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Behaviours and attitudes of consumers towards bioplastics: An exploratory study in Italy

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Abstract: Bio-based and biodegradable plastics produced from wood residues can have a positive impact on the environment by replacing conventional plastics. However, the current bioplastics market is held back by a lack of available information and weak marketing activities aimed at final consumers. To increase the available information, the present study investigated the consumers' attitudes and behaviours towards bioplastic products. A web-based survey was conducted on a sample of potential consumers in Italy. 1 115 consumers filled out the questionnaire with a dropout rate in compilation of 14%. The results showed that the environmental characteristics of bioplastics (lower impact on climate change and renewable sources used to produce them) are considered more important by respondents than the non-environmental characteristics (technical properties, origin of raw material, potential trade-off between bioplastics and food production). The results highlighted that the most important behavioural factor is the purchase intentions, followed by control of perceived cost and subjective norm. It is interesting to emphasize that the cost of bioplastics compared to conventional plastics is a key variable in the choices of many Italian consumers. The results provided can be useful to the manufacturing industries to better understand the consumers' attitudes towards bioplastics.

Keywords: bio-based plastics; biodegradable plastics; innovative forest-based products; theory of planned behaviour; wood residues

Worldwide, the annual global production of fossil fuel plastics – also known as conventional or petroleum-derived plastics – attained 367 Mt in 2020 and the trend has continually grown over the past 70 years (PlasticsEurope 2021). The year 2020 was an exception to this trend with a decrease of one million tons caused by the COVID-19 pandemic. In this context, Geyer et al. (2017) estimated that approximately 6 300 millions t of plastic waste have been generated throughout the history of this material (79% ended up in landfills or in the environment, 12% was destined for incinerators, while only 9% of total plastic waste was recycled). Since the 2000s, plastics accounted for between 60% and 80% of global waste (Derraik 2002) with a further increase in 2020–2021 due to single-use plastics (e.g. face masks, surgical masks, face shields) production to counter the spread of the COVID-19 pandemic (Shams et al. 2021). Historically, the use of petroleum-derived plastics has caused some environmental problems, such as carbon dioxide (CO_2) emissions and the long-term accumulation of non-biodegradable materials in the environment (Nielsen et al. 2020). Therefore, the need to identify appropriate alternatives to petroleum-derived plastics that are ecologically sustainable – e.g. bioplastics – is one of the target objectives for the European Union (EU) policy makers to achieve the target established by the Paris Agreement on Climate Change (2015) and the European Green Deal (Emadian et al. 2017; Di Bartolo et al. 2021).

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In 2015, the European Commission (EC) proposed the full legislative package on waste aimed at achieving huger harmonization and simplification of the legal framework on by-products and end-of-waste status (Scarlat et al. 2019). The waste legislative package revised the Waste Framework Directive (2008/98/EC) stressing the circular nature of bioplastics and the potential of bio-based compostable plastic packaging to foster an EU circular economy (Briassoulis 2019). The main objective of a circular economy is to have minimal input and production of system "waste" by redesigning the life cycle of the "product" (Biancolillo et al. 2019). In this context, the role of bioplastics to minimize the environmental and climate impacts of petroleum-derived plastic packaging and in reducing the dependence of EU member countries on imported raw materials was emphasized (Fornabaios et al. 2019). In other words, the EU legislators recognized that bio-based and recycled materials can play a key role in the transition from the "linear economy" to a "circular economy" paradigm in Europe by replacing fossil fuels with renewable resources and by increasing reusing and recycling (Hetemäki et al. 2020; Tamantini et al. 2021).

From a terminological point of view, plastic material can be defined as bioplastic if it is bio-based, biodegradable or if it has both properties (European Bioplastics 2020). Based on the EU Standard EN 16575 (2014), bio-based products are products wholly or partly derived from biomass – materials of biological origin such as sugar cane, starch from maize or potatoes, cellulose and plant oil – through a physical, chemical or biological treatment of the biomass itself. Among the various feedstocks available, wood-based biomass is an important source for producing bio-based plastics in forest biorefineries (Kangas et al. 2011). Forest biorefineries can use multiple feedstocks – such as pulpwood, harvesting wood residues, recycled paper and industrial wastes – in order to produce both low value-high volume and high value-low volume products (Näyhä et al. 2014). In the diversification of the product portfolio related to the opportunities provided by forest biorefineries, bio-based plastics are among the most attractive options due to the growing demand for these products (Biancolillo et al. 2019). In fact, in bio-based plastics are included bio-based polypropylene (PP), and polyethylene terephthalate (PET) (De Marchi et al. 2020). Biodegradability (or compostability) can be defined as the inherent ability of a material to decompose under microbiological activity into naturally occurring substances, for example, CO_2 and water (Lucas et al. 2008). Polybutylene adipate terephthalate (PBAT) is included in biodegradable but not bio-based plastics, while some bioplastics even possess both characteristics such as polylactic acid (PLA) (Jiménez et al. 2019). This crucial distinction between bio-based and biodegradable plastics, also as environmental impacts and benefits, is not always perceived by consumers (Ansink et al. 2022).

Currently, the bioplastics market represents one of the fastest growing markets; IFBB (2019) estimated the average growth in 2023 compared to 2018 at 72.8% for biodegradable and 62.4% for bio-based plastics. This growth trend should lead to a production capacity of 1.8 million t for biodegradable plastics and 2.6 million t for bio-based plastics in 2023 (Döhler et al. 2020). Bioplastics can be used in several industrial processes, mostly packaging, but also in electronics, agriculture, medical and health applications, toys and automotive. However, currently, the global production of bioplastics still consists of less than 1% of total plastics production worldwide, and therefore it can be considered a niche market (European Bioplastics 2020). High prices, low availability, poor marketing activities, and lack of product information are the main obstacles to the demand increase for bioplastics products (Iles, Martin 2013; Lettner et al. 2017).

In the international literature, studies mainly focused on bioplastic product development and environmental impact (Tsiropoulos et al. 2015; Koch, Mihalyi 2018; Benavides et al. 2020; Atiwesh et al. 2021), while few studies focused on consumers' perspectives and opinions towards some specific bioplastic products (Lynch et al. 2017; Scherer et al. 2018; Ketelsen et al. 2020; Klein et al. 2020). To overcome this knowledge gap, the objective of this study is to investigate consumers' attitudes and behaviours towards bioplastics. From a theoretical point of view, the study was developed following the principles of the theory of planned behaviour (TPB) by Ajzen (1985). The premise of the TPB – an attitude-behaviour relationship model able to predict and explain consumer behaviour (Ajzen 1993) – is that behavioural decisions are not made spontaneously but are influenced by attitudes, norms, and perceptions of control over the behaviour. According to this theory, attitude, subjective norms, and perceived behavioural control influence behaviour primarily through their impact on behavioural intention (Smith et al.

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2008). In environmental issues, interest in the TPB theory has grown (Grilli, Notaro, 2019) as it has proved adequate for the explanation of environmentally friendly behaviors (e.g. Kaiser, Scheuthle 2003; López-Mosquera, Sánchez 2012). From a practical point of view, the attitude-behaviour relationship can be measured through the principle of compatibility so defined by Ajzen and Fishbein (1977): verbal and non-verbal indicators of a given attitude are compatible with each other to the extent that their action is assessed at identical levels of generality or specificity. Taking into account these principles and practical aspects, the research questions analysed within this study are the following: How do consumers value different environmental and non-environmental characteristics of bioplastic products? What are the most important behavioural factors influencing consumer choices toward bioplastics? Could the socio-demographic characteristics of consumers influence preferences for bioplastics?

MATERIAL AND METHODS

Consumer behaviours and attitudes towards bioplastics were analysed using the same questionnaire that Notaro et al. (2022) employed to estimate hypothetical willingness to pay (WTP) for different selected characteristics of two bioplastic products. The questionnaire was administered online to a sample of consumers in Italy. A preliminary version of the questionnaire was pre-tested through in-depth face-to-face interviews with 10 consumers to verify its accuracy and adequacy.

