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Scientific Research and Essays

Full Length Research Paper

Regional sustainability assessment and its sensitivity analysis based on ecological footprint model: A case study of Xingguo County in China

Hualin Xie[1]*, Qu Liu[1], Peng Wang[1] and Zhifei Liu[1,2]

[1]Institute of Poyang Lake Eco-economics, Jiangxi University of Finance and Economics, Nanchang 330013, China.
[2]School of Economics and Management, Jiangxi Agriculture University, Nanchang 330045, China.

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Based on the Ecological Footprint Model, a Sustainability Index is put forward to measure the degree of regional sustainable development. Using correlation and sensitivity analysis, this study explored the level of sustainable development in the Xingguo County of China from 1996 to 2005, and revealed the driving factors of human activities on sustainable development. The results indicate that the consumption footprint of biological resources in the study area shows a slow, fluctuating upward trend. The increasing ratio of ecological carrying capacity is greater than that of per capita ecological carrying capacity. The values of the sustainable index range from 0.5 to 0.6 (which means unsafe), and it shows a slowly increasing trend. This indicates that the rate of population growth is faster than that of ecological recovery and improvement, which is beyond the bearing capacity of the ecological environment. The Sustainability Index in the study area has a significantly positive correlation with Gross Domestic Product (GDP) urbanization level and this has a significantly negative correlation with the proportion of primary industry. The Sustainability Index in the study area is more sensitive to population growth, followed by a decrease in primary industries.

Key words: Sustainability Index, ecological footprint, sensitivity analysis, regional sustainable development

INTRODUCTION

Since the concept of sustainable development which has been put forward by the World Commission on Environment and Development (WCED) in 1987, there have been a lot of practical applications, and it has become a fundamental thing and a common governmental target for all national and governmental policies to be made (Bleys et al., 2011; Gabrielson, 2013; Choi and Yu, 2014). It is a difficult problem worldwide to measure the degree of regional sustainable development. The quantitative evaluation and monitoring of regional sustainable development is an important topic in the field of research (Burke, 2011). There have been some valuable evaluation methods and models, such as the Pressure State Response (PSR) framework model proposed by the Organization for Economic Co-operation and Development (OECD) and the United Nations Environment Program (UNEP) (Yang et al., 2011; Babcicky, 2013), and the Index of Sustainable Economic

*Corresponding author. Email: xiehl_2000@163.com. Tel: +86-791-8381-0957. Fax: +86-791-8381-0892.
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Welfare (Gil and Sleszynski, 2003; Lawn, 2003; Clarke et al., 2005; Pulselli et al., 2006; Bleys, 2008, 2013). The "Index of Sustainable Economic Welfare" is applied to Poland, Belgium, Thailand, Italy and other countries (Gil and Sleszynski, 2003; Clarke et al., 2005; Pulselli et al., 2006; Bleys, 2013). Regional sustainable development must depend on sustainable development of ecological environment. On one hand, the ecological environment is the spatial carrier of regional social and economic activities (Duro and Teixido-Figueras, 2013; Stokols et al., 2013). On the other hand, it provides natural resources and assimilates all the wastes for regional development (Jin et al., 2009; Menconi et al., 2013). In the Ecological Footprint Model, the carrying capacity of an ecosystem under the influence of human activities was measured by the ecologically productivity area (Jin et al., 2009; Li et al., 2010; Kissinger et al., 2013; Menconi et al., 2013). This study aims to deal with the relationship between human activities and natural systems from the perspective of biological parameters, a quantitative measure of resource consumption and sustainable development. Ecological footprint analysis is one of the widely used methods for assessing the sustainable development (Ture, 2013). This can quantitatively characterize the state of regional sustainable development through measuring and comparing the profit and loss situation between the material needs of human society development and the natural ecological system of ecological carrying (Ewing et al., 2012; Kissinger, 2013). This helps to monitor the process and to implement the management of sustainable development. The positive features of ecological footprint is that, it clearly shows results and is simpler to calculate. The complicated relationship between human social and economic activities and nature can be simplified in a quantitative way (Wackernagel et al., 1999). Therefore, the ecological footprint method has been recognized by relevant international agencies, government departments and research institutes. It has been a popular method which is important in measuring regional sustainable development in recent years.

China is not only at an important stage of rapid economic development and urbanization, but also is at a turning point for sustainable development (Liu et al., 2014). How to achieve the harmonious development of socio-economic and natural eco systems in China is significant (Dai et al., 2010; Bao et al., 2011; Galli et al., 2012; Liu et al., 2014). Therefore, this study takes a typical region—Xingguo County as a case study and put forward a Sustainability Index based on the ecological footprint to measure the degree of regional sustainable development. Based on a background of small towns' construction in China, we calculated and analyzed the ecological footprint in Xingguo County from 1996 to 2005. The total population, GDP urbanization level and the proportion of primary industry, four social and economic indicators can be measured against the Sustainability Index. The correlation and sensitivity analysis reveals the driving factors of human activities on Sustainability Index. Some targeted suggestions are provided for the planning of regional sustainable development.

METHODS

Study area

The study area (115°01′∼115°51′E, 26°03′∼26°41′N) (Figure 1) is Xingguo County in Jiangxi province of China, which is located in the mid-southern areas and lies to the North of Ganzhou City, at the headwaters of Pinggu River. It is surrounded by mountains in the east, north and west. There is a valley basin centered in the County in the south-central, mostly low mountains and hills. In 2005, the GDP of Xingguo totaled 3.32 billion Yuan. The proportion of three industrial structures is 39.3:31.3: 29.4, and the rural per capita net income is 2,376 Yuan in 2005. The study area covers an area of 15.5 km^2, and the resident population was 121,000. The County belongs to the subtropical South East monsoon climate, with an annual average temperature of 18.9°C, an extreme maximum temperature of 39.9℃, and an extreme minimum temperature of under 6.3°C.The annual average frost-free period amounts to 248 days. The average annual rainfall is 1516 mm, which is concentrated in April and June, with rainfall from April to June, this accounts for 48.5% of annual precipitation.

Data

The data of land were collected from the current land use database of Xingguo County during 1996 to 2005. And the social and economic data mainly came from the statistical year book of Xingguo County from 1996 to 2005.

Ecological footprint model

The ecological footprint was first put forward by the Canadian ecological economist William Rees in 1992. Thereafter, it was improved and developed into the ecological footprint model by his student, Mathis Wackernagel in 1999, who was studying for his Doctorate degree. The ecological footprint model is a method which is used to measure the degree of sustainable development and a set of quantitative indicators based on land area. It consists of three parts: first is the ecological footprint, second is the ecological carrying capacity or biocapacity and third is ecological deficit or ecological surplus. The ecological footprint of an entity is defined as the sustainably biologically productive land and water area, required to provide resources consumed and assimilate waste produced (Wackernagel et al., 1999). Its computation formula is as follows:

$$EF = N \times (ef) = N\sum_{i=1}^{n}(r_i C_i / P_i) \quad (1)$$

where i is the type of consumer goods and investment, EF is the total ecological footprint, N is the population, ef is the per capita ecological footprint, r_i is the type i's equivalence factor, C_i is the consumption per head of type i's goods, P_i is the world's average productive capacity of type i's consumer goods. The calculation of ecological footprint can be divided into two parts: biological resource consumption and energy consumption. Because the data

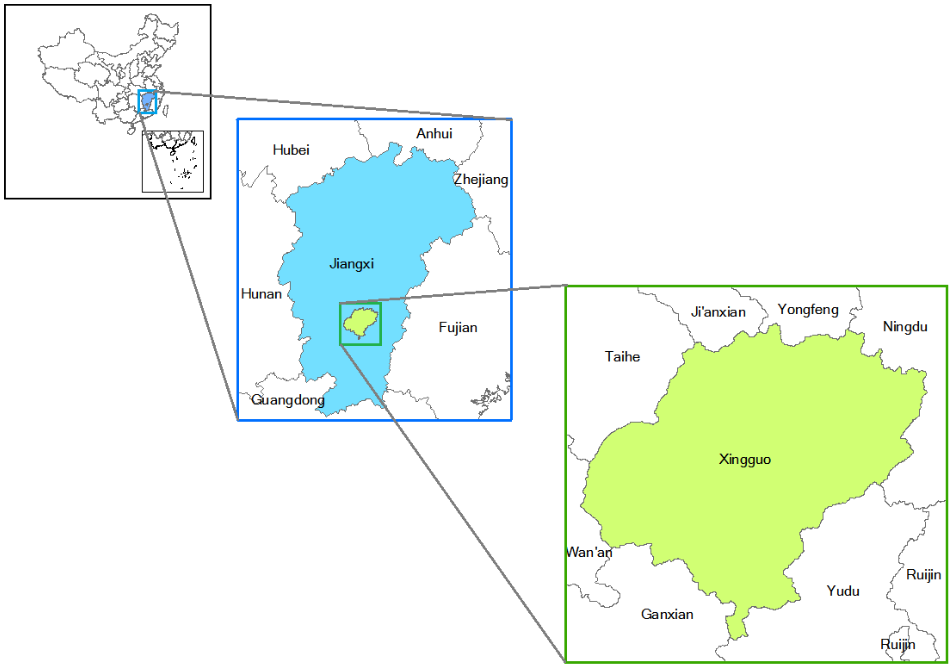

Figure 1. Study area.

needed for calculating the ecological footprint model in Xingguo County is not comprehensive, and it is on the basis of the actual local situation, this study should first state the following instructions:

1) The trade adjustment estimation was not formed due to lack of detailed information on import-export and the domestic and foreign trade. The quantity of energy trade was not taken into account when calculating the quantity of the energy consumed.
2) Replace production with total consumption because the data of consumption per head or total consumption for the past years have not been collected.
3) The type of garden plot was introduced through six types of biological productive land (fossil energy land, arable land, forest land, grassland, construction land and waters). Despite some researchers pointing out in their studies (Wackernagel et al., 1999)that, the soil quality of a garden plot is closer to arable land than forest land and that it belongs to the arable land, the garden plot was separated from the arable land in Xingguo County. In view of this paper we regard the balanced factor and production factor of the garden plot as the average value of the cultivated land and forest land, which is 1.98 and 1.285 respectively.
4) So the ecological footprint calculation formula after adjustment takes this form:

$$EF = \sum C^*_i \, r_i / P_i \tag{2}$$

where C^*_i is the output of type *i*, other parameters are same as the formula (1).

The consumption of biological resources is mainly divided into four categories: agricultural products, animal products, aquatic products and forest products. Each of this categories has the following detailed classification, this study adopts the world's average output data about biological resources which was calculated in 1993 by the United Nations Food and Agriculture Organization (Wackernagel et al., 1999), converts the biological resources consumption to biological production area, providing the consumption needs and energy consumption part which considers several kinds of energy: raw coal, gasoline, kerosene, diesel oil, electric power, liquefied petroleum gas and other fuels. Using the average calorific per unit of fossil fuel in the production of land area in the world value as standard (Wackernagel et al., 1999), this translates the Xingguo County's calories of consumed energy in 2005 into a certain amount of fossil fuel land area. The ecological carrying capacity or biocapacity means the amount of biological productive land in the inner region, the computation formula is as follows:

$$EC = N \times (ec) = N \sum_{j=1}^{6} \left(r_j \times a_j \times y_j \right) \tag{3}$$

where: *j* is the type of biological productive land (fossil energy land, arable land, forest land, grassland, construction land and water), *EC* is the total ecological carrying capacity, *N* is the population; *ec* is the ecological capacity of per capita; a_j for biological production area per capita, r_j is proportional factor; y_j is the yield factor. In this study, the proportional factors and yield factors which are used to calculate the ecological footprint and ecological carrying capacity or biocapacity are shown in Table 1. Ecological deficit (ED) or ecological surplus (ER) refers to the difference between the ecological carrying capacity or biocapacity and the ecological footprint. The computation formula is as follows:

$$EP = EC - EF \tag{4}$$

where the *EP* represents the ecological deficit or surplus. If the *EP* is negative, *EF>EC*, then an ecological deficit is formed, which works against the regional sustainable development; if the *EP* is positive, *EF* < *EC*, then an ecological surplus is formed, which is conducive to the regional sustainable development. For a study object, the observation gap between the ecological footprint and

Table 1. Proportional factors and yield factors.

Land type	Proportional factor (Wackernagel et al., 1999)	Yield factor (Wackernagel et al., 1999)
Arable land	2.82	1.66
Forest land	1.14	0.91
Grassland	0.54	0.19
Water	0.22	1
Construction land	2.82	1.66
Fossil fuel land	1.14	0

ecological carrying capacity or biocapacity, to reflect the state of sustainable development, is the most direct application of the ecological footprint model.

