiser, 2001). To fulfill all the standards of sustainability, bio-plastics have to be sustainable in social, economic and environmental aspects.

Table 1. Three main pillars of the sustainability concept

Social aspects	Economic aspects	Environmental aspects
1. Public acceptance 2. Development of the industry	1. Cost effectiveness 2. Beneficial for farming community 3. Job opportunities	1. Low emissions 2. Biodegradability 3. Waste management

(Rasheed, 2011)

According to Mohanty et al., a bio-based product is derived from renewable resources and has characteristics of stability to complete its intended use phase and degrade at the end of its lifecycle (Mohanty et al., 2002). Alvarez-Chavez et al., have explained that the present bio-based plastics are not fully sustainable because raw materials for making bio-based plastics are obtained from crops which are grown in conventional system of agriculture e.g. using fossil resources such as diesel fuel and synthetic fertilizers (Álvarez-Chávez et al., 2012). But still the bio-based plastics are more biodegradable and more sustainable than their counterpart synthetic plastics.

The sustainability issues of bio-plastics are complex in a way that each bioplastic has specific properties and uses a specific production technology. For the evaluation of each type of bioplastic several parameters should be studied, e.g. their raw materials, production process, how much energy is consumed during their production and finally their disposal (Mohanty et al., 2002). The utilization of the raw materials from plants for making composites instead of synthetic plastics will not only help to make a more healthy environment but will also be beneficial for farmers, improving their economy (Reddy and Yang, 2011a).

1.9 Need for the project

Rising prices and the scarcity of petroleum resources as well as their problems of disposal are the driving forces for the search for materials which are more environmentally friendly and sustainable. Growing amounts of solid waste and accumulation of petroleum-based plastics in water bodies are two important issues related to their use. From an environmental point of view bio-plastics that are renewable, recyclable, have triggered biodegradability and are sustainable can make a difference for the future. Eco-friendly bio-plastics and bio-composites are novel materials for the twenty first century that can solve the problems of disposal but also serve as an option for the uncertain supplies of petroleum resources and their high prices.

1.10 Objectives

In this study I have evaluated different aspects of sustainability related to hemp fiber reinforced wheat gluten plastics. The main objectives of the study are:

1. Farmers willingness to grow hemp
2. Survey on consumer acceptance for these materials
3. Evaluation of the biodegradability of hemp reinforced wheat gluten plastics.
4. Literature review on lifecycle analysis and economic evaluation of the hemp fiber reinforced plastics

2. MATERIAL AND METHODS

2.1 Farmers Meetings

The contact information for five farmers growing hemp crop was obtained from our colleague Thomas Prade (Postdoc student at SLU, Alnarp). All five farmers were contacted and only three of them had time for an interview. The main reason for choosing these farmers for interviews is because of the contact information, willingness and availability of these farmers for the interviews. The interviews were conducted by one person (me) and data was recorded in the form of notes. The language used for the interviews was English and the time for the interviews was approximately 2 hours each.

The objective of the interview with hemp farmers was to get information about their farming practices, opinions, future plans, perception and preferred information about hemp fiber reinforced plastics. The interview was structured to find out some personal information; production process and expenditures; the farmer's perception about the hemp fiber reinforced WG plastics and willingness to increase the production of the hemp crop, and if there were good opportunities to sell the crop (Appendix A). The farmers were selected from southern Sweden and located in Tomelilla, Vollsjö, and Lund.

2.2 Consumer survey

The employees and students at the Swedish University of Agricultural Sciences were selected for the consumer's analysis. The reason for choosing this target group was the easy access to the entire participants through mailing list. The questionnaire was sent online once, via mailing list for employees and student at SLU, Alnarp and no reminder were sent later on. The data was collected through a website for surveys (www.surveymoneky.se) and results were obtained after the completion of the survey. The language used in the questionnaire was English.

The number of questions used in this survey was 10 and multiple choice answers were provided in each question to choose from. These questions include the age of the consumer, knowledge about the bio-plastics and their willingness to pay more for bio-based plastics. The survey was conducted with an online questionnaire to which 80 people responded. The survey form can be found in the appendix B.

2.3 Sample preparation

2.3.1 Materials

Wheat gluten in powder form was supplied by Reppe AB, Lidköping, Sweden and consisted of 84.4% wheat gluten proteins, 8.1% wheat starch, 5% water and 0.76% ash. Hemp fiber mats were commercially purchased and supplied by Hemcore, United Kingdom.