The questionnaire was arranged in four thematic parts, but this paper focuses only on the three parts concerning the key aspects related to the TPB: the first investigated the knowledge and attitudes of respondents towards bioplastics and their environmental and non-environmental characteristics (e.g. technical properties, origin and type of raw material, climate impacts of the production process), the second focused on consumer buying behaviour, while the third considered the socio-demographic characteristics of the respondents. In the preliminary part of the questionnaire, the concept of bio-based and biodegradable plastics was introduced and explained with special regard to the possible feedstocks used to produce them such as potato starch and wood residues. The first group of questions (from Q1 to Q4) focused on consumers' previous experience and familiarity with the concept of bioplastics. To this end, in the first question (Q1) consumers indicated whether they had already heard of bioplastics in the past, while the second question asked whether they bought bioplastic products in the past (Q2). The next two questions investigated the reasons for the past purchase (Q3) or no-purchase of bioplastics (Q4) considering the set of options shown in Table 1.

The following four questions (from Q5 to Q9) focused on consumers' attitudes towards the main characteristics of bioplastic products. For each characteristic considered in the survey, the respondents assigned the degree of importance using a 5-point Likert scale format (from 1 = not at all important to 5 = extremely important). For this purpose, two environmental and three non-environmental characteristics of the bioplastics have been selected and thus described:

– bioplastics must have the same technical properties – e.g. impact resistance, durability, stiffness – as conventional plastics (PROPR);

– bioplastics must have a lower climate impact generated by the production process compared to conventional plastics (CLIM);

– bioplastics must not be produced from fossil sources and must not take 100 to 1 000 years to decompose (FOSSIL);

– bioplastics must be produced from domestic (Italian) crops rather than foreign crops (ORIGIN);

– bioplastics can be produced from organic sources (i.e. maize and potatoes) but without di-

Table 1. Reasons for purchase (Q3) or no-purchase (Q4) of bioplastic products considered in the survey

Reasons for past purchase	Reasons for past no-purchase
product quality (QUALITY)	difficulty to find bioplastic products on the market (MARKET)
convenient price (CONV)	
brand (BRAND)	difficulty to distinguish bioplastic products from non-bioplastic ones (DIFFER)
clear ecological information about bioplastics (ECOL)	
clear information about product disposal at the end of the life cycle (DISPOS)	too high costs of bioplastics (EXPEN)
impact on human health (HEALTH)	I am not interested in bioplastics (INTER)
impact on environment (ENVIRON)	–

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minishing the availability of these sources for food use. In other words, there must be no trade-off between bioplastics production and food production (FOOD).

In the second part of the questionnaire, the three behavioural factors of the TPB were considered and thus defined (Cialdini et al. 1991; Smith et al. 2008; Chen et al. 2020): (*i*) purchase intentions (the tendency, plan, desire and possibility of buying a product or service), (*ii*) perceived behavioural control (the perceived control over the performance of the behaviour which can have a direct effect on behaviour and an indirect effect via intention), and (*iii*) subjective norm (the perceived social pressures from family, partners, friends to perform the behaviour). In particular, the consumers expressed their level of agreement or disagreement with certain statements using a 5-point Likert scale format (from 1 = strongly disagree to 5 = strongly agree). Questions Q10 and Q11 focused on the general purchasing intentions of consumers (PI) considering two key aspects in accordance with the method proposed by Klein et al. (2019): (*i*) the option to pay more attention to bioplastic products in the future purchasing decisions (FUTUR); (*ii*) the option to choose a plastic product made of renewable raw materials rather than a plastic product made of conventional raw materials (e.g. petroleum) (RENEW).

The following three questions (from Q12 to Q14) described respondents' control over the perceived cost of bioplastic products (CPC) based on some key aspects formulated by Ajzen (1991) and Maloney et al. (2014) and thus synthesizable:

– I can afford to buy bioplastic products (AFFORD);

– I am willing to pay a higher price for a bioplastic product (WTP);

– if the cost of bioplastic products was the same as the cost of a conventional plastic product, I would be more likely to buy the bioplastic one (COSTS).

The last question of the second part (Q15) considered consumers' subjective norms (SN) through the following statement (Ajzen 1991; Klein et al. 2019): "People close to me (partners, children, parents, friends) expect me to buy products made of bioplastics rather than of petroleum-based plastics".

Finally, the third part of the questionnaire focused on personal information of respondents such as gender, age (considering six age classes: less than 25 years old, 25–34, 35–44, 45–54, 55–64, and more than 64 years old), annual income (distinguishing among seven classes: no income, less than EUR 10 000, EUR 10 000–19 999, EUR 20 000–29 999, EUR 30 000–39 999, EUR 40 000–60 000, more than EUR 60 000, and degree of education (distinguishing among elementary/middle school degree, high school degree, university/post-university school degree).

During the second phase of this study, the data was collected through a web-based survey targeting Italian consumers aged 18 years and more. The questionnaire was written in the Italian language and developed using the EUSurvey platform. From November 2020 to January 2021, the final version of the questionnaire was distributed following the method proposed by Yao et al. (2019). Specially, a snowball sampling method was applied using a preliminary list of names provided by many public institutions and private organizations located throughout Italy. Then, the questionnaire link was posted to several social network sites (e.g. Facebook, Twitter, LinkedIn) to further recruit respondents from non-institutional and private organizations.

In the last phase, the collected data were processed to produce the main descriptive statistics (mean, median and standard deviation) for the data collected using the Likert scale format, percentage of frequency distribution (%) for Q1. Besides, for questions from Q2 to Q11 the non-parametric Kruskal-Wallis and Mann-Whitney tests were performed using the XLStat 2020 software (Version BASIC, 2020). The non-parametric tests were applied rather than the parametric tests because the assumption of normality was violated (Shapiro-Wilk test: $P < 0.0001$, $\alpha = 0.01$; Anderson-Darling test: $P < 0.0001$, $\alpha = 0.01$).

The Kruskal-Wallis test ($\alpha = 0.01$) was used for data collected through a Likert scale format with the aim to underline differences between three or more groups of respondents with different socio-demographic characteristics (age, degree of education, income).

The Mann-Whitney test ($\alpha = 0.01$) was used through a Likert scale format with the aim to highlight differences between two groups of respondents with different socio-demographic characteristics (gender).

Finally, the chi-square (χ^2) test was applied to analyse the group differences when the depen-

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dent variable is measured at a nominal level like our questions about the reasons for purchase or non-purchase of bioplastic products (Q3 and Q4).

RESULTS

Socio-demographic characteristics of consumers. A total of 1 296 Italian consumers opened the questionnaire link and 1 115 of them completed the survey (dropout rate in the compilation of 14.0%).

The sample is mainly composed of females (67.8% of total respondents), while the remaining 32.2% are males. In the sample, people under the age of 34 (50%) and between the ages of 35 and 54 (31%) prevail, as well as well-educated people (64.3% have a university or post-university degree). With regard to the annual income, the majority of respondents have an annual income between EUR 20 000 and 39 999 (33.2%), but it is interesting to emphasize that 26.3% of total respondents have no income because they are mainly university students.

Characteristics of bioplastics. The results show that 81.6% of respondents declared that they had heard of bioplastics in the past, while 18.4% had never heard of these products. Especially, males have slightly higher knowledge of bioplastics compared to females as well as people over 64 years old compared to the other age classes. Conversely, the results show that the degree of education does not influence the level of knowledge of bioplastics: 83.3% of respondents with an elementary/middle school degree heard of bioplastics before, compared to 78.9% of respondents with a high school degree, and 82.2% with a university/post-university degree.

The results point out that 76.3% of respondents bought bioplastics in the past (11.5% of consumers often bought these products, 56.7% sometimes, and 8.1% once), while the remaining 23.7% of respondents have never bought bioplastic products despite knowing them.