Sustainability index (SI)

In the traditional models of ecological footprint, the ecological surplus or deficit indexes can reflect how regional development depends on the ecological environment, but to what degree is the environmental resources are utilized cannot be well shown. Ecological footprint evaluates the impact of human activities on the regional ecological environment from the perspective of specific biological parameters. Therefore, in this study the ecological footprint acts as a Sustainability Index (SI), the computation formula based on it, is as follows:

$$SI = \frac{EF}{EF + EC} \quad (5)$$

SI ranges from 0 to1, when SI = 0.5, the ecological footprint is equal to the ecological carrying capacity or biocapacity, which means the sustainable development of the region is right on the edge, when SI is between 0 and 0.5, we know the area is in a sustainable state, and when SI is nearly equal to zero, the ecological footprint is negligible and the ecological carrying capacity is high, there is a great opportunity for the region to develop sustainably. When SI is between 0.5 and 1, the area is in an unsustainable state. And when SI tends to be 1, the ecological footprint is much greater than the ecological carrying capacity or biocapacity, and the sustainable development of the regional situation is not good.

Sensitivity coefficient (SC)

According to the Principle of Elastic Analysis in Economics, we canconclude that the elastic value can be used to represent the sensitivity between dependent variable and independent variables as long as there is a functional relation existing between the dependent and independent variables. In this study, the quantified Sustainability Index will be used to analyze the degree of sensitivity factor of social and economic development, by defining the sensitivity coefficient of the Sustainability Index. The formula of the sensitivity coefficient of Sustainability Index is as follows:

$$\mathrm{SC}_{\mathrm{ij}} = \left| \frac{(SI_{i+1} - SI_i)/SI_i}{(IF_{(i+1)j} - IF_{ij} / IF_{ij})} \right| \quad (6)$$

where, SC_{ij} is the sensitive coefficient of the social and economic in *j*, which is effected by *i* year's Sustainability Index. SI_{i+1} and SI_i are the Sustainability Index of *i*+1 and *i* year. $IF_{(i+1)j}$ and IF_{ij} are *j* kinds of the social economic factor influencing the change of the Sustainability Index in *i*+1 and *i* years. If the sensitivity coefficient is greater than 1, it indicates that the large changes of the independent variable are caused by a small change of the dependent variable.

RESULTS AND DISCUSSION

Measurement of sustainability level

The consumption of biological resources in the study area is divided into four categories including agricultural, animal, fish and forest products. Using the world average yield data calculated by FAO in 1993, the consumption of biological resources of the study area in 2005 has been used to measure the biologically productive area provided by such consumer. The results of ecological footprint of the consumption of biological resources are shown in Table 2. Using the average calorific value of the world's fossil fuel production on the unit of land area as the standard, we have made the heat of energy consumption of fossil fuels in study area in 2005 converted into certain land areas of fossil fuels. The results of ecological footprint of the consumption of energy are shown in Table 3. According to the type of biological production area and the related data from Xingguo County in 2005, the ecological carrying capacity or biocapacity in the study area is calculated. And then we get the results of the ecological footprint and the Sustainability Index for Xingguo County in 2005. These results are listed in Table 4. As shown in Table 4, there is obvious asymmetry between the supply structure of ecological productive land and the demand structure of social and economic development in 2005.

From Table 4, we can conclude that per capita ecological deficit of arable land is the largest, amounting to 0.229 hm^2 per capita and the supply is less than half of demand. The supply of garden plot can just meet the needs of social and economic development. The supply of forest land is adequate and has a considerable part of the ecological surplus. And the state of construction land is between them. There is no supply, but demand for grassland and fossil energy land in the study area. Also, the footprint of cultivated land per capita is the largest,

Table 2. Ecological footprint of the consumption of biological resources of study area in 2005.

Land type	Item	Global average yield (kg/hm^2)	Biological production (t)	Ecological footprint (hm^2)	Per capita ecological footprint ((hm^2/per capita)
Arable land	Food categories	2744	258931	266102.5583	0.3647
	Oilseeds	1856	5614	8529.8922	0.0117
	Melons	18000	466	73.0067	0.0001
	Cane	18000	52000	8146.6667	0.0112
	Tobacco leaf	1548	1959	3568.7209	0.0049
	Vegetables	18000	234217	36693.9967	0.0503
Grass	Meat	265.5	74429	151381.0169	0.2074
	Eggs	400	5127	6921.45	0.0095
	Honey	50	54	583.2	0.0008
Garden plot	Teas	566	171	598.19788	0.0008
	Fruits	3500	20192	11422.9029	0.0157
Forest land	Timber	1.99(m^3/hm^2)	1.888(10^{4}m^3)	10815.6784	0.0148
	Bamboo	1.99(m^3/hm^2)	0.24(10^{4}m^3)	1374.8744	0.0019
	Tung tree seeds	1600	50	35.625	4.88E-05
	Tea seed oil	1600	33	23.5125	3.22E-05
	Chinese tallow tree seeds	1600	8200	5842.5	0.0080
	Turpentine	1600	750	534.375	0.0007
	Dried bamboo shoots	3000	100	38	5.21E-05
	Chestnut	3000	135	51.3	7.03E-05
Water	Aquatic products	29	15302	116084.1379	0.1591

Table 3. Ecological footprint of the consumption of energy of study area in 2005.

Energy type	Global average energy footprint (GJ/hm^2)	Conversion coefficient (GJ/t)	Total consumption (t)	Ecological Footprint (hm^2)	Per capita ecological footprint (hm^2/per capita)	Production area type
Raw coal	55	20.934	64537.74	28003.23	0.0384	Fossil fuels land
Gasoline	93	43.124	1736.667	918.03	0.0013	Fossil fuels land
Kerosene	93	43.124	36.25	19.16	2.62589E-05	Fossil fuels land
Diesel fuel	93	42.705	254.2933	133.12	0.00018	Fossil fuels land
Electricity (10 kWh)	1000	36.00#	10657.3	1081.93	0.00148	Building land
LPG	71	50.2	4	3.22	4.41812E-06	Fossil fuels land
Other fuels (tce)	55	36.19	4265.867	3199.91	0.00438	Fossil fuels land

#Power conversion coefficient units GJ/10^{4}kwh.

accounting for almost 49% of the total, followed by grassland, water, fossil energy land, forest land and construction land (Figure 2). This indicates that the agriculture, forestry and fishing is the main mode of economic development in the study area at present, which is a typical mountainous area economy. The low level of industrial development is evident, and social and economic development is relatively lacking, but there is still a great potential to develop. The ecological deficit in the study area is 0.325 hm^2 per capita, which means that the existence of the social and economic system has gone beyond the threshold value of ecological environment. The study areas is in a state of unsustainable development. Conclusively, in Xingguo County there are opportunities to develop its economy but challenged by the ecological deficit. The government should ensure that the ecosystem and the development of the economy are balanced at all times. As can be seen

Table 4. Ecological Footprint and Sustainability Index of Xingguo County in 2005 (hm^2/per capita).

Land use type	Per capita ecological footprint	Per capita ecological carrying capacity	Per capita Ecological footprint surpluses or deficits	Sustainability Index
Arable land	0.443	0.214	-0.229	0.674
Garden plot	0.017	0.018	0.001	0.486
Forest land	0.026	0.350	0.324	0.069
Grassland	0.218	0	-0.218	1.000
Water	0.159	0.002	-0.157	0.988
Construction land	0.002	0.026	0.024	0.071
Fossil fuel land	0.044	0	-0.044	1.000
Total	0.907	0.582*	-0.325	0.609

* 12% of biodiversity conservation area is deducted.

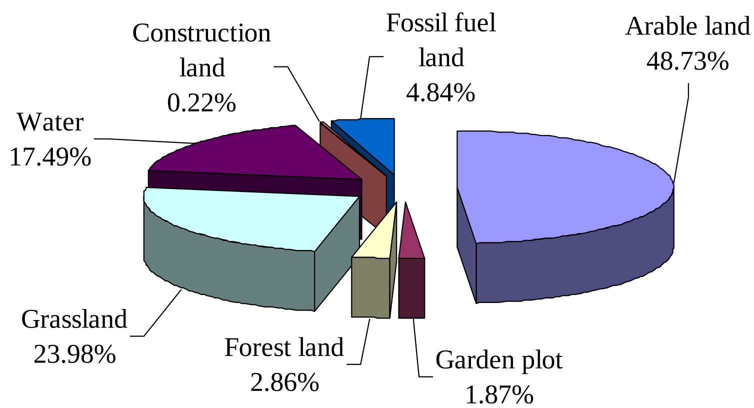

Figure 2. The proportion of ecological footprint per capita for different land use types in 2005.

from Table 4, in terms of measuring the degree of regional sustainable development, the Sustainability Index (SI) based on the ecological footprint is better than the indicator of ecological surplus or deficit. The ecological deficit per capita of grassland is less than that of cultivated land, but its Sustainability Index is larger than that of arable land. From the investigated data of land use in Xingguo County, we can conclude that there are no data for grassland due to the area being scattered and small. From this perspective, the ecological carrying capacity of grassland in Xingguo County is less than which necessary meet the needs of its social and economic development, being in a completely unsustainable state. The situation also occurred in water land and fossil energy land. This shows that the ecological footprint model of ecological surplus or deficit only reflects the status of regional development demand for ecological environment, but can not reflect the degree of regional sustainable development very well. For the parts with ecological surplus or the area whose Sustainability Index is less than 0.5, there is a principle which goes like this: the larger the ecological surplus, the smaller the Sustainability Index, but the rates at which each changes are different.

Analysis of time series

According to the same methods and steps, the per capita ecological footprint and ecological carrying capacity in Xingguo County from 1996 to 2005 were calculated. The detailed results are listed in Table 5; Figure 3 shows the changing trends of per capita ecological footprint of different land use types from 1996 to 2005 in the study area. From Figure 3, we can conclude that arable land, grassland and water occupied a major share, and combined measure 90.41%. The state of arable land kept constant before 1999.The value was decreasing during the years 1999 to 2003. Then it was steadily increasing. Overall, it showed a declining trend, though contributing the most. The footprint per capita of grassland and water were increasing year by year. The value of Sustainability Index (SI) increased from 0.527 in 2005 to 0.609 in 1996. In addition to the slow increase in the ecological carrying capacity or biocapacity per capita of garden land, ecological

Table 5. Supply and demand of Per Capita Ecological Footprint in Xingguo County (hm^2 per capita).

Year	Demand of ecological footprint								Supply of ecological footprint						The per capita ecological footprint surpluses or deficits	Sustainability Index
	Arable land	Garden plot	Forest land	Grassland	Water	Fossil fuel land	Construction land	Total	Arable land	Garden plot	Forest land	Grassland	Water	Fossil fuel land		
1996	0.449	0.007	0.025	0.158	0.060	0.039	0.000	0.737	0.254	0.006	0.407	0.002	0.081	0.661	-0.076	0.527
1997	0.439	0.010	0.031	0.159	0.071	0.042	0.000	0.753	0.250	0.006	0.403	0.002	0.081	0.654	-0.099	0.535
1998	0.442	0.009	0.034	0.127	0.088	0.057	0.002	0.759	0.248	0.006	0.398	0.002	0.081	0.648	-0.111	0.539
1999	0.446	0.011	0.012	0.163	0.096	0.053	0.000	0.780	0.245	0.006	0.394	0.002	0.081	0.641	-0.139	0.549
2000	0.419	0.008	0.026	0.192	0.130	0.078	0.000	0.854	0.242	0.006	0.390	0.002	0.081	0.635	-0.219	0.574
2001	0.391	0.012	0.015	0.180	0.150	0.035	0.000	0.784	0.226	0.006	0.364	0.002	0.077	0.594	-0.190	0.569
2002	0.359	0.016	0.014	0.181	0.134	0.034	0.001	0.739	0.223	0.009	0.359	0.002	0.076	0.589	-0.150	0.556
2003	0.335	0.015	0.030	0.187	0.137	0.036	0.001	0.741	0.214	0.012	0.350	0.002	0.076	0.575	-0.166	0.563
2004	0.417	0.015	0.026	0.196	0.145	0.039	0.001	0.841	0.211	0.015	0.346	0.002	0.076	0.572	-0.269	0.595
2005	0.443	0.017	0.026	0.218	0.159	0.044	0.002	0.907	0.214	0.018	0.350	0.002	0.078	0.582	-0.325	0.609

* 12% of biodiversity conservation area is deducted.