2.3.2 Extraction of wheat gluten proteins

Sixteen g of wheat gluten were dissolved in 200 ml of 70% ethanol. To avoid clump formation in the mixture, the WG powder was slowly poured into the ethanol, while stirred constantly. The solution was thereafter placed on a shaker, IKA-KS 500 (IKA, Germany) for 30 minutes and finally centrifuged for 10 minutes at 12000 rpm in a Sorvall RC 6+ centrifuge (Thermo Scientific, Japan). The supernatant containing the gliadins which are dissolved in ethanol was decanted into a separate flask. The solution of gliadins in 70% ethanol was distilled to remove the ethanol and get the pure fraction of gliadins precipitated in water using a rotary vacuum evaporator (Buchi, Switzerland) at a temperature of 65±5^{o}C.The remaining pellet contained the glutenins with some starch, fibers and residual gliadins. The pellet containing glutenins were washed with 5 ml of distilled water to clean the surface. Glutenin and gliadin fractions were freeze dried (Scanvac Coolsafe, Denmark) at a temperature of -80°C and vacuum pressure of $4*10^{-4}$ to remove any water content and then ground into powder by using laboratory mill (Yellow Line A10, IKA, Germany) at room temperature.

2.3.3 Sample preparation for compression molding

The hemp fiber in the form of randomly folded and pressed mats, were cut into pieces of 5×10 cm. Whole WG, glutenin enriched and gliadin enriched powders were separately poured on the surface of hemp fiber mats in a 5x10 cm tray and the hemp with the powder was shaken for 1 minute at 2000 rpm with a laboratory shaker, IKA-VIBRAX VXR (Germany), to move the powder into the empty spaces between the hemp mat fibers. The protein to hemp fiber weight ratio was approximately 50%.

2.3.4 Compression molding

Compression molding was carried out at three different temperatures, 110 °C, 120 °C and 130 °C. The pressing time and pressure was kept constant; 15 minutes and $4000N/cm^2$, for wheat gluten, glutenin and gliadin, respectively. The samples were placed between two PET sheets as a non-stick surface together with aluminum plates above and below the sample and placed in the pressing machine (Polystat 400s, Servitech, Germany). After pressing, the samples were removed from the hot aluminum plates and kept between two other aluminum plates to cool at room temperature.

2.4 Biodegradability Experiment

For evaluation of the biodegradability of the hemp fiber reinforced WG bio-composites, a procedure based on international standard ASTM D5988-03 (Determining aerobic biodegradation in soil of plastic materials or residual plastic materials after composting) was followed (Li et al., 2010, ASTM-D5988-03, 2003).

2.4.1 Soil preparation

The soil was obtained from a field of Swedish University of Agricultural Sciences, Alnarp, Sweden, which has been under organic production since 1996. All the stones and wood present in the soil was removed and sieved through a 2 mm sieve, and stored at 4°C for one week before the start of the experiment. The pH value of the soil was calculated by taking 2 g of soil dispersed in 10 ml of water and measured using a pH meter (Autocal PHM83, Denmark). The moisture content of the soil was determined by oven drying the soil at 105°C for 24 hours and calculated the weight loss for a subsample (Li et al., 2010, ASTM D5988-03, 2003).

2.4.2 Procedure

Evaluation of CO_2 released from the samples was used as a measure of their biodegradation according to ASTM D 5988-03. The experiment was carried out at room temperature (20 ±4°C) in darkness. The test was performed in airtight rectangular plastic containers with a 4 liter capacity. 200 g of soil was placed in 3x6 cm rectangular boxes with a measured amount of ammonium phosphate to make the C:N ratio 1:10 (ASTM D5988-03, 2003). C:N ratio was calculated with known amounts of C and N in the samples calculated with Carlo Erba Analyser. A 2 g sample of WG, gliadin and glutenin based hemp composite were cut into rectangular pieces with dimensions of 1x2 cm. Three replications of each sample, three technical controls, three soil controls and three positive controls were used. All the boxes contained 2 beakers, one with 50 ml water and other with 20 ml 0.5M KOH. In the technical controls the container contained only 50 ml water and 20 ml of KOH with no soil. The 50 ml beaker of water was placed in each container to keep the moisture of the soil according to its moisture holding capacity whereas 20 ml KOH was placed in the container so it can absorb the CO_2 produced in the box during the degradation process. Soil controls had no wheat protein-hemp composite samples in them, whereas positive controls contained 2 g of potato starch dispersed in the soil container. The hemp fiber reinforced WG, glutenin and gliadin plastic samples were each buried in the soil and CO_2 released was calculated after predetermined intervals by titrating against 0.25N HCL with a phenolphthalein indicator. During the measurement of the CO_2 the container lids were left open for 30 to 60 minutes so that the air in the container could be renewed. After measurement the KOH beakers were rinsed and filled with 20 ml fresh KOH at the start of each interval.