Therefore, the results highlight that our sample of consumers has a high level of knowledge of bioplastics both from a theoretical (heard/read about bioplastics) and practical (purchased bioplastics) point of view.

The results about the reasons that led to the purchase of bioplastics show the following order of priority (Figure 1): impacts on the environment (ENVIRON), impacts on human health (HEALTH), clear ecological information about bioplastics

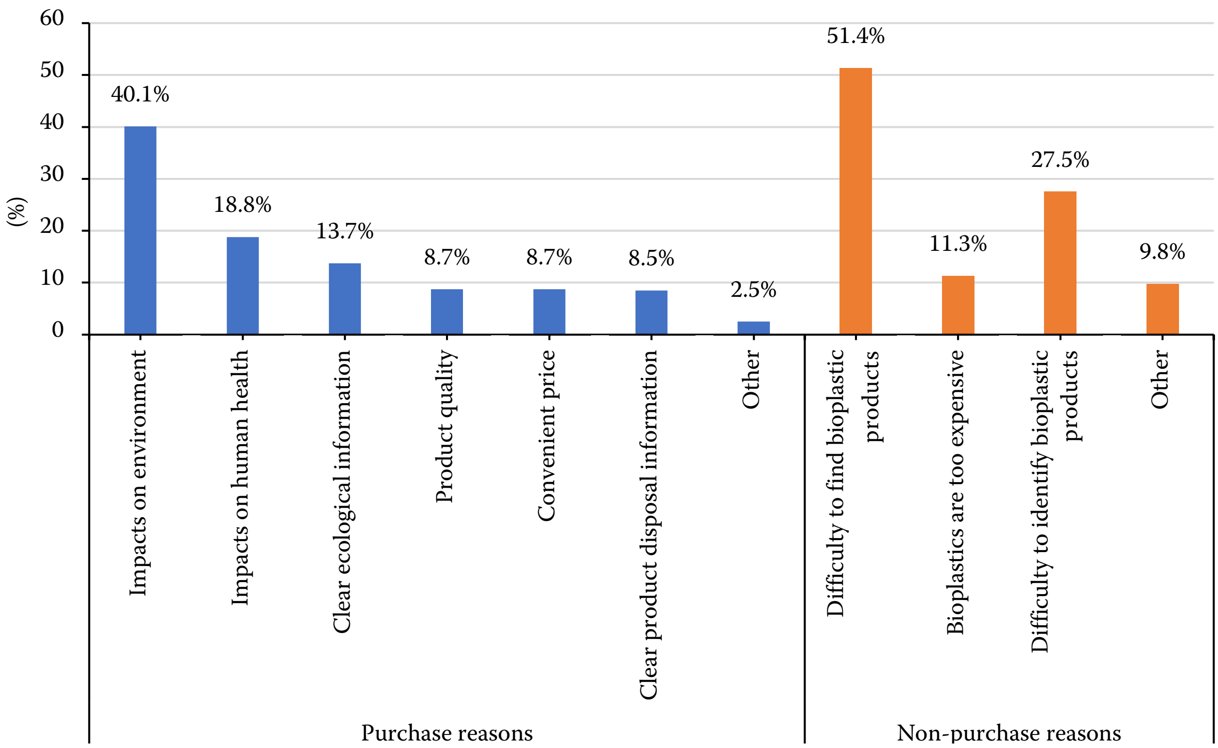

Figure 1. Importance of the reasons for purchasing or no purchasing bioplastic products (% of respondents)

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(ECOL), product quality (QUALITY), convenient price (CONV), and clear information about product disposal at the end of the life cycle (DISPOS). Accordingly, there is consumer awareness of the negative impacts of petroleum-derived plastics on both the environment and human health compared to bio-based and biodegradable plastics.

Regarding the reasons why bioplastic products were not purchased, the most important are as follows (Figure 1): difficulty to find bioplastic products on the market (MARKET), difficulty to distinguish bioplastic products from non-bioplastic ones (DIFFER), and bioplastic products are too expensive compared to conventional plastics (EXPEN), while 9.8% of respondents indicated other reasons among which none exceeds 1%. These results show that only a minority of respondents report the higher cost of bioplastics compared to conventional plastics as a reason for the no-purchase of these more sustainable products. Conversely, the importance of making more information on the quality of bioplastic products and the environmental impacts available for consumers are two key aspects highlighted by our results. In particular, it is of key importance to be able to find and easily recognize bio-based and biodegradable plastics from conventional ones. The label of bioplastic products must summarize the main characteristics such as the type and origin of raw material used, and possibly the time of biodegradability.

Observing the data by socio-demographic characteristics, the results show that the females assigned higher importance to ENVIRON and HEALTH compared to the males within purchase reasons. Conversely, males emphasized two other reasons more than females: CONV and QUALITY. Regarding the no-purchase reasons, females highlighted more than males the importance of MARKET, while males emphasized more than females the importance of DIFFER. However, the χ^2 test did not show any statistically significant differences between males and females both for purchase (P = 0.943) and no-purchase (P = 0.837) reasons. With regard to age, the results highlight that young people less than 25 years old assigned higher importance among the reasons for purchasing bioplastic products to ECOL compared to the other age classes. Instead, older people more than 64 years old emphasized more than young people the importance of QUALITY and DISPOS. Even for age, the χ^2 test did not show any statistically significant differences between age classes for pur-

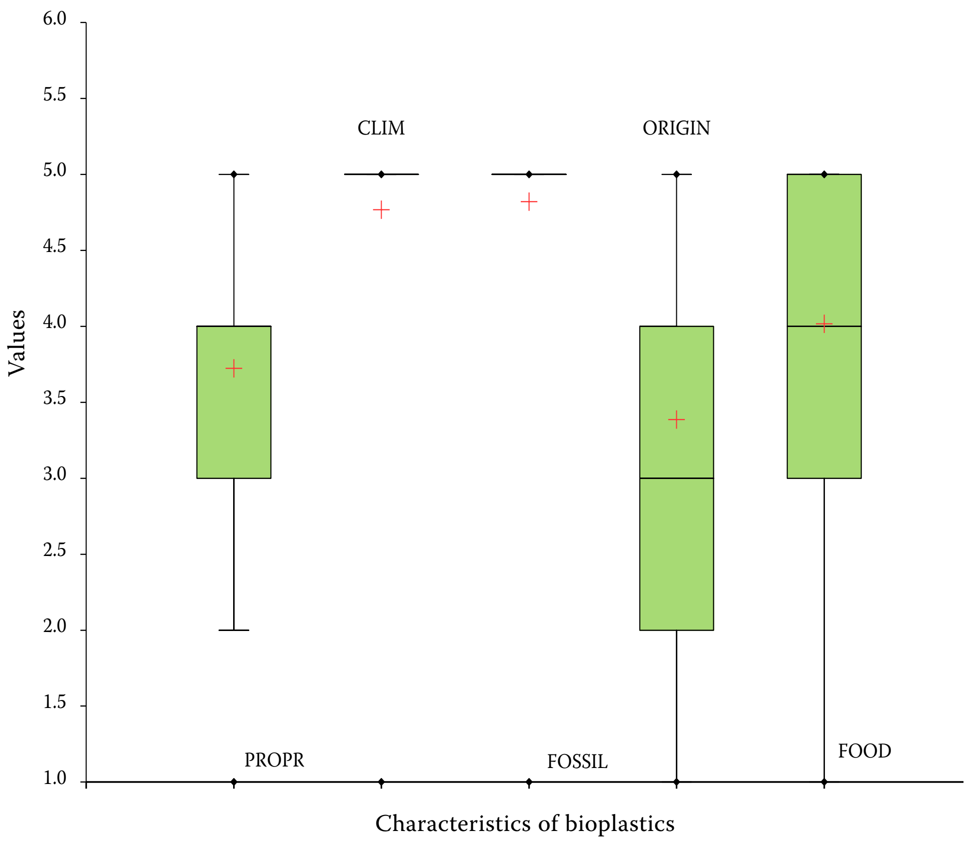

Figure 2. Box-plots for the importance of the characteristics of bioplastics

PROPR –technical properties; CLIM – lower climate impact; FOSSIL – not produced from non-renewable sources; ORIGIN– produced from domestic crops; FOOD – not produced using sources for food purpose

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chase reasons (P = 0.873), while there were statistically significant differences between age classes for non-purchase reasons (P = 0.001). Within the reasons for bioplastics purchase, the results highlight that respondents with a low level of education emphasize more the importance of ENVIRON than respondents with a high level of education. Within the reasons for the non-purchase of bioplastics, it is interesting to highlight that respondents with a high level of education assigned higher importance to QUALITY and MARKET compared to the others. Conversely, respondents with a low level of education assigned higher importance to DIFFER. However, the χ^2 test did not show any statistically significant differences between respondents with different levels of education either for purchase (P = 0.828) or no-purchase reasons (P = 0.554).