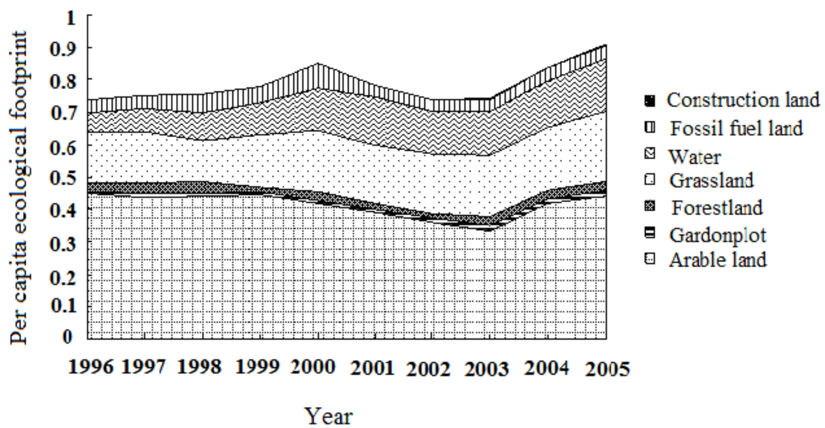

Figure 3. Changing trends of per capita ecological footprint of different land use types from 1996 to 2005.

carrying capacities or biocapacity for other land use types were either slowly decreasing or keeping unchanged.

The changing trend of the ecological footprint, ecological carrying capacity or biocapacity per capita and the Sustainability Index were shown in Figure 4. Between 1996 and 2005, the ecological footprint per capita in Xingguo County showed a fluctuating upward trend and the per capita ecological carrying capacity or biocapacity is reduced (Figure 4). The changing trend of the Sustainability Index and the per capita ecological footprint is the same, and the change is small. The value of the Sustainability Index was between 0.5 ~ 0.6 (insecurity interval of the Sustainability Index) and increases slowly, over 0.6 for the first time in 2005. This illustrates that the social and economic activities are beyond the ecological

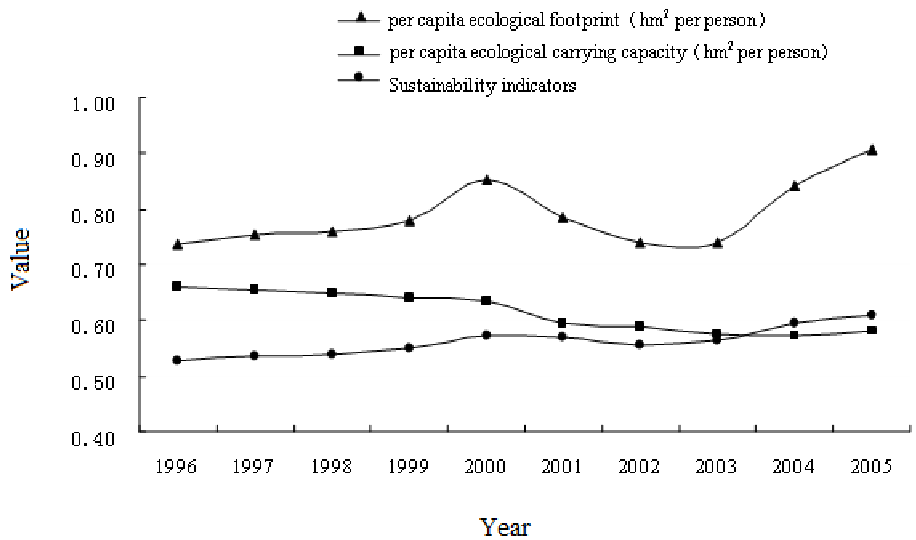

Figure 4. Changing trend of ecological footprint, ecological carrying capacity per capita and Sustainability Index from 1996 to 2005.

Table 6. Correlation coefficient between SI and social economic indicators.

	Population ($\times 10^3$)	GDP($\times 10^{10}$)	Urbanization level (%)	Primary industry proportion (%)
Correlation coefficient	0.796**	0.766**	0.847**	-0.847**
Significance level	0.006	0.010	0.002	0.002

** Pearson correlation coefficient (P<0.01).

carrying capacity and the ecological capacity or biocapacity cannot sustain current human activities. Humans in the study area had to rely mostly on other resources. Regional development is in a state of being relatively unsustainable, which is going to become more serious.

Correlation analysis

Although the ecological footprint model has the characteristics of ecological bias, actually a time series evolution of the ecological footprint has a particularly close connection to the social and economic development. Based on the calculation principles of the Sustainability Index and considering that Xingguo County is a typical hilly mountain area, four indicators of the social-economic system were used to analyze the correlation using the software SPSS17.0. The results of correlation analysis between the Sustainability Index and social-economic indicators are listed in Table 6. And the Changing trend of correlation between SI and the total population, GDP, urbanization level and proportion of primary industry can be seen from Figure 5.

From Table 6 and Figure 5, we can conclude that the Sustainability Index was significantly positively related with total population, GDP and urbanization level. That means that population growth, economic development and urbanization level had a negative effect on regional sustainable development in the study area. With the development of society and the economy, the quality of the ecological environment declined. There is a strong negative correlation between the Sustainability Index and the proportion of primary industry. As a large agricultural County, the ecological footprint of biological resources consumption in Xingguo County accounted for 95.15% in 2005.The larger the proportion of primary industry, the more the corresponding biological resources consumption. With the current production model unchanged, it is harmful for regional sustainable development.

Sensitivity analysis

Using the formula (6), we calculated the sensitivity coefficients of the Sustainability Index related to total population, GDP, level of urbanization and primary industry proportion (Table 7). From Table 7, we can see that in most years the sensitivity coefficients of the Sustainability Index related to the four social and economic

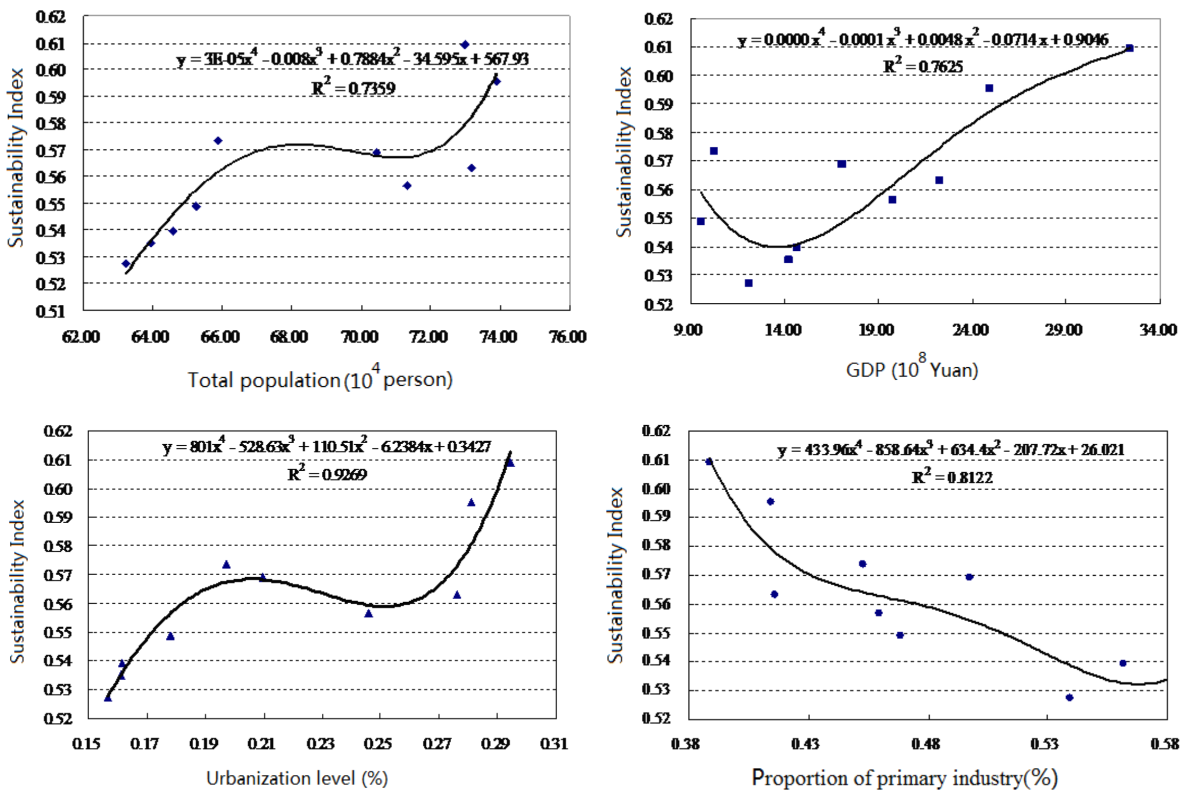

Figure 5. Changing trend of correlation between the SI and the total population, GDP, level of urbanization and proportion of primary industry.

Table 7. Sensitivity coefficient of the Sustainability Index related to the total population, GDP, level of urbanization and primary industry proportion.

Year	$SC_{Total\ population}$	SC_{GDP}	$SC_{Urbanization\ level}$	$SC_{Primary\ industry\ proportion}$
1996	1.3911	0.0871	0.5807	0.1759
1997	0.8145	0.2452	1.8327	0.1935
1998	1.6654	0.0502	0.1730	0.1061
1999	4.5635	0.5795	0.4184	1.3363
2000	0.1158	0.0122	0.1275	0.0818
2001	1.7538	0.1380	0.1262	0.2873
2002	0.4588	0.0945	0.0962	0.1261
2003	5.7804	0.4706	3.3532	14.3077
2004	1.8940	0.0791	0.4914	0.3768
2005	1.0108	0.0929	0.1774	0.5575

indicators are less than 1. This indicates that in the social - economic - natural complex system, the ecological environment is the order parameter. When the complex system is unbalanced, ecological environment plays a key role on the system. Therefore, in the process of developing the social economy, we should pay more attention to the protection of ecological environmental at the large scale. From Table 7, we concluded that the Sustainability Index (SI) is most sensitive to population growth, followed by the decline in the proportion of primary industry. This is mainly because with the increasing population growth, the consumption of food and energy increase, which is the major factor effecting an increasing ecological footprint. As a typical hilly mountain area, the largest ecological footprint in the study area is the consumption footprint of biological energy. With the rate of primary industry in China reduced, the consumption of biological resources will decrease the ecological footprint to a large extent, thereby reducing the Sustainability Index. On one hand, urban expansion makes the transition from arable land, forest land, grassland and other types of land to construction land, conversely, it increases the demand on regional material energy level and waste disposal space, which will make the Sustainability Index rise. Therefore, the Sustainability Index also has a relatively high sensitivity to the level of urbanization.

Conclusion

Based on the ecological footprint model, this article used a Sustainability Index to measure the level of sustainable development in Xingguo County in China. Through the correlation and sensitivity analysis, we reveal the driving factors of human activities on the regional sustainability in the study area**.** The consumption of biological resources in the study area, accounted for the vast majority in the footprint, and its proportion showed a somewhat slowly upward trend of fluctuations from 1996 to 2005. It illustrates that economic development in the Xingguo County is still mainly dependent on agriculture and forestry production the typical mountain economic model has not changed from 1996 to 2005. The increasing ratio of the ecological carrying capacity is greater than the per capita ecological carrying capacity, which indicates the rate of population growth is much faster than that of the ecological recovery and improvement, and it is beyond the bearing capacity of ecological environment. The values of the Sustainable Index range from 0.5 to 0.6 (which means unsafe), and show a slowly increasing trend. This means that the development of Xingguo County is in a state of relative unsustainability, and the unsustainability has a further expanding trend. The value of the Sustainability Index shows a significantly positive correlation with GDP and the level of urbanization. And it has a significantly negative correlation with the proportion of primary industry. The change of the Sustainability Index is most sensitive to the population growth, followed by decreases in primary industries.

To improve the ability of sustainable development in study area, we put forward the following corresponding suggestions: first is to keep control of the population growth rate, second is to carry out strict farm land protection system and improve the quality of forest land, third is to accelerate the transformation of agricultural economic development mode, to improve the utilization rate of resources, to develop ecological agriculture, and to realize the development cycle of social and economic systems and the last is to develop ecological tourism and to raise the proportion of tertiary industry. In terms of measuring the degree of regional sustainable development, the Sustainability Index in this article is better than the index of ecological surplus or deficit. When evaluating the area at the small scale (such as county), we should establish the model of county hectare. But we can s ,,ensure the balanced factor and yield factor according to local condition, to reflect the supply of natural capital more fairly at the small scale, and then optimize the ecological footprint model in the application of the measurement of sustainable development at the small scale.