2.5 Life cycle assessment analysis

Commonly used life cycle assessment (LCA) includes analyzing the steps from the production of raw materials of a product through the formation of its final shape, its use and the end of life of the product, as well as an environment impact analysis of the product (Shen and Patel, 2008). Unfortunately there is not enough information in the literature about LCA of the final product from hemp fiber reinforced composites for a complete analysis. This study only includes a short literature review of the life cycle assessment of production and use of hemp fiber and WG for making composites.

3. RESULTS

3.1 Farmer interviews

Formal interviews with selected hemp farmers were carried out comprising specific questions about the production of hemp and hemp fiber and their perception about hemp fiber reinforced wheat gluten plastics. The selected hemp farmers have small scale production of hemp from 1 to 10 hectares, and this number varies with the demand of their potential buyers. The growing season for hemp starts in April and May, and ends in September the same year or March the following year in the case of winter harvested hemp. Varieties of seeds are imported from France; the most common is Futura 75 which costs from 16 to 18 SEK/kg. For growing one hectare, 20 to 25 kg of seed is required. According to the farmers, hemp doesn't need herbicides or pesticides, but they use 80 kg/ha urea for nutritional supply to the crop. The yield of the hemp lies between 9000 and 5000 kg/ha in terms of biomass, depending upon autumn or winter harvest respectively.

The farmers interviewed do not grow the hemp crop for the production of fiber; their main focus is to get the highest amount of above ground biomass for the production of briquettes for energy purposes, insulation materials and bedding for horses and cattle. The prices for the end products vary, briquettes cost from 5 to 10 SEK/kg, while insulation and bedding for the horses and cattle ranges between 5 to 12 SEK/kg depending on the season. The weather influences the prices as when the winter is longer and colder, farmers sell more briquettes compared to bedding and insulation.

Farmers showed a very positive response to the questions about the hemp fiber reinforced composites, as they were not familiar with use of hemp fiber for making reinforced plastics.

Farmers were very much interested in knowing more about the markets for the hemp crop, and they were willing to increase their production if the market demand existed for their products. When they were asked how much they want to get for the 1 kg of hemp fiber if they are provided with the access to the markets, they said that they are not sure about the current price. However, they will grow the crop if the market is available.

3.2 Consumer analysis

The questionnaire was sent to 650 people to whom 80 people responded resulting in response rate of only 12.3%. The consumer survey respondents covered a wide range of ages, 52.6% were over 36 years old, 29.5% between 26 and 30 years old, 11.5% were 31-35 years old and only 6.4% were between 15 to 25 years old. When asked how much they know about the bio-plastics, 68.8% people answered that they know very little about it, whereas only 20% people said that they know bio-plastics very well. 41.3% of people answered that they have used bio-plastics and 21.3% have said that they have not used bio-plastics, whereas 37.5% people said that they don't know if they have used bio-plastics or not. 67.1% people have said that they feel that bio-based plastics are better that synthetic plastics and only 2.5% people have answered negatively regarding bio-plastics (Figure 1).

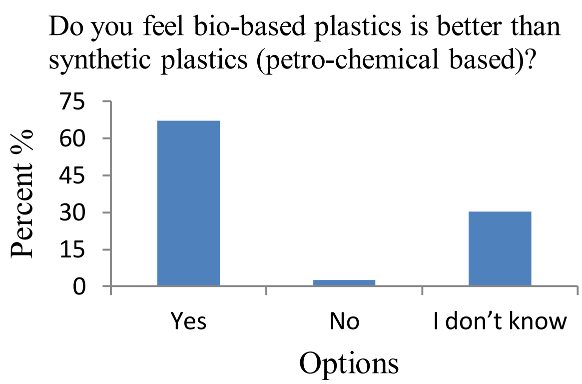

Figure 1: Perception of people regarding bio-plastics and petro-chemical based plastic (n=80).