The environmental characteristics of bioplastics (FOSSIL and CLIM) have higher average importance to consumers than the non-environmental characteristics (FOOD, ORIGIN and PROPR). In particular, 86.2% of respondents declared that it is really important that bioplastics will not be produced from non-renewable sources and will not require long decomposition times (FOSSIL), and most respondents (82.2%) think that it is very relevant that bioplastics have a much lower impact on climate change than petroleum-derived plastics (CLIM). The results show the following mean values for the first two factors (Figure 2): FOSSIL and CLIM. In addition, the results highlight that the origin of raw material used to produce bioplastics (ORIGIN) has the lowest mean value of all other characteristics.

Considering the respondents' characteristics (Table 2), the results show that females assigned higher importance to all characteristics of bioplastics than males except for the technical properties of bioplastics compared to conventional plastics (PROPR). However, the Mann-Whitney non-parametric

Table 2. Importance assigned to the characteristics of bioplastics by consumers

Socio-demographic characteristics	PROPR	CLIM	FOSSIL	ORIGIN	FOOD
Gender					
Male	**3.80 ± 0.98**	4.70 ± 0.72	4.77 ± 0.62	3.19 ± 1.19	3.98 ± 0.96
Female	3.69 ± 0.95	**4.78 ± 0.51**	**4.84 ± 0.45**	**3.50 ± 1.17**	**4.03 ± 0.92**
Age (years)					
< 25	3.83 ± 0.87	4.76 ± 0.63	4.75 ± 0.63	3.24 ± 1.17	3.90 ± 0.92
25–34	3.77 ± 0.96	4.72 ± 0.60	4.80 ± 0.53	3.26 ± 1.16	3.89 ± 0.95
35–44	**3.87 ± 0.89**	4.79 ± 0.52	4.83 ± 0.49	3.39 ± 1.29	4.14 ± 0.92
45–54	3.60 ± 0.98	4.75 ± 0.56	4.84 ± 0.47	3.62 ± 1.12	4.11 ± 0.94
55–64	3.64 ± 1.08	4.80 ± 0.60	4.90 ± 0.36	3.55 ± 1.22	**4.26 ± 0.81**
> 64	3.42 ± 1.03	**4.83 ± 0.56**	**4.92 ± 0.28**	**3.69 ± 1.09**	3.83 ± 1.02
Degree of education					
Elementary/middle school degree	3.56 ± 1.17	4.54 ± 0.91	4.59 ± 0.85	**3.69 ± 1.06**	3.95 ± 0.97
High school degree	3.72 ± 0.99	4.72 ± 0.65	**4.83 ± 0.51**	3.60 ± 1.19	**4.11 ± 0.92**
University/post university degree	**3.74 ± 0.94**	**4.79 ± 0.53**	4.82 ± 0.48	3.29 ± 1.18	3.97 ± 0.93
Income (EUR)					
No income	3.84 ± 0.88	4.77 ± 0.55	4.79 ± 0.52	3.24 ± 1.19	3.93 ± 0.91
< 10 000	3.68 ± 0.93	4.75 ± 0.57	4.82 ± 0.50	3.37 ± 1.08	3.89 ± 0.95
10 000–19 999	3.61 ± 0.97	4.73 ± 0.64	4.74 ± 0.67	3.57 ± 1.22	4.12 ± 0.93
20 000–29 999	3.67 ± 1.01	4.77 ± 0.51	4.85 ± 0.44	3.47 ± 1.22	4.02 ± 0.94
30 000–39 999	3.77 ± 1.03	4.73 ± 0.71	4.84 ± 0.47	3.31 ± 1.12	4.06 ± 0.98
40 000–60 000	3.74 ± 1.03	**4.87 ± 0.40**	**4.94 ± 0.24**	**3.61 ± 1.13**	**4.18 ± 0.85**
> 60 000	**3.94 ± 0.93**	4.55 ± 0.96	4.77 ± 0.50	3.32 ± 1.28	4.13 ± 0.85

Bold – the highest value for each factor; PROPR –technical properties; CLIM – lower climate impact; FOSSIL – not produced from non-renewable sources; ORIGIN – produced from domestic crops; FOOD – not produced using sources for food purpose

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test shows statistically significant differences only for one of all characteristics of bioplastics: ORIGIN ($P < 0.0001$).

With regard to age, the results highlight that older respondents assigned higher importance to three of the four characteristics of bioplastics compared to the other age classes: CLIM, FOSSIL, and ORIGIN. Contrariwise, for technical properties of bioplastics (PROPR) the highest values are assigned by the respondents between 35 and 44 years of age, while for the impact on food availability (FOOD) they are assigned by the respondents between 55 and 64 years of age. Also, it is interesting to highlight that young people assigned less importance than other age classes to two of the five characteristics of bioplastics: FOSSIL and ORIGIN. The Kruskal-Wallis non-parametric test shows statistically significant differences only for two non-environmental characteristics: ORIGIN ($P = 0.0004$) and FOOD ($P < 0.0001$).

Regarding the degree of respondents' education, the results show that two characteristics of bioplastics (PROPR and CLIM) are considered more important by respondents with a higher degree of education (university/post-university degree) compared to those with a lower degree of education. Conversely, respondents with an elementary/middle school degree attached more importance to the Italian origin of raw materials (ORIGIN) compared to the other groups of respondents. However, the Kruskal-Wallis non-parametric test shows statistically significant differences only for the geographical origin of raw material – ORIGIN ($P = 0.0003$), while there are no statistically significant differences for the other characteristics.

Taking into account the income of respondents, the results evidence that people with the highest annual income (between EUR 40 000 and 60 000, and more than EUR 60 000) emphasized more than other income classes the importance of all characteristics of bioplastics, but with limited differences. For this reason, the Kruskal-Wallis non-parametric test shows no statistically significant differences for all characteristics considered in the survey.

Behavioural factors. The results of the behavioural factors are shown in Figure 3. Purchase intentions (PI) are characterized by the highest mean value, followed by control on perceived cost (CPC) and subjective norm (SN). In particular, in the PI both sub-factors have a similar level of importance (FUTUR and RENEW), while for the CPC, the results show that the most important sub-factor is related to the costs of bioplastics compared to the conventional plastics (COSTS), while the other two sub-factors are considered less important (WTP and AFFORD).