Conflict of Interests

The author(s) have not declared any conflict of interests.

ACKNOWLEDGMENTS

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Scientific Research and Essays

Full Length Research Paper

Development of a device adapted to perform the torch gas tungsten arc welding (GTAW) hardfacing using alloys in powder form

Paulo Cezar Moselli, Marcelo Falcão de Oliveira and João Roberto Sartori Moreno

Department of Mechanical and Materials Engineering, University Federal Thecnological of Paraná, Brazil.

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This work was aimed at developing a device adapted to any gas tungsten arc welding (GTAW) torch, allows obtaining hard coatings by depositing alloys in powder form. For the purpose of verifying the feasibility of implementing this process, the results and parameters were compared with the plasma transferred arc (PTA) process. Due to good wear resistance was used as the substrate alloy SAE 1020 and alloy STELLITE 6 powder as depositor/hardfacing. Deposition rate, ideal flow of protection, dilution, micrographic and X-ray diffraction analysis results were raised to evaluate the proposed technique. The data showed a coating by the process GTAW pore-free and lowest dilution for both the GTAW and PTA process semi-automatics. However, gas consumption was lower for the GTAW process (8 L/min), due to reduced flow of the carrier gas. Microstructural analysis showed a microstructure similar for both processes, but the process PTA presented a more refined microstructure, possibly due to the low dilution rate. We also conclude that the presence of phases identified as γ-Fe and γ-Ni led to an increase in dilution rate of the GTAW processes.

Key words: Gas tungsten arc welding (GTAW), plasma transferred arc (PTA), wear resistance, phase γ-Fe, phase γ-Ni.

INTRODUCTION

The industry currently suffer the effects of various mechanisms of wear in the surface of the pieces, generally characterized by friction, which enables increasing the process of preventive maintenance and recovery equipment. Aiming to extend the life of parts and reduce costs with the same exchange, periodic repairs welding deposition of coatings on most worn areas, has been an important alternative in maintenance.

Research on new materials and updated manufacturing processes of surface coating has sought to address this problem, since the tendency is to use quality alloys to generate the formation of carbides and nitrides, to remedy this deficiency as reported (Midha. et al., 2001). Thus, a major breakthrough for the application of gas tungsten arc welding (GTAW) welding process or the realization of hard coatings based on the use of alloys in the form of powder deposited on the weld pool has been proposed. For both devices must be adapted welding torch that allows obtaining these hard coatings by depositing alloys in powder form.

Despite this difficulty in preparing satisfactory even with the use of different alloy compositions, substrates and results of the welding parameters are obtained. The use of Stellite 6 alloy powder or in the form of rods, have

*Corresponding author. E-mail: joaosartori@utfpr.edu.br
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Table 1. Comparison between current processes PTA and GTAW as related by D'Oliveira et al. (2008).

Variables	GTAW	PTA
Deposition of alloys	Powder	Powder
surface finish	Good	Good
Deposition rate	Low - Rod And Powder	High
Dilution	High	Low
Porosities	Absence	Absence
Inclusions	Absence	Absence
Gas system	Protection	Gas complex system protection, drag and plasma
Gas consumption	7 L/min	20 L/min

Table 2. Values of the welding parameters to determine the ideal flow of protection gas.

Combined parameters	Range of variation		
Welding current - A	130	150	180
Welding speed -cm/min	10	12	15
Flow of protection gas-L/min	5	10	15

Table 3. Parameter values used to determine the minimum flow of the carrier gas and powder feed rate.

Combined parameters	Range of variation		
Welding current - A	130	150	180
Welding speed -cm/min	10	12	15
Flow of carrier gas-L/min	1.0; 1.5; 2.0	1.0; 1.5; 2.0	1.0; 1.5; 2.0
Powder feed rate -g/min	9.5; 14; 19	9.5; 14; 19	9.5; 14; 19

been studied in the deposition of coatings chemical composition in its neat or with the addition of other elements, in an attempt to improve the properties of the coatings. The performance of these properties is directly related to the process parameters such as the intensity of the welding current, which has a direct influence on the microstructure and dilution according to Pradeep et al., 2010). Table 1 shows a graph theoretical comparison between the current processes when applied in coating operations.

This work aims to develop an adaptive to a GTAW welding torch, capable of producing hard coatings with deposition of the alloy in powder form, directly into the weld puddle device. In order to verify the viability applying this procedure, the results will be compared with the usual PTA process, using the approximate inclusive as reported in Madadi et al. (2012).

MATERIALS AND METHODS

Ideal flow protection gas

To determine the ideal flow rate protection gas tests were performed with deposition welding speeds ranging from 10 to 15 cm/min and welding currents ranging 130-180 A. For these parameters we used a gas flow 5-15 L/min, where it was observed to protect the weld puddle to solidify without the occurrence of visually observable defects, even with the increased flow followed by the increase in current and welding speed. Table 2 shows the parameters used to determine the ideal flow of shielding gas to achieve the coatings.

Flow ideal carrier gas and powder feed rate of metallic

The determination of these values was analyzed considering that the flow value for the carrier gas should be at least possible and sufficient to drive all the metal powder to puddle without causing instability of the arc and weld puddle. The feed rate was varied to between 9.5 and 19 g/min with a gas flow as shown Table 3 and verified the fusion of material deposited to track current and welding speed mentioned above.

Preparation of coating substrates

As substrate we used the SAE 1020 steel, machined dimensions 120 × 50 × 12 mm and were later rectified to remove oxides, oil and dirt was used as the filler material, a cobalt alloy commercially known as STELLITE 6 powder form and with a particle size around 45 and 180 μm and specification of hardness between 390 and 470

Table 4. Composition of the nominal substrate (SAE 1020) and filler material (STELLITE 6).

	Co	Fe	C	Cr	Ni	W	Si	Mo	Mn	P	S	Others
SAE 1020	-	Bal.	0.19	-	-	-	-	-	0.4	0.03	0.04	-
STELLITE 6	Bal.	2.13	1.13	30.85	2.39	4.65	1.40	0.35	0.25	0.005	0.006	0.40

Table 5. Parameters used in the processes GTAW.

Continuous current	GTAW1 */**	GTAW2 */**
Current - A	155	
Amplitude - mm	15	
Distance between pass - mm	4	
Welding speed - cm/min	10	
Shielding gas flow - Lpm	10	
Carrier gas flow - Lpm	1.5	
Distance electrode to workpiece - mm	10	
Sharpening the electrode tip	30°	
Distance nozzle to the piece - mm	13	
Speed feed - rpm	0.5	1.0
Deposition rate – g/min	9.5	19

P.S. * Automatic ** Semiautomatic.

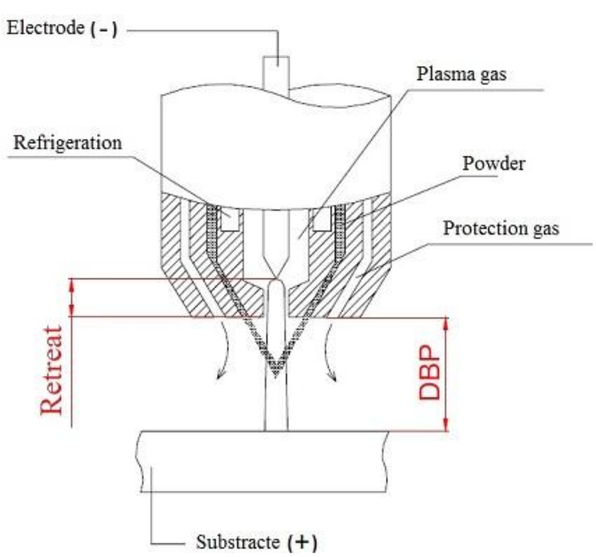


Figure 1. Schematic representation of the process PTA according to Balasubrarnanian et al. (2009).

HV. Table 4 shows the nominal chemical composition of the substrate and the alloy STELLITE 6, supplied by the manufacturer. For deposition of metal powder was used automatic and semi-automatic feeding system type ADP-2, and the deposition controlled by adjusting the speed of a toothed wheel that directs the powder into a chamber, where the supply line will be aided by a gas drag. For the purpose of comparing the processes PTA and GTAW with powder deposition welding electrical parameters used are shown in Table 5.

The weld beads were performed by a central welding INVERSAL 450 a device which enables the execution of all processes of arc welding. Each plate was deposited on a cord with the development of a welding torch displacement in the form of arc oscillation amplitude of 15 mm and advancement of 4 mm, by an automated system called Tartilope model WELDING V2/IMC. Figure 1 shows the device for applying the coating process by PTA and Figure 2 by GTAW, developed and adapted to deposit the alloy torch directly on the weld pool.

Figure 3 shows a photo of the whole nozzle/nozzle device driver to adapt the GTAW torch after preliminary test coating, where it can be observed that there was no adherence of the material in both the driver as the electrode tip. Figure 4 shows the prototype adapted to GTAW torch with 8 holes as the previous Figure 3. For the effective operation of the device was needed an additional system for cooling water and an automatic system for feeding the powder, which satisfied the GTAW and PTA processes. The GTAW process weld deposits showed good quality depending on the alloy (powder), but always on the basis of low deposition rates, the device had to control automatically.

Characterization of coatings

Visual inspection

The coatings were analyzed by simple observation the eye, with the intention to qualitatively assess the overall surface finish to the determination of discontinuities that could cripple the procedure, such as: porosity, cracks, longitudinal and transverse to the weld cords.

Metallographic analysis

The methodology to evaluate the coatings was proceeded through qualitative visual analysis macrografics cross sections of the cords and microstructural analysis. The microstructural analysis was

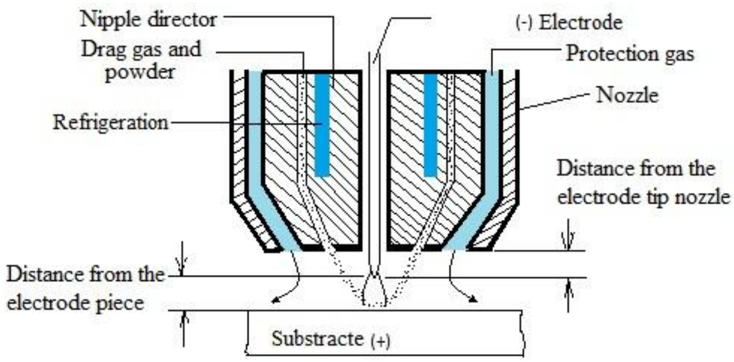


Figure 2. Schematic representation of the device for powder deposition process by GTAW studied.

Figure 3. Photo of the bottom view of the torch adapted test after deposition.

Figure 4. Photo of the device after the operation, configuration concentric with 8 holes, adapted to the torch GTAW/PTA with deposition automatic.

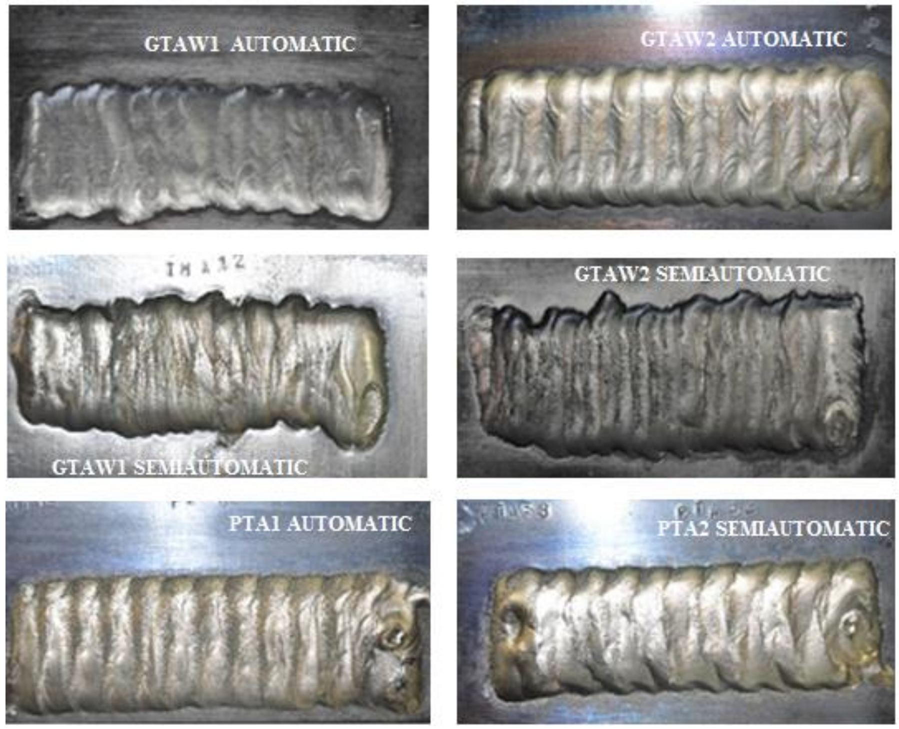


Figure 5. Photos cords deposited (surface view) – GTAW and PTA automatic and semi-automatic respectively.

carried out in KOZO metallographic microscope, model XVM 300 digital camera with DCM 510, on surfaces and in the regions of the interface between the coating and substrate, and the attacks to disclosure were made in specific solution based alloys Cobalt, consisting of: 15 ml H_2O, 15 ml HNO_3, 15 ml of CH_3COOH and 60 ml of HCl according to Madadi et al. (2011).