In another question about the people's willingness to pay more for bio-based plastics, 46.1% said that they can pay 10% more for bio-based packaging and 30.3% said that they can pay 20% more for the bio-based packaging (Figure 2).

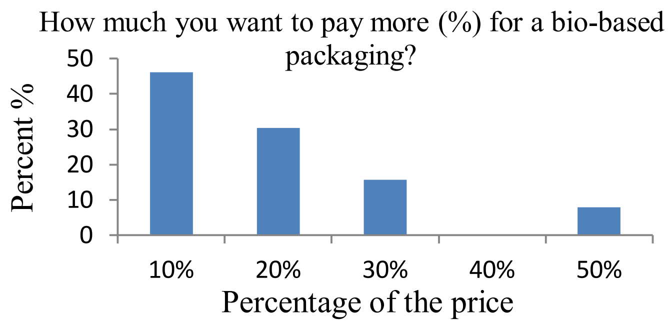

Figure 2: Percentage of the people who want to pay more for bio-based plastics related to the added value they perceive in the bio-plastics (n=80).

Another question about people's preference for hemp fiber reinforced plastics revealed that 75.3% of people will prefer hemp fiber reinforced WG plastics, 4.9% will prefer to buy synthetic plastics whereas 19.8% said that they don't know if they will choose either of bio-plastics or synthetic plastics (Figure 3).

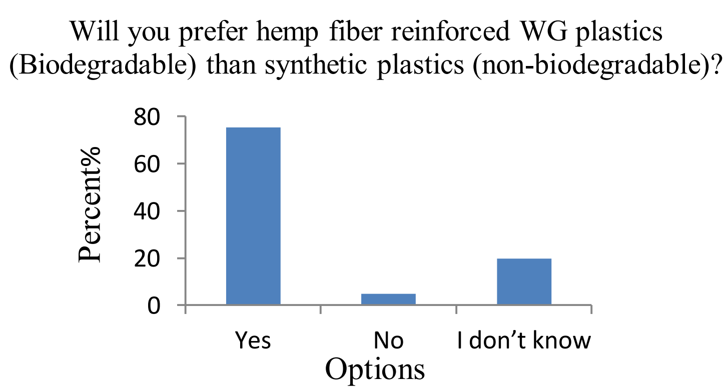

Figure 3: People's preferences about choosing the hemp fiber reinforced WG plastics or synthetic plastics (petrochemical based plastics) (n=80).

3.3 Biodegradability analysis

The hemp fiber reinforced WG, glutenin and gliadin composites were subjected to soil biodegradation and were found to be biodegradable. The results showed that, 37% of carbon was converted to CO_2 in case of WG, 29% for glutenin and 34% gliadin after 90 days. The conversion of carbon to CO_2 was a result of the activity of microorganisms. According to ASTM-D5988-03 standard, the materials should show about 70% of carbon conversion to CO_2 after 180 days or more, in this study the materials showed half of the required amount of CO_2 in 90 days. The composites showed a consistent amount of CO_2 produced by biodegradation during the 90 day time period.

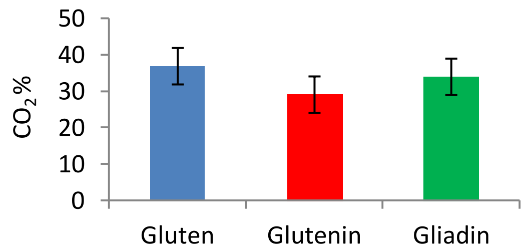

Figure 4: Percentage of CO_2 evolved during biodegradation of hemp fiber reinforced composites for 90 days at 20±4 °C.

Figure 5: Biodegradation of hemp fiber[1] reinforced composites in soil after 60 days at 20±4 °C.

[1] The samples were buried in the soil in the actual experiment.

4. Discussion

4.1 Farmer's willingness to grow

The selected farmers are not specifically hemp growers but they also grow other crops such as wheat, barley and oilseed rape. Farmers interviewed in this study are among few hemp growers in the southern part of Sweden, who have all the equipment for cultivation, harvesting and processing of hemp crop for energy purposes. These farmers mainly represent the signs of hemp crop cultivation in Skåne, which makes them representative in the region for hemp cultivation as compared to other farmers. The main reason for the farmers to grow the hemp crop is for energy purposes for the local market and for an extra income. The scale of production is small and limited. The production technology which famers are following is similar to data found in the literature (US Congress, 1993). As the farmers are willing to grow the hemp crop, I propose a plan for the production of hemp crops in the future which will provide the farmers access to the market but also make it easy to sell their crop.