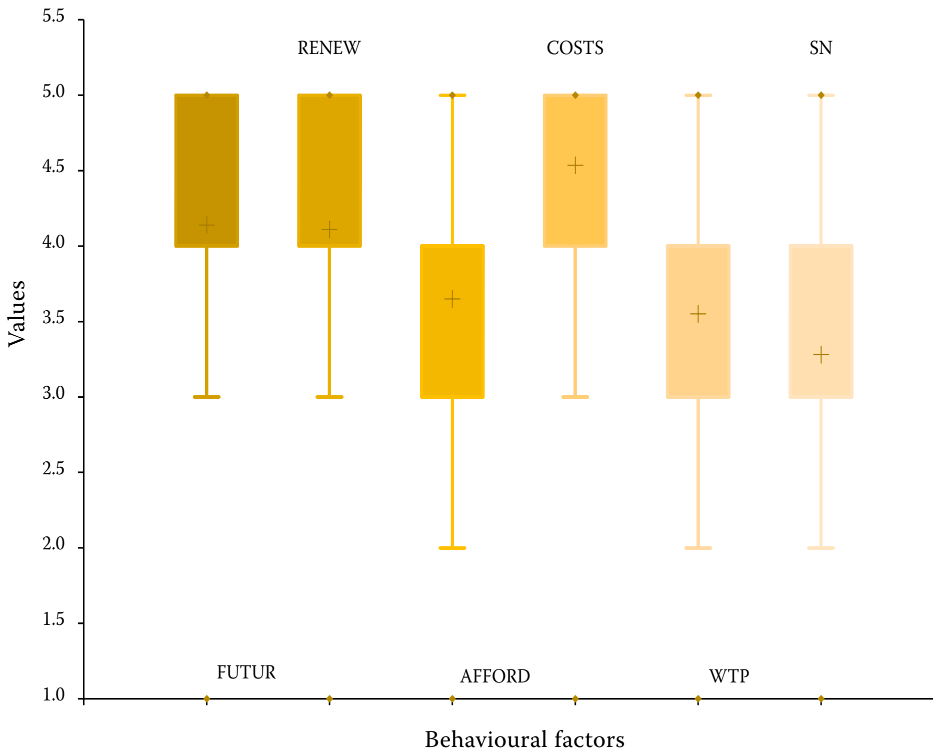

Figure 3. Box-plots for the behaviour factors related bioplastics

SN – subjective norms; FUTUR – future purchasing decisions; RENEW – plastic product made of renewable raw materials; AFFORD – afford to buy bioplastic products; WTP – willing to pay a higher price for a bioplastic product; COSTS – cost of bioplastic products

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The results show that socio-demographics influence the purchasing behaviour of consumers (Table 3). Females seem to have higher purchase intentions (PI) than males as confirmed from the statistical point of view by the non-parametric Mann-Whitney test ($P = 0.0037$). Older generations stated higher values for all three behavioural factors. Especially, people over 64 years old assigned higher importance to two CPC sub-factors (AFFORD and WTP) and one PI sub-factor (RENEW) compared to the other five age classes. Moreover, it is interesting to emphasize that people under 24 years old assigned particularly low importance to SN. The non-parametric Kruskal-Wallis test confirmed that there are statistically significant differences between the six age classes in five of the six sub-factors: FUTUR ($P < 0.0001$), RENEW ($P = 0.001$), AFFORD ($P < 0.0001$), WTP ($P = 0.001$), and SN ($P < 0.0001$).

With regard to the degree of respondents' education, the results show that people with an elementary/middle school degree stated higher SN, while CPC and PI are higher for people with a high school degree. In particular, the latter group of respondents emphasizes three sub-factors more than the other groups: FUTUR, WTP, and COSTS. However, the non-parametric Kruskal-Wallis test showed statistically significant differences between respondents with different degrees of education only in three sub-factors: AFFORD ($P < 0.0001$), WTP ($P < 0.0001$), SN ($P < 0.0001$).

Finally, consumers with lower income showed a lower level of agreement with all three behav-

Table 3. Importance assigned to the behavioural factors by consumers

Socio-demographic characteristics	PI		CPC			SN
	FUTUR	RENEW	AFFORD	WTP	COSTS	
Gender						
Male	4.03 ± 0.69	4.03 ± 0.80	**3.69 ± 0.81**	3.52 ± 0.82	4.47 ± 0.82	3.26 ± 1.00
Female	4.19 ± 0.63	4.15 ± 0.70	3.57 ± 0.83	**3.55 ± 0.80**	**4.57 ± 0.72**	**3.27 ± 0.93**
Age (years)						
< 25	4.03 ± 0.71	4.06 ± 0.80	3.50 ± 0.87	3.42 ± 0.83	4.59 ± 0.68	2.92 ± 0.96
25–34	4.07 ± 0.64	4.04 ± 0.74	3.35 ± 0.90	3.47 ± 0.82	4.53 ± 0.76	3.02 ± 0.96
35–44	4.24 ± 0.67	4.05 ± 0.76	3.73 ± 0.76	3.56 ± 0.75	4.58 ± 0.78	3.21 ± 0.81
45–54	4.19 ± 0.64	4.12 ± 0.69	3.67 ± 0.74	3.56 ± 0.81	4.49 ± 0.83	3.51 ± 0.85
55–64	**4.27 ± 0.52**	4.27 ± 0.66	3.95 ± 0.65	3.74 ± 0.70	**4.58 ± 0.68**	3.79 ± 0.78
> 64	4.23 ± 0.75	**4.44 ± 0.62**	**4.00 ± 0.55**	**3.79 ± 0.77**	4.35 ± 0.86	3.85 ± 0.88
Degree of education						
Elementary/middle school degree	4.03 ± 0.81	**4.13 ± 0.66**	**3.67 ± 0.93**	3.41 ± 0.82	4.26 ± 1.02	**3.59 ± 0.97**
High school degree	4.16 ± 0.65	4.13 ± 0.76	3.64 ± 0.80	**3.56 ± 0.84**	**4.54 ± 0.73**	3.36 ± 1.00
University/post university degree	4.05 ± 0.65	4.09 ± 0.74	3.61 ± 0.82	3.54 ± 0.82	4.48 ± 0.80	3.21 ± 0.88
Income (EUR)						
No income	4.06 ± 0.66	4.04 ± 0.76	3.42 ± 0.91	3.45 ± 0.82	4.58 ± 0.72	2.93 ± 0.95
< 10 000	4.09 ± 0.62	4.09 ± 0.78	3.35 ± 0.77	3.44 ± 0.78	4.56 ± 0.69	3.16 ± 0.89
10 000–19 999	4.07 ± 0.74	4.09 ± 0.74	3.55 ± 0.86	3.45 ± 0.84	4.37 ± 0.88	3.31 ± 1.00
20 000–29 999	4.23 ± 0.62	4.12 ± 0.74	3.70 ± 0.76	3.55 ± 0.81	4.56 ± 0.73	3.38 ± 0.90
30 000–39 999	4.16 ± 0.66	4.18 ± 0.67	3.80 ± 0.72	3.70 ± 0.69	**4.63 ± 0.70**	3.50 ± 0.91
40 000–60 000	4.29 ± 0.51	**4.29 ± 0.57**	4.09 ± 0.57	**3.85 ± 0.65**	4.58 ± 0.73	**3.69 ± 0.82**
> 60 000	**4.32 ± 0.60**	4.19 ± 0.91	**4.10 ± 0.60**	3.74 ± 0.93	4.55 ± 0.77	3.58 ± 0.89

Bold – the highest value for each factor; PI – purchase intentions; CPC – control on perceived cost; SN – subjective norms; FUTUR – future purchasing decisions; RENEW – plastic product made of renewable raw materials; AFFORD – afford to buy bioplastic products; WTP – willing to pay a higher price for a bioplastic product; COSTS – cost of bioplastic products

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ioural factors (PI, CPC, and SN), but the non-parametric Kruskal-Wallis test revealed statistically significant differences only in CPC ($P < 0.0001$) and SN ($P < 0.0001$).

DISCUSSION

The present study provides a preliminary overview of the behavioural factors that influence the purchasing decisions toward bioplastics based on the responses of a sample of Italian consumers. Our sample of respondents is mainly composed of females (67.8% of the total) as well as the distribution at the national level but with more marked differences (Istituto Nazionale di Statistica 2021): 51.8% of females and 48.2% of males. With regard to age, our sample has a higher percentage of young respondents and a lower percentage of older respondents compared to the Italian population characterized by 8.2% of people between 18 and 24 years old and 27.6% over 64 years old. In addition, our sample is overrepresented by people with a university degree (17.9% of the Italian population), while it is underrepresented by people with an elementary/middle school degree (38.7%) (Istituto Nazionale di Statistica 2021).