Determination of the dilution

The quantification of the dilution of the cords was made by the method of area ratio based on participation of the substrate to form the coating using the Digital Image Tool for calculating and delineation of the areas. The higher the dilution, the more the properties of the coatings are distant from the nominal properties of the alloy. Thus we tried to keep the dilution in the lowest level possible while obtaining a proper metallurgical bonding to the coating, whereas an increase in the dilution causes a decrease in the hardness of the deposit, and this in turn increases the wear volume to deposit diluted as Bond and D'Oliveira (2012). On the other hand it is known that dilution is influenced by the arc current, the deposition rate, speed of the torch, the arc length and frequency of oscillation of the torch second (Balasubrarnanian et al., 2009).

X-ray diffraction analysis

The X-ray analysis were conducted on the Diffractometer Model Rotaflex Rigaku RU 200B X-ray Laboratory of Crystallography Group of the IFSC USP São Carlos used to determine the spectra of all tested variations of deposition. The scan parameters of the electron beam that is, speed and scan range was 2-Theta (0) and monitored with software "Match - Phase Identification from Powder Diffraction".

RESULTS AND DISCUSSION

Visual analysis

Figure 5 shows the surface appearance of strings of all variations generated where the cords showed a good surface finish (roughness), but with different widths and heights in relation to manual. However, as shown in the literature, the PTA processes (D'Oliveira et al., 2008) have lower dilutions for the same deposition rate, but the deposition proceeds similar to GTAW, which shows characteristics similar to visual PTA and both have good wettability and free of cracks. But PTA process has a better surface finish taking into account only the roughness.

For comparison among the processes PTA - Powder (PTA) and GTAW – Powder (GTAW), welding parameters used are showed in Table 2, where the number 1 correspond to 9.5 g/min dilution rate and the number 2 the rate of 19 g/min. Table 3 shows the analysis results of dilution and calculation of income for the deposition processes PTA, GTAW1 and GTAW2 automatic and semiautomatic (Table 6).

However, as shown in the literature, the process introduces PTA lowest dilution even by varying the deposition rate of metallic powder, but with yields similar deposition. Analyzing only the cords deposited by GTAW there is a considerable reduction of dilution, when increasing the deposition rate, reaching values near the

Table 6. Deposition efficiency and dilution of coatings.

Variables	PTA1*	PTA2*	GTAW1*	GTAW2*	GTAW1**	GTAW2**
Deposition rate g/min	9.5	19	9.5	19	9.5	19
Efficiency to diluition(%)	93	93	94	87	85	85
Diluition(%)	7.0	4.2	17.4	7.0	10.0	5.0

P.S. * Automatic, **Semi-automatic.

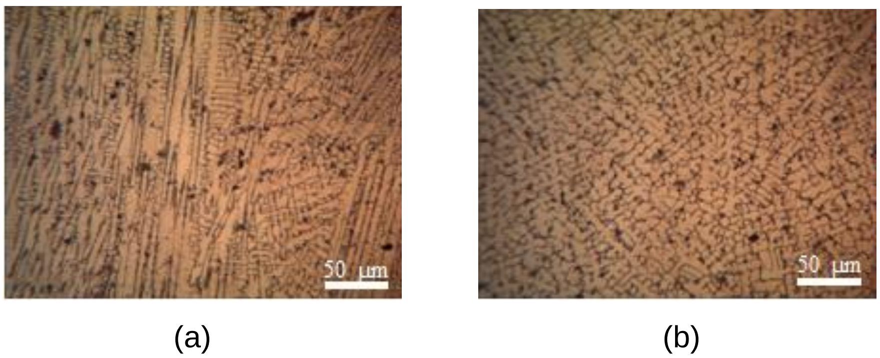


Figure 6. Photomicrographs of the powder coating GTAW1 (a) close to the interface and (b) near the surface.

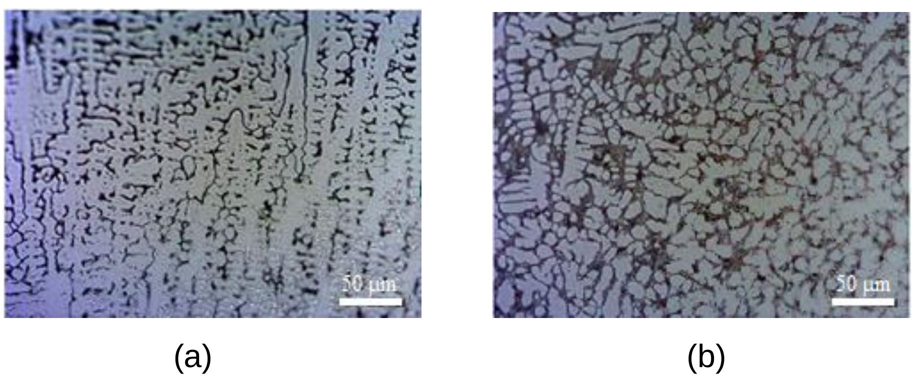


Figure 7. Photomicrographs of the powder coating PTA1 (a) close to the interface and (b) near the surface.

PTA. This observation is in agreement with that found in the literature, or the higher the deposition rate for the same level of energy, less dilution as reported by Balasubrarnanian et al. (2009). The low dilution procedure manual or semi-automatic may be due to another factor, namely, the non-constant speed in the welding for example.

Micrographic analysis

Figures 6 and 7 show micrographs of deposits made near the interface of coating/substrate and the coating surface in both cases. It is noted that the micrographs are similar to results obtained in Kashani et al. (2008) and Hou et al. (2007) which are more refined structures near the surface and melting in the region close to where there is a growing dendritic growth followed by a planar microstructure featuring a hipoeutetic. Still comparing the coatings was observed carefully with the deposit PTA showed a more refined microstructure, perhaps due to the low dilution caused by the process second (Fei et al., 2006).

X-ray diffraction analysis

Figures 8, 9, and 10 show diffraction patterns of the

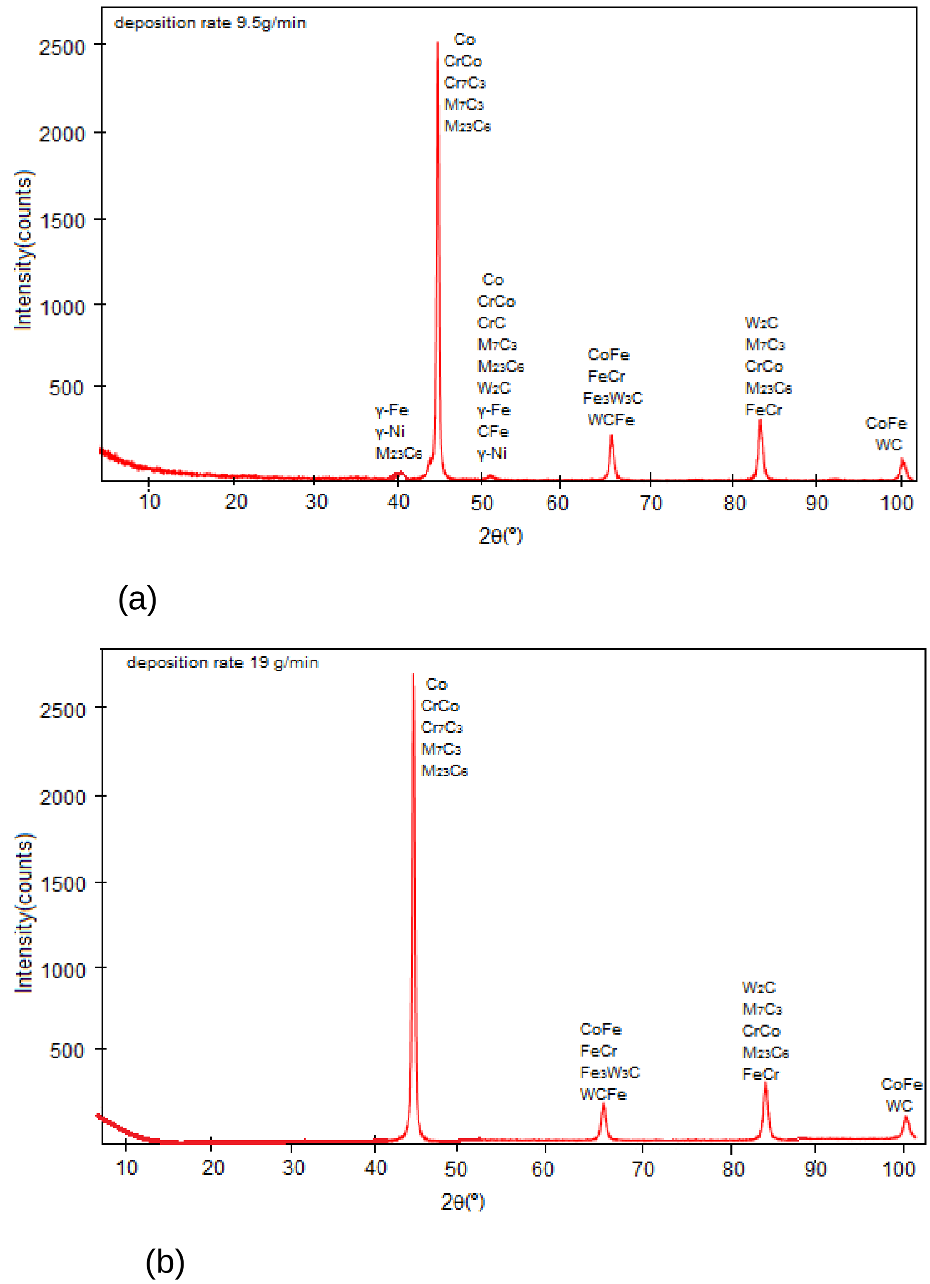
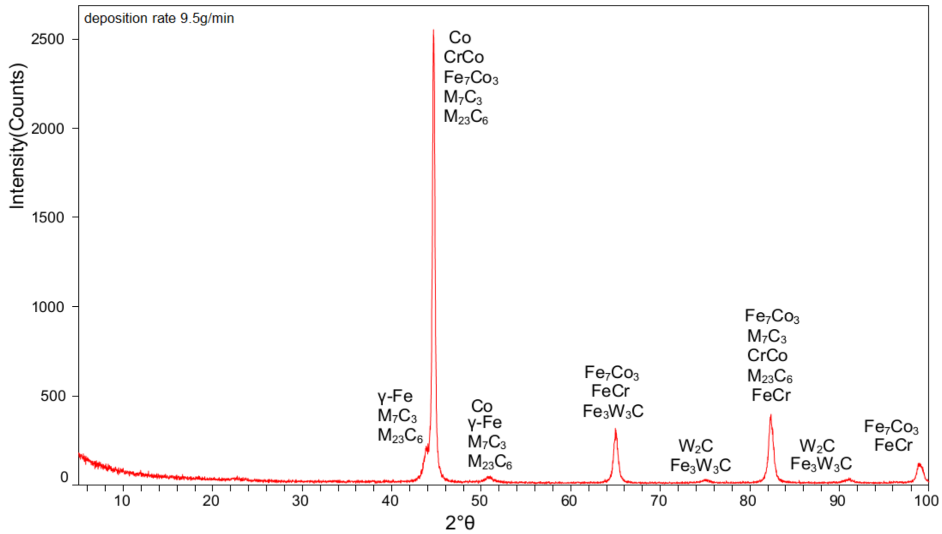


Figure 8. Diffractogram of the GTAW process automatic: (a) deposition rate 9.5 g/min, (b) deposition rate19 g/min.