The infrastructure for the processing of the hemp crop can be centralized for making value added products like fiber, briquettes, bedding and insulation material. This centralized system of processing hemp will not only increase the profit of farmers but also help them to get more value added products for selling e.g. hemp fiber (for automotive industry, paper and pulp industry) and hemp hurds for animal bedding, construction materials and energy purposes (Karus and Vogt, 2004). The plan can be devised for the hemp farmers who are located in southern Sweden (Skåne) in a way that they can have a single processing plant where they can bring their harvest for processing. In the central processing unit all the machines for processing can be installed with a share of money from the farmers and private industries together, as well as a transport system, which can bring the harvest to the plant. It will be much easier for the farmer to sell their products at one central point.

Strategies for the improved production and processing technology will be needed for obtaining high quality fibers. However, it is possible to increase the production of fiber and lessen the expenses for processing of fiber with close cooperation of the farmers, government and private industries. With this kind of cooperation farmers will get more profit by processing the fiber from their hemp crop, which is 35-38% of the total biomass (Svennerstedt and Svensson, 2006). There are 4 companies in the European Union (EU) which are working with cultivation and processing of hemp fiber, these are AGRO-Dienst (Denmark), Hemcore (United Kingdom), LCDA (France) and Hemp Flax (Netherland), these companies provide the basis for the market status of hemp fiber (Karus and Vogt, 2004)

The motivation and positive response of the farmers about hemp fiber reinforced WG composites is an encouraging sign for future development of this industry as the race for developing more sustainable plastics is on and we need to think of production methods which are sustainable in the long run.

4.2 Consumer’s acceptance for hemp fiber reinforced WG composites

Low response rate in this study could have affected the representativeness of the results. The percentage of response rate of 30% to 50% from a study is expected to be adequate over mailed questionnaires (Babbie, 1973, Black et al., 1976). However, data attained from the survey about bio-based plastics turned out to be very informative and surprising as a large number of people have shown a positive response towards the use of bio-based plastics. This survey showed that people generally perceive the petro-chemical based plastics in a negative way. There was some percentage of the people who have answered that they don't know if these kinds of plastics will be useful or not, it may be the case that they are not informed enough about the process for making bio-plastics or they are not sure if they will have the same performance. Providing more information about bio-based plastics can motivate people to choose products with a lower environmental impact. However, the target population was from an agriculture university's employees and students, being well educated and in the green sector. Furthermore, part of the respondents may also be aware of plant based products or they are working with them in one way or another. This biasness of the selected sample may have affected the results and given positive response to the bio-based plastics.

There is a great consumer demand with the introduction of products named under the "eco-friendly" label or as sustainable in the food and clothing market (Poole et al., 2008). The results of this survey are a reflection of the above statement. In this survey the respondents didn't actually see the final product, Thiry (2007) stated that, there is a demand and attraction for eco-friendly products in the market; it is likely that consumers will not compromise on the quality of the products.

4.3 Biodegradability results

Results of this study have shown that the biodegradation rate of all the samples was very close to each other during the three month period of biodegradability test (Figure 4). Wheat gluten showed the highest percentage of biodegradation as compared to glutenin and gliadin samples at 90 days. After the 90 day period the materials were observed visually and it was found that all the WG, glutenin and gliadin materials were degraded and only hemp fiber was visible in the soil. Domenek et al. found that WG-glycerol based plastics subjected to farmland soil were fully degraded after 50 days (Domenek et al., 2004). It has been found that soy protein-wheat gluten films which were subjected to farmland soil were degraded to about 50% of the original weight after 10 days and 95% after 30 days (Park et al., 2000). As the ratio of hemp to WG, gliadin and glutenin was almost 50%, the WG, glutenin and gliadin present in the composites was easy to degrade by the microorganisms. Hemp fibers are a lignocellulosic material and cellulose/hemicellulose is difficult to access for the microorganisms as it is partly protected by the lignin, which slows microbial degradation processes. Comparing these results with natural fiber reinforced polypropylene composites showed that they take much longer time to degrade as compared to wheat gluten based composites (Chattopadhyay et al., 2011). Industrial use of hemp fiber reinforced wheat gluten plastics in this state can be a problem because of their susceptibility to moisture, which can lead to decreased strength, deformation and fungal growth. However the material after shear stress and high temperature remain biodegradable and can be used in application where short packaging period is required or material can be modified for longer useable period.