The results point out that the most important characteristics of bioplastics for our sample of consumers are related to the environmental aspects of the product. First of all, a bioplastic product must be produced from renewable resources (e.g. wood, algae, maize, sugar cane) rather than from non-renewable sources (e.g. petroleum), and it must be produced with a low impact on climate change. This result is congruent with the international literature which shows a reduction from –50% to –70% of GHG emissions in the use of PLA rather than conventional petroleum-derived plastics (Atiwesh et al. 2021), while other studies highlighted that substituting maize-based PLA bioplastics for conventional petroleum-derived plastics can reduce GHG emissions by 25% (Sabbah, Porta 2017). Therefore, these two environmental characteristics of bioplastics are closely interrelated. Our results show that consumers are aware of the importance of using renewable resources rather than fossil fuels also with the aim to reduce the negative impacts of the production process on climate. This is in line with the findings of other researchers on consumer preferences for products with low carbon emissions (Yue et al. 2010; Scherer et al. 2017; De Marchi et al. 2020). In summary, we can assert that the majority of consumers would shift their choices from conventional plastics to bioplastics mainly for environmental reasons related to climate change. Conversely, the other three characteristics of bioplastics evaluated in this study – technical properties, the origin of raw material, the trade-off between food and bioplastics production – are considered less important by our sample of consumers. Particularly, technical properties do not have a direct effect on environmental and climate impacts, but they are linked to the intrinsic characteristics of the product influenced by the type of raw material (Kadtuji et al. 2021). Contrariwise, the importance of the origin of raw material used for bioplastics production is related to two aspects: the first one is due to a greater trust in domestic products than in those of foreign origin, while the second one includes environmental reasons due to the greater environmental and climate impacts of the transport phase compared to the other production phases. With regard to the first aspect, consumer preferences for foreign and domestic products could be influenced by trust in foreign firms and consumer ethnocentrism (Kaynak, Kara 2002; Jiménez, San Martín 2010). Trust in firms is related to their country-of-origin reputation to manufacture goods with specific characteristics, while consumer ethnocentrism is a belief held by consumers in the appropriateness and indeed morality of purchasing foreign-made products (Shimp, Sharma 1987). The combination of these two aspects can induce consumers to prefer domestic products rather than foreign products in particular low-cost products produced by low-reputation countries such as plastic products. Regarding the second aspect, many studies have emphasized the high environmental impacts of the transport phase in the production process due to the long distances travelled (Manfredi, Vignali 2014; Notaro, Paletto 2021). For this reason, environmentally friendly consumer preferences are directed towards local or national products characterized by limited travel distances.

Other international studies have pointed out comparable results with those provided by our study. In a study carried out in the Netherlands, Lynch et al. (2017) showed that consumers prefer bioplastics rather than fossil fuel plastics because they believe that these biomaterials have a more positive impact on the environment and that pur-

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chasing bioplastic products contributes to a green lifestyle. In a choice-based conjoint analysis conducted in Germany, Scherer et al. (2018) highlighted a consumer preference for a bio-based plastic bottle and running shoes with a biopolymer sole compared to conventional plastics. Those authors also showed that the origin of the raw materials (i.e. cultivated in Germany) was the most important factor in purchasing choices (Scherer et al. 2018). In another more recent study carried out in Germany, Klein et al. (2020) found that consumers with no previous experience with bio-based products preferred not to purchase the bio-based product. The results provided by those authors suggested that consumer "green" values and attitudes toward bioplastics are influencing factors for purchasing decisions. Again with reference to the German context, Rumm (2016) analysed consumer preferences for bio-based shopping bags and disposable cups highlighting that the reduction of the dependence on crude oil and carbon dioxide emissions of bio-based alternatives over the production of conventional plastics was a particularly positive aspect during the purchasing decision process. With regard to the information to be provided on bioplastics to consumers, Kainz et al. (2013) highlighted that for German consumers the most important types of information concerning bioplastics are: the type and origin of raw material used to produce them (43% of total respondents) and the effects of bioplastics on environment and climate (36%). Conversely, other types of information – such as areas of application (24%), price (16%), and product characteristics (7%) – are considered less important by the sample of consumers involved in that study. In another study conducted in Italy, Banterle et al. (2012) showed that consumers emphasized the lack of information on sustainability, recyclability and reusability of packaging, noting that they would be interested in having such additional information about the environmental characteristics of these products.

The present study also reveals the importance of the behavioural factors influencing consumers' purchasing decisions toward bioplastics. From this point of view, our results are consistent with the TPB by Ajzen (1985, 1993), who highlighted that positive behavioural intentions increase the probability of carrying out the actual behaviour. In the international literature, other studies investigated drivers of purchase intentions and purchasing behaviour towards bio-based and environmentally friendly products. In accordance with the theoretical principles of TPB, the results of those studies confirmed that for consumers the most important influencing factors are: purchase intentions (Osburg 2016), attitudes towards bioplastics, including the reduction of environmental and climate impacts (Osburg 2016; Scherer et al. 2017), perceived control (Maloney et al. 2014; Osburg 2016), and subjective norm (Osburg 2016; Onwezen et al. 2017). In addition, the results of our study highlight the importance of the purchase costs of a bioplastic product compared to an equivalent conventional plastic product. A high number of consumers are willing to buy bioplastics only if the costs of these are not higher than those of conventional plastics.

Finally, some socio-demographic characteristics of respondents are shown to have a significant impact on consumer preferences. Our results show that females assigned greater importance to all environmental characteristics of bioplastics – use of renewable resources and low impacts on climate – compared to males who emphasize more the technical properties of the products than females. In the international literature, some studies have shown that females have a more positive attitude than males towards environmental protection (Hirsh 2010) and towards bioplastics purchase (Yue et al. 2010; Kainz 2016; Scherer et al. 2018). Besides, our results highlight that people with a higher degree of education assigned higher importance to the environmental characteristics of bioplastics as well as older people. With regard to the influence of consumers' age on preferences for bioplastics some international studies have highlighted conflicting results (Yue et al. 2010; Scherer et al. 2018), while in the literature a high degree of education is normally associated with environmentally friendly consumers (Finisterra do Paço et al. 2009).

Considering the potential growth of the bioplastics market in the coming decades, it is important that the forest-based sector can supply quality raw materials with low environmental impacts (Jonsson et al. 2021). To make this possible, it is first of all necessary to enhance the wood residues deriving from silvicultural interventions and from the woodworking process rather than realizing *ad hoc* plantations for woody biomass production (Schnabel et al. 2020). The valorisation of wood residues could have low environmental impacts as required by final consumers and could have competitive advantages compared to other biomass also used for

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food purposes (e.g. sugar cane, starch from maize or potatoes). The use of wood residues for the production of bio-based products would be an efficient way to economically exploit this by-product of the forest-based sector as emphasized by many authors (Tamantini et al. 2021; Paletto et al. 2022). However, this innovative use of wood residues should not decrease the availability of raw materials for traditional uses such as bioenergy production (potential trade-off between bio-based products and bioenergy production). In Italy, the results of some forecast models show a theoretical wood biomass potential capable of satisfying a growing demand for bioenergy and bio-based products in the coming decades (Panichelli, Gnansounou 2008; Sacchelli et al. 2013). Nevertheless, the wood biomass potential from forests would only be available if the price of the raw material is higher than the harvesting and transport costs to supply it.

From a methodological point of view, the main strength of this study is the large sample size (more than a thousand respondents) and the distribution of respondents by socio-demographic characteristics which permitted a comparison between different potential groups of consumers. The web-based dissemination of the survey has accelerated and facilitated the data collection compared to the other administration systems such as face-to-face, mail, and phone surveys. Instead, the main weakness of the study is related to the snowball sampling techniques used to identify potential consumers to be involved in the survey. In the snowball sampling techniques, the sample may depend on the initial contacts; therefore, it can be characterized by a potential bias. Here, an attempt was made to overcome this weakness by distributing the questionnaire link on many social networks and web pages. An additional weakness concerns the underrepresentation of some categories of respondents – people with an elementary/technical school degree and people over 64 years old – due to the administration system used. Usually, older and low-educated people are the least likely to fill in online questionnaires for a gap and mistrust in the use of new technologies.