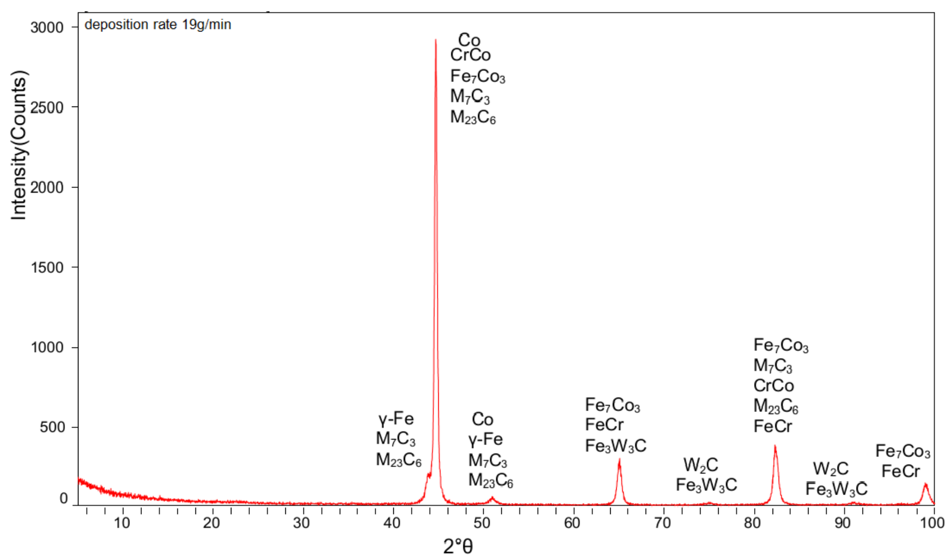
deposition made by automatic GTAW, semi-automatic GTAW and PTA process, with rates of 9.5 and 19 g/min respectively. It was observed that the diffractometric analysis of the cords presented spectrum similar but not identical, and that the deposits made by the device in both cases, where there was the appearance of Cr-rich carbides transform from M_7C_3 to $M_{23}C_6$ in a Co–Cr–W–C Stellite 6 alloy as related (Shin et al., 2003) and phases identified as γ-Fe, γ-Ni as shown in Figures 8a and 9a, especially in the automatic GTAW process.

These phases only appeared for the GTAW process and the low deposition rate (9.5 g/min), which led to higher values of deposition rate. However, for the semi-automatic GTAW process such developments occur for two deposition rates 9.5 and 19 g/min, perhaps because the movement of the torch ensued manually with some overlaps passes.

Nevertheless, if we consider that the diffraction pattern of Figure 10 reflects the analysis of a region where the first pass was performed by the operator, so may have



(a)



(b)

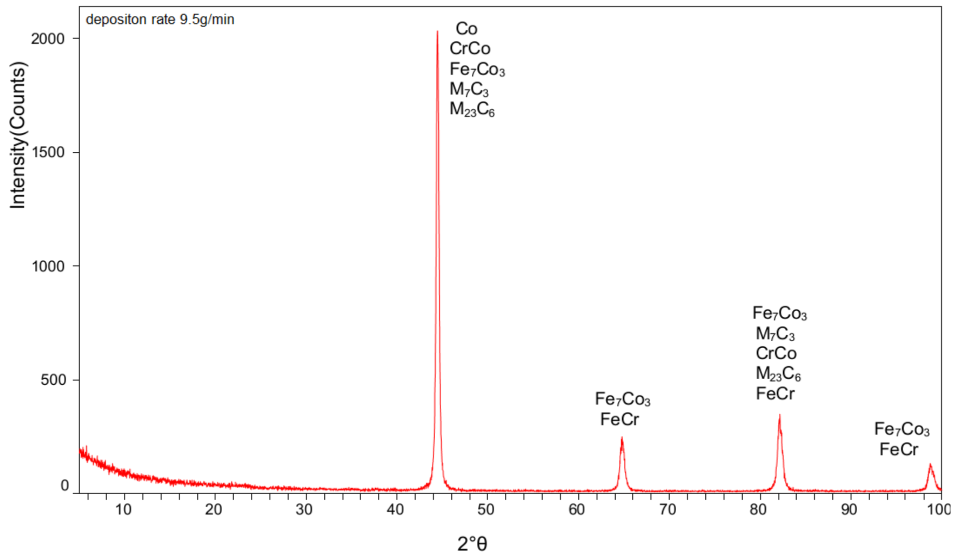
Figure 9. Diffractogram of the GTAW process semi-automatic: (a) deposition rate 9.5 g/min, (b) deposition rate19 g/min.

occurred at this point greater dilution was inhibited by the second pass as Cinca and Guilemany (2013).

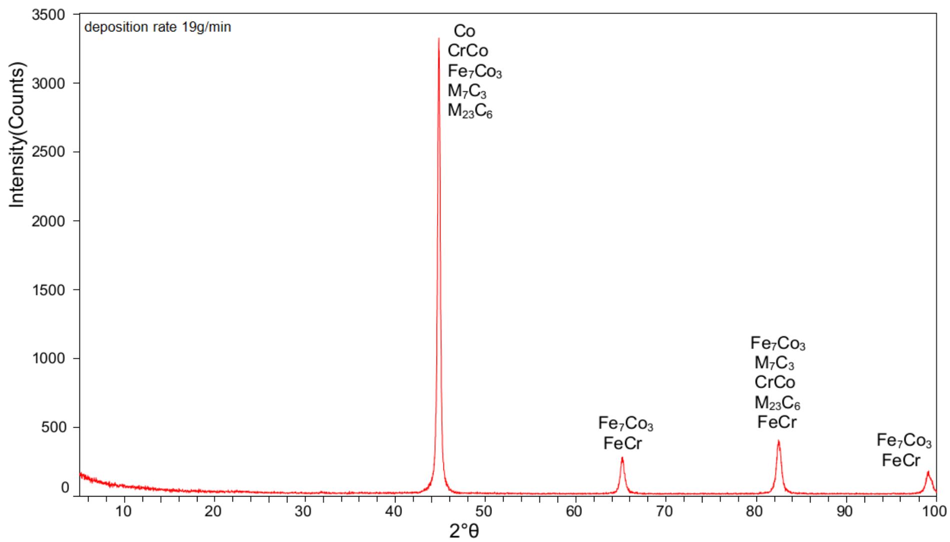
Conclusions

As the main objective was to develop a device to torch GTAW process for producing a hardfacing and so detects that its performance is very similar to that just PTA process, that is, the hard coating with properties almost similar. However, we observed that the diffractometric analysis of the cords presented spectrum near, but that the deposits made by the device in both cases, where there was the appearance of phases identified as γ-Fe, γ-Ni. These phases are appeared for the GTAW process and the low deposition rate, which led to higher values of dilution rate characteristic of this device.

However, for the semi-automatic GTAW process such developments occur for two deposition rates 9.5 and 19 g/min, perhaps because the movement of the torch ensued manually with some overlaps passes. Therefore, it is thought that with improved GTAW process parameters, such as: increasing the deposition rate by increasing the speed or decreasing the welding current



(a)



(b)

Figure 10. Diffractogram of the GTAW process PTA: (a) deposition rate 9.5 g/min, (b) deposition rate19 g/min.

value and considering its lower cost compared to PTA, the process was more important for operational and protective coatings purposes.

Conflict of Interest

The author(s) have not declared any conflict of interests.

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Scientific Research and Essays

Full Length Research Paper

Toxicity and repellent effects of some botanical insecticides on the egg-larval parasitoid *Chelonus oculator* Panzer (Hymenoptera: Braconidae)

Hilal TUNCA*, Neşet KILINÇER and Cem ÖZKAN

Department of Plant Protection 06610 Diskapi Ankara, Faculty of Agriculture, Ankara University, Turkey.

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Chelonus oculator **Panzer is an egg-larval parasitoid of the cotton leaf worm, *Spodoptera littoralis* (Boisd.) with a broad geographical area. Four botanical insecticides - azadirachtin (Neem Azal), pyrethrum (Spruzit Neu), capsaicin (Hotpepper wax) and d-Limonene (Orange guard) - were investigated regarding their side effects on *C. oculator*. Sub-lethal concentrations (LC_{25} and LC_{50}) were determined for azadirachtin and pyrethrum. Then, the parasitized third larval stage of *S. littoralis* was treated with LC_{25} and LC_{50} values for the same insecticides. Behavioural effects of the botanical insecticides on *C. oculator* were performed by choice tests using a Y-tube olfactometer. The results revealed that LC_{50} value of pyrethrum was very harmful causing 100% mortality to *C. oculator.* LC_{50} and LC_{25} values of azadirachtin and LC_{25} values of pyrethrum prolonged development time whilst reducing the longevity, emergence rate and adult dry mass. The behavioural test indicated that the tested botanical insecticides have strong repellent effects on the parasitoid. Thus, this study contributes to the amelioration of the safe use of botanical insecticides against the natural enemy in integrated pest management programs.**

Key words: *Chelonus oculator,* side effect, azadirachtin, pyrethrum, capsaicin, d-Limonene.

INTRODUCTION

Cotton is an important agricultural crop for many countries. Several insect pests, however, have negatively affected output in all cotton planting areas (Luttrell et al., 1994). There are different methods of controling these agricultural pests. Chemical control is the most common method for pest control in cotton agriculture. The negative effects of synthetic insecticides resulting from their uninformed use include environmental and human health problems. Recently plant protection application has proposed to decrease the use of synthetic insecticides (Mullen and Durden, 2002; Ofuya, 1997). An important application for controling these pests is the use of biological control methods, which have been accented by researchers, as getting a bright view of alternative to insecticide application (Crespo et al., 1998; Hogsette, 1999; Carmo et al., 2010). There are, however, alternative

*Corresponding author. E-mail: htunca@agri.ankara.edu.tr. Tel: (90 312) 5961140. Fax: (90 312) 3187029.
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chemical control methods such as the use of botanical insecticide that is less harmful to the environment and humans, yet some of them are very toxic to fish and other cold-blooded animals, and there in should be used with care (Illinois Pesticide Review, 2004). In addition, botanical insecticides have detrimental and behavioral effects on insect pests: They affect insect growth and development, have antifeedant and arrestant effects, and they also have antifungal, antiviral and antibacterial properties against pathogens (Prakash and Rao, 1986, 1997). Botanical insecticides can be divided into five major chemical categories: Nitrogen compounds, terpenoids, phenolics, proteinase inhibitors and growth regulators (Khater, 2012). However, these botanical insecticides should not be considered to be the only solution. It is indeed crucial to define the side effects of these insecticides on natural enemies since they may have a negative effect on natural enemies; and therefore botanical insecticides should be tested for their toxic effects on parasitoids and predators.

Parasitoid *Chelonus oculator* Panzer (Hymenoptera: Braconidae) could parasitize important lepidopterous pests. These pests are *Spodoptera littoralis* Boisd (Lepidoptera: Noctuidae), *Tuta absoluta* Meyrick (Lepidoptera: Gelechiidae), *Agrotis segetum* Denis & Schiffermüller, *Helicoverpa armigera* Hübner, *Heliothis viriplaca* Hufnagel, *H.peltigera* Denis & Schiffermüller, *Spodoptera exigua* Hübner, *Photedes elymi* Treitschke (Lepidoptera: Noctuidae), *Etiella zinckenella* Treitschke (Lepidoptera: Phycitidae), *Pyrausta sticticalis* (L.) (Lepidoptera: Pyraustidae), *Coleophora anatipennella* Hübner (Lepidoptera: Coleophoridae), and *Zeiraphera isertana* (F.) (Lepidoptera: Tortricidae) (Tobias, 1995; Özkan and Özmen, 2001; Desneux et al., 2010). Parasitoid's eggs are laid in the host eggs individually. They hatch in the host eggs, and the first and second instar of the parasitoid feed internally. In its third instar, the parasitoid larvae leave the host to feed externally, consuming all except the skin and head capsule. The parasitoid then spins its cocoon in the pupal cell which was previously prepared by the host larva (Özkan and Özmen, 2001).