4.4 Life cycle assessment of hemp fiber reinforced WG plastics

Life cycle assessment (LCA) is a technique for assessing the processing, use and disposal of a product, where its impacts on the environment, economics and energy use are studied. Such an assessment includes a study of inputs and outputs, their impacts and compiling the results of the outcomes (Joshi et al., 2004). Environmental aspects and potential impacts are often considered for the product's raw materials, use and end of lifecycle (ISO, 1997), i.e. from cradle to grave.

Unfortunately an LCA study for hemp fiber reinforced WG composites has not been carried out before and was not found in the literature. Instead, examples were taken from previous LCA studies of hemp fiber in making different composites. In economic terms WG is an inexpensive by-product from bio-ethanol industry which costs about 1 US$/kg (Ye et al., 2006) as compared to Polylactic acid (PLA) which is a biopolymer synthesized by fermenting the starch from crops like corn and potatoes which costs between 2.2 to 3 US$/kg (Vink et al., 2003). Both WG and PLA are biodegradable, but the advantage for using WG in plastics can be its price which is almost 1.2 US$/kg less than PLA and elimination of the steps like fermentation and polymerization and their associated life cycle impacts.

Figure 6 shows a simplified flow diagram of the production steps of hemp fiber reinforced WG composites from the production of inputs to the production of composites and to landfill or biodegradation process. In order to produce 1 kg of hemp fiber, 6.8 MJ energy input were required compared to fiber glass production which needs 54.7 MJ/kg (Table 2). Furthermore, for producing 1 kg of WG it needs only 25.4 MJ (WG taken to be equivalent to thermoplastic starch), energy as compared to PP which needs 78.25 MJ of energy to produce 1 kg. Production of 1 kg of WG leads to the emission of 1.40 kg of CO_2 as compared to PP which results in emission of almost 1.85 kg of CO_2 per kg PP produced (Table 3). The lower level of CO_2 emissions from the production of hemp fiber reinforced WG composites indicates a better sustainability in terms of global warming potential than the production of glass fiber-PP composites (Tables 2,3). However, there are other factors which affect the sustainability of a product i.e. its potential for acidification, eutrophication and nutrient leaching which are not accounted for.