CONCLUSION

The results provided by this study can contribute to supporting decision makers (policy makers and entrepreneurs) to address suitable strategies toward a zero-emission economy and to replace conventional petroleum-derived plastics with environmentally friendly materials (e.g. bio-based plastics). Likewise, the present study can contribute to filling up the knowledge gap on consumers' behaviours and attitudes towards bioplastic products and the key factors influencing purchasing decisions. For this reason, the results provided can be useful to increase the information on bioplastics from a consumer perspective and, consequently, to identify new marketing strategies capable of increasing the market penetration of bio-based and biodegradable plastics.

With regard to the three research questions, the results of this study highlight that consumers assign higher importance to the environmental characteristics of bioplastic products compared to the non-environmental ones. Besides, the most important behavioural factor influencing consumer choices toward bioplastics is the origin of raw materials used (renewable raw materials rather than conventional raw materials). Finally, the socio-demographic characteristics of consumers are an important explanatory factor for consumer choices. Considering bioplastic products, females and more educated people are the types of consumers most inclined towards these environmentally friendly products.

Future research could provide insights into consumers' behaviours, attitudes and preferences toward specific bioplastic products with different environmental characteristics (raw material used in the production process, bioplastics percentage, biodegradability) and investigate the importance of environmental characteristics for low, medium and high-end bioplastic products.

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Climate resilient traditional agroforestry systems in Silite district, Southern Ethiopia

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Abstract: Agroforestry is recognized as one of the strategies for climate change mitigation and adaptation under the Kyoto protocol. The system has been practiced in Ethiopia for a while by smallholder farmers by incorporating crops with trees providing extensive socio-economic and environmental benefits. This unaccounted benefit of the system needs further and specific study. Thus, this study aimed to examine the resilience of three (homegardens, woodlots, and parkland) traditional agroforestry systems (TAFS) on the basis of biomass carbon accumulation and socio-economic characteristics in Silite district, Southern Ethiopia. Systematic random sampling was employed to collect social and biological data. Height and diameter at breast height (*DBH*) were measured to determine the biomass carbon stock and a questionnaire was performed for the socio-economic data. The mean differences across the system were analyzed using a post hoc test. Socioeconomic data were analyzed using descriptive statistics and the chi-square test. Climate change awareness was perceived almost by half of the respondents, thus the contribution of TAFS to climate change adaptation and mitigation was revealed socio-economically and ecologically. Carbon stock and socio-economic benefits gained from agroforestry systems consist in a great sink of carbon and food security.

Keywords: adaptation; biomass carbon stock; climate change; mitigation

Agroforestry practice is a long-standing land use practice which incorporates woody perennials, trees, crops, herbaceous plants and/or animals either on spatial or on rotational basis (Doyle et al. 1986). Agroforestry is used in greenhouse gas (GHG) mitigation and adaptation strategies. The use of agroforestry should not create gap that would result in the conversion of forest land into agricultural land. Additionally, in agroforestry agricultural land use will remain the landowner's primary intent (Dixon 1995). Agroforestry can play a vital role in enhancing productivity and sustainability, and agroforestry systems are believed to have a high potential to contribute to climate change adaptation and mitigation. Integration of trees on farmlands minimizes environmental degradation and enhances productivity. Other than the economic contribution, carbon stock estimation in agroforestry systems (AFS) ensures the significance of the system for global carbon balance and enhances the potential of farmers in AFS expansion (Nair 2012).

Agroforestry (AF) is one of the most important land use systems since it has multiple advantages of mitigating and adapting to change. Smallhold-

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er farmers are the most vulnerable to the effect of climate change and variability. Environmental degradation and deforestation through the poor land use system and high demand for fuel wood are the major causes for the changing climate. Ethiopia has a good system of homegarden agroforestry as compared to other tropical African countries, especially grain-based cultivation and enset-based mixed cultivation are the major agricultural systems in Ethiopia. The latter system occurs in the southern part while the former is found in northern and northwestern parts of the country (Negash et al. 2013).

This study was carried out in Silite district in the southern part of Ethiopia, which was selected because of its popular and widely held agroforestry system application for a long period of time. The area dominantly includes woodlots, homegarden and parkland agroforestry systems. A homegarden agroforestry system provides the year round production of food and saleable products which are very common practices in the present study area. Enset- and coffee-based homegarden agroforestry systems are the most common ones. *Eucalyptus* dominated woodlot agroforestry is the most dominant system in the study area with high wood product provision for market and for domestic consumption as a source of fuel wood and construction material. The parkland agroforestry system is defined as areas where scattered multipurpose trees occur on farmlands as a result of farmer selection and protection. *Federbiya albida* is the most common tree species that is incorporated into parkland AFS in this study site. The species mostly takes over an inverted phenology with physiological dormancy and sheds its nitrogen rich leaves during the early rainy season (Nair 1989; ICRAF 2000). Furthermore, the shed leaves improve the soil fertility (Dangasuk et al. 2006). Thus, this study was aimed to evaluate the unaccounted contribution of agroforestry system by assessing the carbon stock amount stored on the three selected AFS in Silite district.

MATERIAL AND METHODS

Site description. The study was conducted in two selected rural kebeles, namely Balokeriso and Welay Sedest of Silite district, SNNP (Figure 1). They have a total area of 3 047.83 km^2 and are geographically located between 7°43' to 8°10'N latitude and 37°86' to 38°86'E longitude with the mean annual temperature ranging from 10.1 °C to 22.5 °C while the annual precipitation ranged from 650 mm to 1 818 mm. The targeted wereda has the altitude from 1 501 m a.s.l. to 3 500 m a.s.l. (CSA 2007).

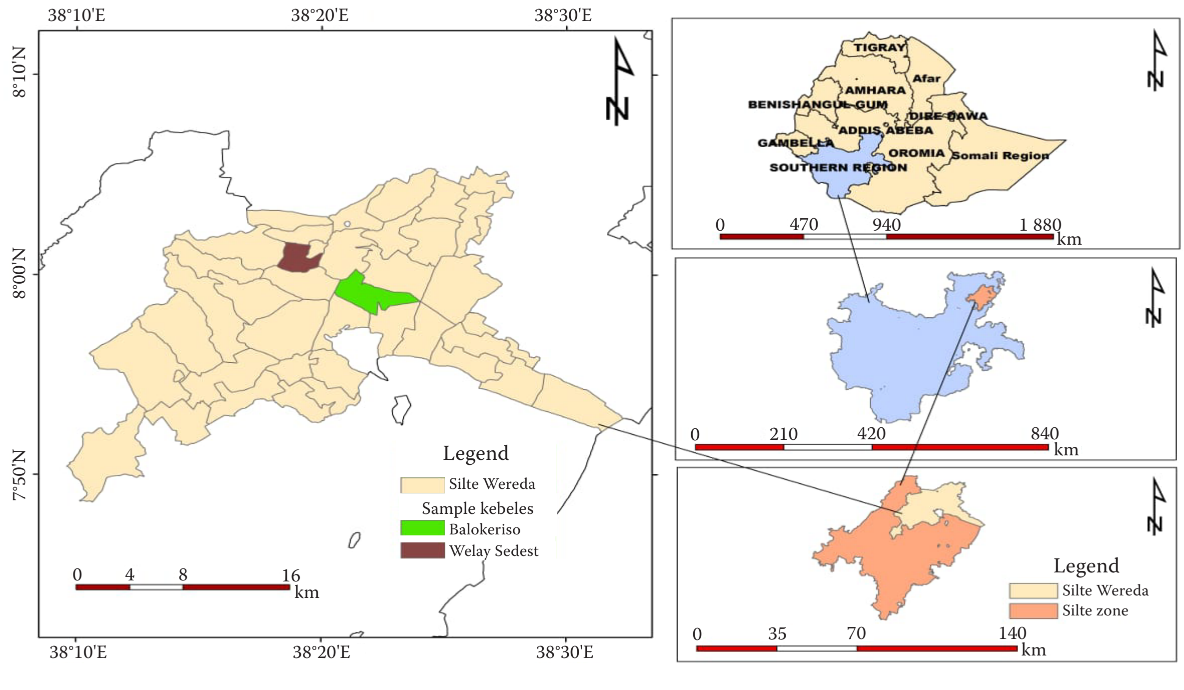

Figure 1. Map of the study site

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Landscape characteristics of the studied land use system. The selected AFSs are composed of components like staple foods, crops, fruit trees, coffee and other woody species such as *Federbiya albida* and *Eucalyptus viminalis* for parkland and homegarden AFS, respectively. Coffee, enset, fruit trees and other woody species are incorporated into homegarden AFS.