This study, thus, examines the toxic effects of some botanical insecticides using *C. oculator* Panzer (Hymenoptera: Braconidae), a solitary egg-larval endoparasitoid of the cotton leaf worm, *Spodoptera littoralis* (Boisd.). The botanical insecticides, azadirachtin and pyretrum tested in this study are used to control the cotton pest *S. littoralis.* In the cotton agroecosystem, we can also see different groups of pests (e.g. aphids, whiteflies, mites). Other botanical insecticides such as the hotpepper wax (capsaicin) and Orange guard (d-limonene) are proven effective against aphids, mites, whiteflies, leaf hoppers, scale insects etc. in the cotton agroecosystem. Hotpepper wax and Orange guard used for these target pests indirectly affect natural enemies. In this study, the repellent effects of capsaicin and d-limonene were examined against *C. oculator* in this study. Toxicity bioassays were conducted to assess the sub-lethal effects of two products derived from azadirachtin and pyrethrum on the parasitoid. Also the repellent effects of azadirachtin, pyrethrum, capsaicin and d-Limonene were investigated through the use of Y tube olfactometer. This study aims to incorporate these botanicals with biological control into integrated pest management approach.

MATERIALS AND METHODS

Culture of the hosts and parasitoid

Ephestia kuehniella, *S. littoralis* and *C. oculator* were obtained from the University of Ankara, Faculty of Agriculture, Department of Plant Protection. *Chelonus oculator* was reared on *Ephestia kuehniella* under laboratory conditions of 25 ± 1°C, 60-70%R.H. The *Ephestia* cultures were kept in plastic cages (27 × 37 × 7 cm) on a 2 : 1 mixture of wheat flour and rough wheat bran containing approximately 400 g food, which was sterilized at 60°C in 3 days, and 5000 (0.078 g) host eggs (Özkan, 1999).

S. littoralis was used as the natural host of *C. oculator. S. littoralis* larvae were reared on lettuce leaves in plastic containers (15 × 20 × 7.5 cm). Lettuce leaves were sterilized by 1% NaOCl before being given to the larvae. Lettuce leaves were given to larvae every day. By pupation, individual pupae were transferred into adult rearing cages with 20% honey solution. A paper strip (5 × 15) was suspended in the cage during the laying of eggs. Eggs on the paper towel strip were transferred into a clean plastic container for hatching. *S. littoralis* were reared under controlled conditions of 25 ± 1°C, 60-70%R.H. and 16 : 8 h (L : D) photoperiod (Ozmen, 2004).

C. oculator was reared at 25 ± 1°C, 60-70%R.H., 16 : 8 h (L : D) photoperiod. Eggs obtained from the *E. kuehniella* culture, were used for production. Average 500 eggs of the host (24-48 h old) were glued on to paper sheets (4 × 15 × 10 cm) and set up with the fed and reproduced parasitoids located in a 10 L glass jar. For adult parasitoids, honey was spread over the paper strips carrying the host eggs. Parasitized *E. kuehniella* eggs by *C. oculator* adults for 24 h, were placed into plastic containers (15 × 20 × 7.5 cm) carrying 400 g of sterile food. This process was repeated daily. Adult parasitoids were utilized both for the existing experiments and for the set-up of the parasitoid culture (Ozkan, 2006).

Acute toxicity bioassays on *S. littoralis*

In the experiment two botanical insectides, azadirachtin (Neem Azal ®-T/S, Trifolio–M GMBH, Germany-10 g/L azadirachtin) and pyrethrum (Spruzit® Neu, Neudorff, Germany-18.36 g/L Natural-Pyrethrum) were used. LC_{50} and LC_{25} values were determined on the third-instar larvae of *S. littoralis* for azadirachtin and pyrethrum with 8 (10, 50, 100, 250, 500, 1000, 1500, 2000 ppm) and 6 (10, 50, 100, 250, 500, 1000 ppm) doses. Four replicates were used for each dose. Each set of four dishes containing 30 larvae was sprayed with an experimental treatment, allowed to dry for 10-15 min in a laminar flow cabinet and maintained at 25 ± 1°C and 16-h photophase. Mortality was assessed after 24 h.

Sublethal effects of the botanicals on the development of the *Chelonus oculator*

In order to obtain the parasitized host, a single wasp was put

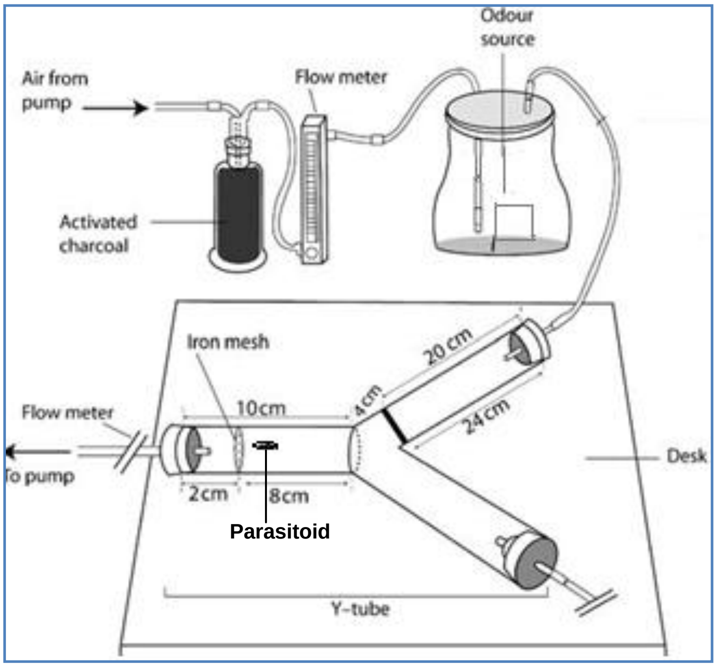

Figure 1. A schematic diagram of the Y-tube olfactometer.

together with the host eggs in Petri dishes (9 cm). The parasitoid was observed during oviposition until the characteristic parasitization behavior occurred (Ozkan, 2006). If the egg was rejected by the parasitoid, the host egg was eliminated. Parasitized eggs were immediately placed into plastic containers (15 × 20 × 7.5 cm) with excess food until first instar larva eclosion and first instar larvae were separated into groups including 15 larvae. These larvae were fed with lettuce leaves. The parasitized third-stage larvae of *S. littoralis* were sprayed LC_{50} and LC_{25} concentrations with azadirachtin and pyrethrum, and kept dry in a laminar flow cabinet. After 24 h, the living larvae were transferred to a plastic container with excess food. These larvae were reared in the laboratory to assess adult emergence. In the control, only distilled water was sprayed. LC_{50} and LC_{25} concentrations were applied using a Potter spray tower (Potter, 1952). Treatments were repeated three times. The effects of two botanical insecticides on development time, emergence ratio, longevity and adult dry mass of *C. oculator* were defined.

Olfactory bioassays

Olfactometric assays were performed using the methods described by Akol et al. (2003). In choice testing, the behavioural response of naive female *C. oculator* adults to azadirachtin (LC_{50} and LC_{25}), pyrethrum (LC_{50} and LC_{25}), capsaicin (1:32) (Hotpepperwax) and d-limonene (1:4) (Orange guard), and clean air was evaluated by a Y-tube olfactometer.

The source of test odours was placed in a glass flask (250 ml capacity) (Figure 1). Two pressure pumps (Cole-Parmer Air cadet vacuum/pressure station, Illinois, U.S.A) pumped air into and out of the system. Air from the recess pressure pump was passed through a carbon filter (Whatman Carbon-Cap 75, Clifton, NJ) for purification, then through a flowmeter (Cole-Parmer Instrument Co., Vernon Hills, Illinois, USA) and finally split into two currents with each current passing into an odour source flask. A second flowmeter was connected to the stem of the olfactometer and to a second pump, which exhausted air out of the system. Airflow into the olfactometer was set at 100 ml/min and at the exit at 500 ml/min.

The filter papers were then sprayed to near run-off with azadirachtin, pyrethrum, capsaicin, d-limonene or water alone and allowed to air-dry before being used in the tests. Naïve female parasitoids (2-3 days old) were introduced singly into the stem of the olfactometer and allowed 5 min to choose one of the arms of the olfactometer. Parasitoids that passed the finish line (marked 4 cm past the intersection) and remained for more than 15 s in the olfactometer arm were recorded as having made a choice. For the control, air was drawn through an empty flask. In all of the tests, each parasitoid was used only once and then discarded. The experiments were conducted three times, and each replicate involved 10 adult parasitoids. All the tests were conducted at 25°C, 65-75% RH. All materials used in the experiments were sterilized with alcohol following each use.

Statistical analysis

The dose-response bioassay data for LC_{50} and LC_{25} determinations were analyzed by the probit procedure (Finney, 1971). Differences were considered significant when 95% fiducial limits (FL) did not overlap. Emergence, longevity and reproduction data were analyzed with one-way analyses of variance (ANOVA), and means were separated using the Duncan's test at a significance level of $\alpha = 0.05$ (SAS Institute, 2003). Percentage data was arcsine transformed before analysis. In the olfactometric assay, the data was analysed using the Z test.

RESULTS

Acute toxicity bioassays on *S. littoralis*

Table 1 displays the LC values obtained by the treatment

Table 1. Results of probit analysis of the concentration-mortality data for *Spodoptera littoralis.*

Larval stage-a.i	n	Slope±SE	X^2 (df)	LC_{50}(95% CL)	LC_{25}(95% CL)
L3-azadirachtin	960	4.614±0.723	39.693(30)	979.316(783.939-1109.015)	699.441(468.962-358.929)
L3-pyrethrum	720	1.680±0.107	37.154(22)	129.972(104.748-160.231)	51.571(37.797-33.005)

Table 2. Sublethal effects of azadirachtin on the development of *Chelonus oculator.*

Sex	Dose	Development time (day)	Emergence* ratio (%)	Longevity (day)	Adult dry mass (mg)
♀	LC_{25}	27.23 ± 0.26^{B}; n=17	40.43^{B}	10.23 ± 0.32^{B}; n=17	1.65 ± 0.002^{B}; n=17
	LC_{50}	36.81 ± 0.31^{A}; n=16	33.46^{C}	6.81± 0.34^{C}; n=16	1.60 ±0.004^{C}; n=16
	Control	21.30 ± 0.33^{C}; n=23	53.96^{A}	18.56 ± 0.37^{A}; n=23	1.76 ±0.013^{A}; n=23
♂	LC_{25}	22.65 ± 0.27^{B}; n=23	40.43^{B}	5.91 ± 0.23^{B}; n=23	1.59 ±0.003^{B}; n=23
	LC_{50}	31.76 ± 0.31^{A}; n=21	33.46^{C}	5.23 ± 0.21^{B}; n=21	1.55 ±0.004^{C}; n=21
	Control	18.70 ± 0.30^{C}; n=27	53.96^{A}	13.63 ± 0.30^{A}; n=27	1.68 ±0.003^{A}; n=27

Columns with the different letter are significantly different (DUNCAN test, P <0.05). *The emergence rates were calculated together for both sexes.

Table 3. Sublethal effects of pyrethrum on the development of *C. oculator*

Sex	Dose	Development time (day)	Emergence ratio (%)	Longevity (day)	Adult dry mass (mg)
♀	LC_{25}	35.08 ± 0.41^{A}; n=12	33.30^{B}	8.00± 0.27^{B}; n=12	1.61± 0.004^{B};n=12
	LC_{50}	-	-	-	-
	Control	21.30 ± 0.33^{B}; n=23	53.96^{A}	18.56 ± 0.37^{A}; n=23	1.76 ±0.013^{A}; n=23
♂	LC_{25}	28.88 ± 0.37^{A}; n=18	33.30^{B}	4.11 ± 0.26^{B}; n=18	1.53±0.004^{B}; n=18
	LC_{50}	-	-	-	-
	Control	18.70 ± 0.30^{B}; n=27	53.96^{A}	13.63 ± 0.30^{A}; n=27	1.68 ±0.003^{A}; n=27

Columns with the different letters are significantly different (DUNCAN test, P <0.05).*The emergence rates were calculated together for both sexes.

of the 3rd larval instars of *Spodoptera littoralis* with different concentrations of the tested compounds. LC_{50} and LC_{25} values of azadirachtin were higher than pyrethrum.

Sublethal effects of the botanicals on the development of *Chelonus oculator*

The results of this study have been summarized in Tables 2 and 3, showing the effects of azadirachtin and pyrethrum. Azadirachtin caused significant effects on the development time, emergence ratio, longevity and adult dry mass (Table 2).