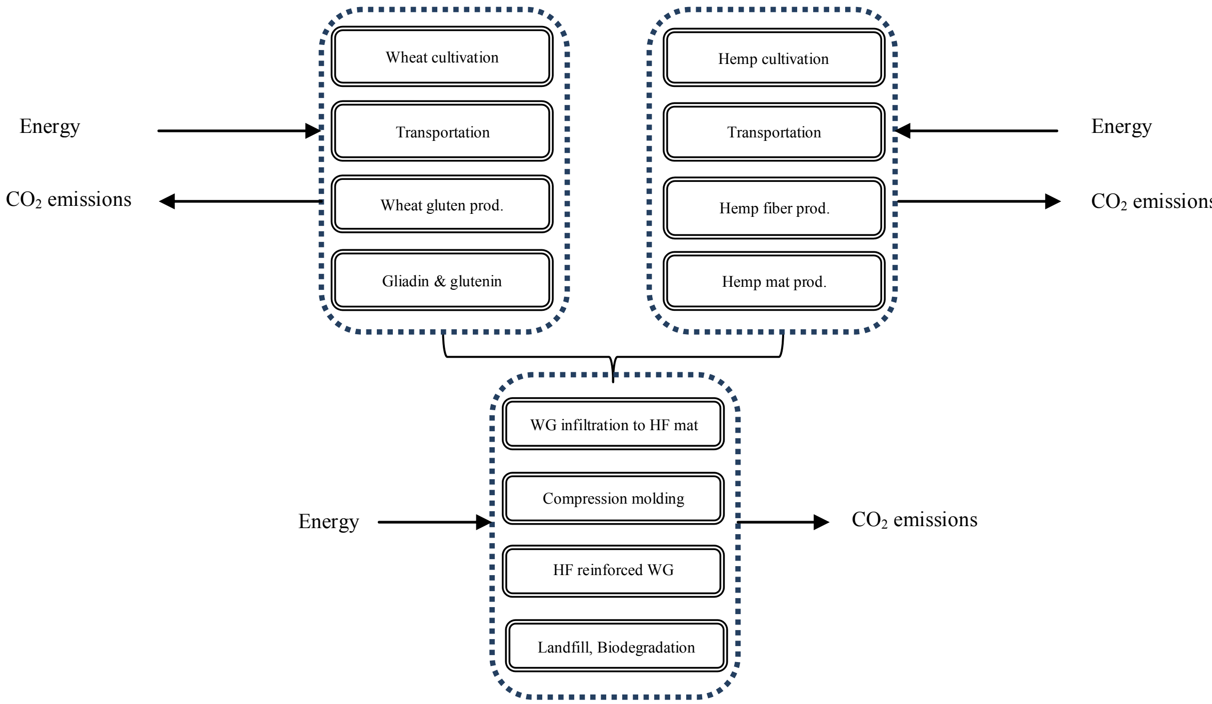

Figure 6: Life cycle assessment analysis for hemp fiber reinforced WG composite

Table 2. Non-renewable energy consumption for the production of hemp and glass fiber

Hemp fiber production [a]	**Energy used/kg**	**Glass fiber** [b]	**Energy used/kg**
Hemp cultivation	1.8 MJ	Production	2.7 MJ
Transport	0.2 MJ	Transport	1.6 MJ
Fiber production	1.8 MJ	Melting and spinning	27.4MJ
Mat production	2.9 MJ	Mat production [c]	23.0MJ
CO_2 emissions	N/A	CO_2 emissions (prod.)	2.04 kg
Total energy	**6.7 MJ**	Total energy	**54.7MJ**

[a] (Diener and Siehler, 1999)

[b] Wötzel et al, 1999

[a] and [b] as referenced in Shen and Patel (2008)

Table 3. Non-renewable energy consumption for the production of WG and PP

Wheat production [d]	**Energy used/kg**	**PP production** [e]	**Energy used/kg**
Wheat cultivation	2.2 MJ	Production	77.19 MJ/kg
Transport	N/A	Transport	1.6 MJ
Wheat gluten production [f]	23.4[2]		
Separation of glutenin and gliadin	N/A		
CO_2 emissions [f]	1.40kg	CO_2 emissions	1.85 kg

[d] (Meisterling et al., 2009)

[e] (Boustead, 2002) reproduced in Joshi et al., 2004

[f] reproduced from Shen and Patel (2008)

Life cycle assessment of hemp fiber production has been studied for automotive applications because of its lower weight, better elongation and impact properties than the glass fibers (Wötzel et al., 1999, Schmidt and Beyer, 1998). Wötzel et al., (1999) have studied LCA of hemp fiber (66% volume) together with epoxy resin and acrylonitrile-butadiene-styrene copolymer (ABS) and compared them for making the internal body panel of a car door. The results have shown that hemp fiber together with epoxy resin consumes 45% less energy (73 MJ) as compared to ABS copolymer (132 MJ) per functional unit[3]. More interestingly, the hemp fiber which was 66% in the composite used only 5.3% of the cumulative energy demand. The same was the case with CO_2 values, which were less than the ABS copolymer based panel.

[2] Data corresponds to thermoplastic starch production, the process for making WG is very similar

[3] One functional unit is an internal door panel of a car in the mentioned study

Based on results of above mentioned studies, it has been found that the door panel made from hemp epoxy resin weighs 27% less than an ABS copolymer based panel and an insulation panel made from hemp fiber-PP composite weighs 26% less than PP-glass fiber. One kilogram in the weight reduction of a vehicle results in a fuel savings per automobile of 6.0 to 8.4 L for gasoline and 5.1 to 5.8 for diesel, during its lifecycle of 175000 km (Joshi, 1999). That means the reduction of CO_2 from 8 to 12 kg for petrol cars and 8 to 10 kg diesel during their lifetime.

Pervaiz and Sain (2003) compared hemp fiber-PP composites with glass fiber-PP for their carbon storage potentials and energy benefits. Results showed that almost 50 GJ (about 3 tons of CO_2 emission) per ton of thermoplastic can be saved by replacing 30% of glass fiber with 65% hemp fiber. In the same study it has been estimated that about 3.07 million tons of CO_2 and 1.19 million m^3 crude oil can be saved by replacing 50% of the glass fiber with natural fibers only in USA (Pervaiz and Sain, 2003).