The development time of female and male *C. oculator* was 27.23, 22.65 days for LC_{25} concentration and 36.81, 31.76 days for LC_{50} concentration. Both sublethal doses of azadirachtin prolonged development time of female and male as the control (df = 2, F_{female} = 599.77, P = 0.000; df = 2, F_{male} = 491.60, P = 0.000). The emergence rates of *C. oculator* treated with azadirachtin were 40.43 and 33.46 for LC_{25} and LC_{50} concentrations, respectively. Azadirachtin reduced the emergence rate of *C. oculator* as a control (df = 2, F = 67.85, P = 0.000). Azadirachtin drastically reduced longevity of adults and adult dry mass in all the tested concentrations. Means for these parameters were significantly different (df = 2, F_{female} = 302.01, P = 0.000; df = 2, F_{male} = 329.96, P = 0.000) for adult longevity; (df = 2, F_{female} = 68.19, P = 0.000; df = 2, F_{male} = 346.95, P = 0.000) for adult dry mass.

Like azadirachtin, pyrethrum caused significant effects on the development time, emergence ratio, longevity and adult dry mass (Table 3). The results indicated that pyrethrum was highly toxic. LC_{50} value caused 100% mortality in *C. oculator.* Development time of *C. oculator* from parasitized *Spodoptera* larva was significantly affected by LC_{25} value (df = 1, F_{female} = 619.24, P = 0.000; df = 1, F_{male} = 448.53, P = 0.000). The resulting progeny emergence rate decreased considerably by 33.30% (df = 1, F = 112.38, P = 0.000). In line with this, pyrethrum drastically reduced longevity of adults and adult dry mass at LC_{25}. Means for these parameters were significantly

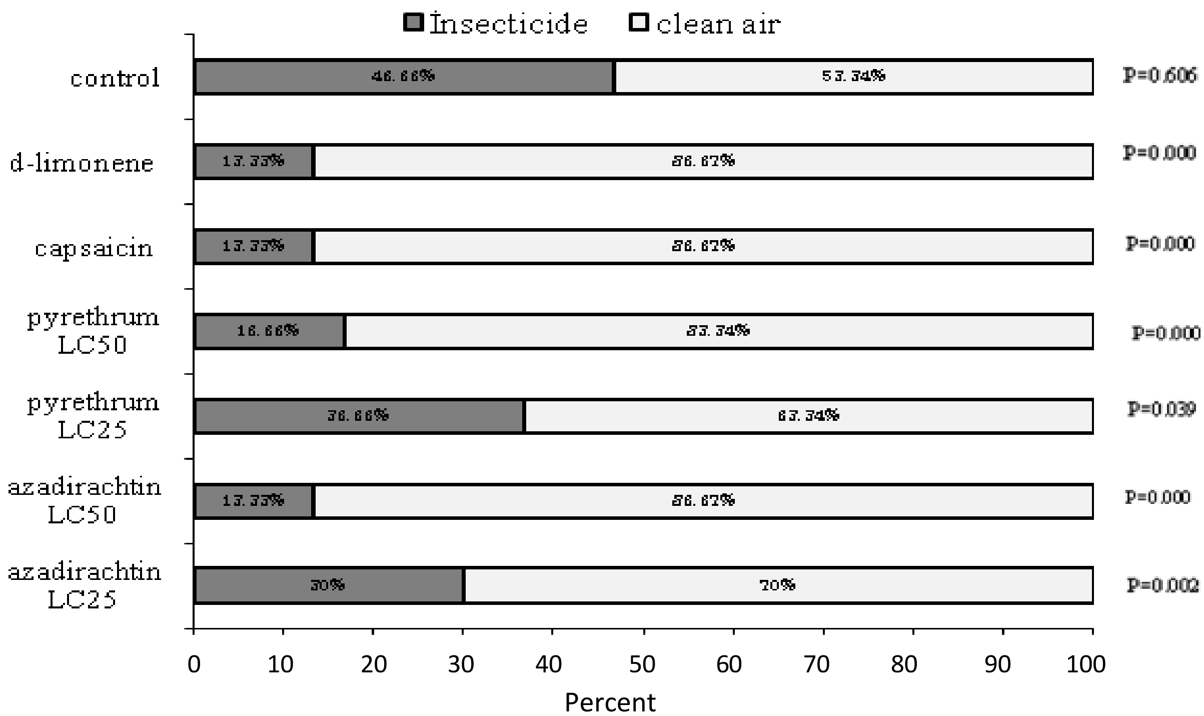

Figure 2. Response of naive female *C. oculator* to odours from a filter paper sprayed with azadirachtin, pyrethrum, capsaicin, d-limonene, and water.

different (df = 1, F_{female} = 364.68, P = 0.000; df = 1, F_{male} = 488.83, P = 0.000) for adult longevity; (df = 1, F_{female} = 61.51, P = 0.000; df = 1, F_{male} = 654.94, P = 0.000) for adult dry mass (Table 3).

Olfactory bioassays

This Y-tube olfactometer facilitated the rapid covering of volatiles depending on attractiveness or repellency to *C. oculator*. There was no significant difference between clean air and water sprayed ones (P>0.05). Female *C. oculator* responded considerably to the botanical insecticides (Figure 2). Regarding the choice between a hotpepper-clean air and orange guard-clean air, it was found that significantly more parasitoids chose the arm from clean air (P<0.05; P<0.05). Similarly, in the choice test between azadirachtin (LC_{25} and LC_{50})-clean air (P<0.05; P<0.05) and pyrethrum (LC_{25} and LC_{50})-clean air, the parasitoid chose clean air (P<0.05; P<0.05) (Figure 2).

DISCUSSION

Natural enemies account for an important element of many integrated pest management programs just as parasitoids and predators adversely affect synthetic chemical insecticides. Botanical insecticides offer an alternative to synthetic chemical insecticides, especially azadirachtin and pyrethrum-based insecticides which are used in ecologically-based pest management. Yet, botanical insecticides can be harmful to beneficial insects. Recently, side effect studies have become increasingly important, and thus, these studies of botanical insecticides should also be tested on natural enemies, as is the case with synthetic chemical insecticides.

The present study shows that the egg-larval parasitoid of *C. oculator* has shown sensitivity towards azadirachtin and pyrethrum. The development time of the parasitoid increased seriously by different sublethal doses of azadirachtin for both sexes. LC_{25} and LC_{50} doses of azadirachtin increased the development time of female parasitoid by 5.93 and 15.51 days respectively. In the male parasitoid, this increase was 3.95 and 13.06 days respectively. The emergence rate of the adult parasitoid was affected by both azadirachtin doses (LC_{25}-LC_{50}). LC_{25} and LC_{50} doses of azadirachtin reduced the mean emergence ratio of the adults by 13.53 and 20.5% respectively. The longevity of female and male *C. oculator* treated with the LC_{25} and LC_{50} doses of azadirachtin reduced compared to that of the control (8.33 and 11.75 days; 7.72 and 8.4 days respectively). In addition, azadirachtin was observed to have a significant effect on the adult dry mass of female and male *C. oculator.* As with emergence ratio and longevity, data indicated that increasing the sublethal concentration from

LC_{25} to LC_{50} decreases the adult dry mass of female *C. oculator* from 1.76 to 1.60 and 1.65 respectively, and the dry mass of male *C. oculator* from 1.68 to 1.55 and 1.59 respectively (Table 1).

However, pyrethrum was found to be of toxic compounds to *C. oculator*. Application of LC_{50} completely prevented the development of the parasitoid. Our study showed that application of LC_{25} of pyrethrum negatively affects the development of *C. oculator*. LC_{25} dose of pyrethrum increased the development time of the female and male parasitoid by 13.78 and 10.18 days, respectively – an increase which was more than the azadirachtin. LC_{25} dose of pyrethrum reduced the mean emergence ratio of the adults by 20.66%. The longevity of female and male *C. oculator* treated with the LC_{25} dose was reduced in comparsion to the control (10.56 and 9.52 days, respectively). Similarly, pyrethrum reduced adult dry mass of female and male *C. oculator* (Table 2).

Studies on the side effects of botanicals - some of which have been summarized below - have revealed a polarity in that while some studies have reported that plant-derived insecticides have very little or no effect on natural enemies, others have stated that botanical insecticides have serious side effects on beneficial insects.

The side effects of two commercial neem products (Neem Azal T/S as foliar application and Neem Azal- U as soil application) on *Eretmocerus warrae* Naumann & Schmidt (Hym: Aphelinidae) and *Encarsia formosa* Gahan (Hym: Aphelinidae) were investigated. The results of this study showed that both parasitoids were higly susceptible to the neems. Parasitoid emergence was affected in a dose-dependent manner, but parasitoids were less exposed to damage with the soil application (Kumar et al., 2010). Tang et al. (2002) investigated the effects of 11, 45 and 180 ppm of azadirachtin on the development of parasitoid *Lysiphlebus testaceipes* (Cresson) (Hymenoptera: Aphidiidae). The results of the study also indicated that 11 and 45 ppm of azadirachtin was not harmful to survival and adult emergence, but 180 ppm of azadirachtin caused a small, significant reduction in the survival and emergence rate of parasitoids. In their study, Price and Schuster (1991) reported that neem seed extract reduced the population of *Encarsia* spp. and *Aleurodiphilus* spp., parasitoids of *Bemisia tabaci* Genn (Homoptera: Aleyrodidae). In a later study conducted by Saber et al. (2004) the negative effects of Neemazal 1% on *Trichogramma cacoeciae* Marchal (Hymenoptera: Trichogrammatidae) were found. Younes (2008) obtained a significant side effect of azadirachtin on the predator *Eretes sticticus* Linnaeus (Coleoptera: Dytiscidae). LC_{50} and LC_{90} treatments of azadirachtin had adverse effects on development, immature survival and prey consumption. Mordue and Blackwell (1993) reported that nymphs and larvae of some beneficial insects were more vulnerable to direct contact with azadirachtin under the laboratory conditions. Simmonds et al. (2002) found that pyrethrum was very toxic to both whitefly and *E. formosa*.

The moderate effects of azadirachtin on adult survival and reproduction, however, were detected only at the highest concentration assayed on the egg parasitoid *Trichogramma chilonis* Ishii (Hymenoptera: Trichogrammatidae) (Raguraman and Singh, 1999) and the coreid parasitoid *Gryon fulviventre* Crawford (Hymenoptera: Scelionidae) (Mitchell et al., 2004). Other reports pointed to the lack of negative effects on the survival of the diamondback moth parasitoids *Cotesia plutellae* Kurdjumov (Hymenoptera: Braconidae) or *Diadromus collaris* Gravenhorst (Hymenoptera: Ichneumonidae) (Charleston et al., 2005), or on longevity and reproduction of the larval parasitoid *Bracon hebetor* Say (Hymenoptera: Braconidae) (Raguraman and Singh, 1998) were observed. All these studies suggested that azadirachtin and pyrethrum have different effects on parasitoids. Their side effects may vary depending on formulation, dose, host and beneficial insect species and stages.

In biological control, behavioral studies frequently reveal important aspects of biology that would otherwise be neglected - such as the influence of pre-release handling on establishment success and the response of natural enemies to host-induced plant volatiles (Mills and Kean, 2010). Repellent or attractive volatiles could be used to improve the success of pest management strategies. In this study, the repellent effects of azadirachtin, pyrethrum, capsaicin and d-Limonene on the parasitoid were defined by choice tests in Y-tube olfactometer, and important repellent effects were observed in all the insecticides tested (Figure 1). The repellency was related to the type of botanicals and doses. This repellency can negatively affect host acceptance, host suitability and parasitism rates in *C. oculator*.

In their studies Satti et al. (2010) and Mandal (2011) reported that azadirachtin has a repellent effect. Boeke et al. (2003) found that in the choice test with Y tube, oil of the *Azadirachta indica* (Meliaceae) has displayed a repellent effect on the parasitoid *Uscana lariophaga* Steffan (Hymenoptera: Trichogrammatidae). A similar result was obtained for *B. hebetor* (Raguraman and Singh, 1998). In their 2002 study, Simmonds et al. showed that pyrethrum extract did deter the parasitoid *E. formosa* from stabbing into treated host nymphs.

In conclusion, this study, designed to integrate these botanical pesticides with biological control, points out that the use of botanical insecticides should be considered alongside the use of biological controls agent. For instance, pyretrum has been found to be non-compatible with *C. oculator* - it was very toxic for the parasitoid, leading to the conclusion that the insecticide was a risk factor for the parasitoid. The introduction of azadirachtin resulted in significant reduction in the development of parasitoid. These botanical insecticides have odors, chemical signals, and they affect the parasitoid *C.*

oculator behavior; thus, this chemical signal can play an important role in the relations between *C. oculator* and *S. littoralis*. Taking all these effects into consideration, this study argues that side effect studies should be conducted before plant-derived insecticides are integrated into biological control agents.

Conflict of Interest

The author(s) have not declared any conflict of interests.

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