5. Conclusion

Environmental aspects of making bio-composites from WG and hemp are superior to petro-chemical based composites. Hemp fiber reinforced WG composites are biodegradable because of their plant based feedstock source. Hemp is easy to produce; requires few inputs like tillage, pesticides, herbicides and nutrients which consume less fossil resources when compared to glass fiber which requires more energy for its production. Production of hemp fiber and WG results in lower environmental problems of disposal, because of their rapid biodegradability and reduced CO_2 emissions when compared to synthetic polymers and glass fibers.

Hemp fiber reinforced WG composites are biodegradable and more environmental friendly in the way that they require fewer inputs and energy resources, are plasticizer and solvent free. Wheat gluten has a lower selling price as compared to other biodegradable polymers such as PLA; the same is the case with hemp fiber, which has a lower selling price compared to glass fibers.

Even though hemp is not produced in large quantities in Sweden, farmers are willing to increase the production with demand of the product. Survey show that consumers are aware of environmental problems and they are willing to pay more for plastics which are more environmentally friendly compared to petroleum based plastics. However, there is need for the development of commercial production methods for making hemp fiber reinforced WG composites.

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Appendix A

1) Total land owned by the farmer.

2) Total yield per hectare obtained by the farmer.

3) What kind and how much of inputs needed for hemp cultivation?

4) What kind of values added products produced after harvest from hemp crop?

5) What are the target markets for selling these products?

6) How much they earn from 1 hectare of hemp?

7) Farmer's interest for hemp fiber reinforced WG composites.

8) Farmer's willingness to grow hemp crop.

9) What they think about the hemp fiber reinforced WG composites?

10) If the farmers are interested in grow more hemp crops?

11) If farmers are interested to produce hemp fiber?

Appendix B

1) What is your age?

a) 15-25years b) 26-30years c) 31-35years d) 36 years or more

2) How much do you care about the environment in everyday life (Household)?

Never……………………Always

1 2 3 4 5

3) How much do you know about bio-based plastics (Plant resource based)?

a) Don't know b) know very little c) know very well

4) Have you ever used bio-based plastics, e.g. Bio-based packaging?

a) Yes b) No c) I don't know

5) Do you feel bio-based plastics is better than synthetic plastics (petro-chemical based)?

a) Yes b) No c) I don't know

6) If a package of beans is packed in a bio-based plastic costs 22 SEK versus a same packet of beans packed in synthetic plastics costs 20 SEK, which one you will choose?

a) Yes b) No c) I don't know

7) How much you want to pay more (%) for a bio-based packaging?

a) 10% b) 20% c) 30% d) 40% e) 50%

8) Do you know that we can use wheat gluten and hemp fibers for making plastics?

a) Yes b) No c) I don't know

9) Will you prefer hemp fiber reinforced wheat gluten plastics (Biodegradable) than synthetic plastics (non-biodegradable), if they are available in the market?

a) Yes b) No c) I don't know

10) Do you think agricultural land should be used for food crops and industrial crops together?

a) Yes b) No c) I don't know

Sustainability of hemp fiber reinforced plastics

Hemp fiber reinforced wheat gluten plastics are based on renewable resources which are inexpensive and easily produced. Wheat gluten is an inexpensive by-product from the bio-ethanol industry and abundantly available. Hemp fibers are obtained from industrial hemp crops which are inexpensive to grow and have by-products with several applications e.g. energy purposes, insulation materials, animal bedding, and fibers used for the reinforcement of plastic and mulching. Eco-friendly bio-plastics have interesting mechanical properties which can be further developed with research and development and can be used in many applications as an alternative to petro-chemical based plastics. Sustainability issues are still a concern for these eco-friendly bio-based plastics which should be studied before their commercial production can be started. This study was aimed at evaluating the sustainability of hemp fiber reinforced plastics with focus on people's willingness and perception about buying and paying more for the WG-hemp plastics, farmer's willingness to grow the hemp crop, product biodegradability and life cycle assessment. The survey has shown a positive perception regarding hemp fiber reinforced wheat gluten plastic compared to petro-chemical based plastics. The biodegradability analysis has shown a rapid biodegradability of the materials in soil. Interviews with the farmers revealed their interest for growing the hemp crop for fiber production. It has also been reported that the hemp crop has influence on the growth of weeds because of its high shading capacity, which can benefit the next crop. Life cycle assessment analysis has shown that the hemp fiber reinforced WG plastics use less energy and emit less CO_2 compared to petro-chemical based plastics. The growth and development of bio-based plastic will not only lead to a sustainable future for plastics with low environmental impacts and biodegradability but also help the farmers' community on the global level.

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