Selection of study sites and sampling size. Prior to further studies, a reconnaissance survey was done to identify a suitable study site and agroforestry system. The survey was conducted through the collection of information about agroforestry types of the targeted zone in spatial distribution, and on a rotational basis. Then Silite district in Silite zone was selected based on the aforementioned parameters. Accordingly, homegarden, parkland and woodlot AFS were identified. Two potential kebeles Welay Sedest and Balokeriso were selected. Twenty households for each AFS were selected randomly. A total of 60 farms consisting of 20 farms for each land use were randomly selected.

Data collection. Socioeconomic data were collected using systematic random sampling and the sample households were selected following the procedures of Kothari (2004) [Equation (1)]:

$$n = \frac{Z^2 \times N \times \sigma^2}{(N-1) \times e^2 + z^2 \times \sigma^2} \qquad (1)$$

where:

n – sample size;
N – population size;
e – acceptable error (the precision);
σ – population standard deviation;
Z – standardized normal deviation;
z – standard variant at a given confidence level.

For the sake of uniformity the following values will be used for calculations: e = 0.5, σ = 3 and z = 1.96 (95% confidence level).

For woody biomass inventory, sample plots were randomly laid down of 20 × 20 m in size for homegardens (Molla, Kewessa 2015), 50 × 100 m for parklands and 10 × 10 m for woodlots (Bajigo et al. 2015). Each tree within the plot was identified and recorded. Data on life forms (tree, shrub, etc.) are shown. All trees in the sample plot with diameter at breast height (*DBH* at 1.3 m) ≥ 5 cm and total tree height (*TH*) ≥ 1.5 m were measured and recorded (MacDicken 1997).

For coffee plants, stem diameter at stump height (40 cm, d_{40}) was measured in two times perpendicular to each other. For enset-based homegarden agroforestry systems, the basal diameter of the enset (at 10 cm height, d_{10}) in all enset plants one year old or older was measured and recorded (Negash et al. 2013). In the case of multi-stemmed woody species, each stem was measured separately and DBH was squared (Snowdon et al. 2002) [Equation (2)].

$$d_e = \sqrt{\sum_i^n d_i^2} \qquad (2)$$

where:

d_e – equivalent diameter (at breast or stump height);
d_i – diameter of the i^{th} stem at breast or stump height (cm).

Woody species and fruit trees incorporated within homegarden agroforestry (aboveground biomass; *AGB*) were estimated using an allometric equation [Equation (3)] developed by Kuyah et al. *(*2012) and 48% were used for carbon stock conversion.

Table 1. Adopted allometric models for biomass

Species	Allometric model		Carbon equivalent (%)
	AGB	*BGB*	
Federbiya albida	$AGB = 7.985 \times W \times 32.277$ (Larwanou 2010)	26% of *AGB* (Cairns et al. 1997)	50% (MacDicken 1997)
Eucalyptus viminalis	$AGB = 0.45X^{3.41}$ (Zewdi et al. 2009)		
Coffea arabica	$AGB = 0.147d_{40}^2$ (Negash et al. 2013)	$BGB = 0.490AGB^{0.923}$ (Kuyah et al. 2012)	49% (Negash et al. 2013)
Ensete venticosum	$\ln(AGB_{\text{enset}}) = -6.57 + 2.316\ln(d_{10}) + 0.124\ln(h)$ (Negash et al. 2013)	$BGB = 7 \times 10^{-6} \times d_{10}^{4.083}$ (Negash et al. 2013)	47% (Negash et al. 2013)

AGB – above ground biomass; *BGB* – below ground biomass; *W* – wood density; *X* – predictor variable; *d* – diameter at breast height; *h* – total tree height

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$$AGB = 0.091 \times d^{2.472} \quad (3)$$

Belowground biomass (BGB) was estimated using the global average value of 26% of aboveground biomass (Cairns et al. 1997) and 50% (default values) was used for carbon stock conversion (MacDicken 1997).

The total carbon stored in the system was estimated by Equation (4):

$$T_{BC} = T_{AGBC} + T_{BGBC} \quad (4)$$

where:

T_{BC} – total biomass carbon [Mg(C)·ha^{-1}];

T_{AGBC} – total aboveground biomass carbon [Mg(C)·ha^{-1}];

T_{BGBC} – total belowground biomass carbon [Mg(C)·ha^{-1}].

For the adopted allometric models for biomass, see Table 1.

Data analysis. The collected data was analysed using SPSS software (Version 20, 2020). The variations in biomass carbon stock among the selected agroforestry systems were examined by one-way analysis of variance (ANOVA). The mean differences across the system were analysed using a post hoc test. Socioeconomic data were analysed using descriptive statistics and chi-square test.

RESULTS

Socioeconomic characteristics of respondents. The socioeconomic characteristics of respondents included gender, age, farm size, occupation and educational level. A high proportion of male respondents was involved in the sample (73%) and the remaining respondents were females. The average age, family and land holding size of the respondents ranged between 40–42 years, 5–6 members and 0.5–0.7 ha, respectively. About 35.2% of the respondents were illiterate and the rest completed the first and second cycle. The most popular income source of the respondents is crop production; 58% of them depend only on crop production, more than 90% of them practice multiple cropping and the rest of the respondents are engaged in crop production, livestock production and agroforestry. Fertilizer application in crop production is the most certain activity which is practiced almost by all of the respondent farmers. Respondents had an average of USD 1 098.79 annual income. The majority of the farmers (40%) get their farming materials from natural forests and the rest get them from their own farmlands (25.3%) and from the local market (28.5%), the remainder obtain the materials from both the market and their own farmlands (Table 2).

Table 2. Household characteristics of the two selected kebeles

Variable	Balokeriso	Welay Sedest
No. of respondents	81	47
No. of male respondents	56 (69%)	36 (76.5%)
No. of female respondents	25 (31%)	11 (23.5%)
Average age of the respondent	40	42
Average family size	5	6
Average land holding size (ha)	0.65	0.55
Average annual family income (USD)	1 568.73	706.85

Topologies of traditional agroforestry system. The homegarden agroforestry system was the most dominant which comprises 49.3% followed by parkland and woodlot agroforestry systems which account for 43.2% and 7.5%, respectively, in Balokeriso kebele. The same trend was followed in Welay Sedest kebele which is encompassed by 44.4% of homegarden agroforestry and 37.7% and 18% of parkland and woodlot agroforestry system, respectively (Figure 2).

Importance of trees incorporated into agroforestry system. The results found that the contributions of products from trees were significantly different ($P < 0.05$) between the two kebeles. Fuel wood and tree fruit were the main products of agroforestry in the targeted kebeles for livelihood sources and household consumption. Fuel wood and fruit trees accounted for about 42% and 25% and 32% and 20% for Balokeriso and Welay Sedest kebeles, respectively (Figure 3).

Importance of trees incorporated into agroforestry system for livelihood. The farmers sustain and expand their livelihood according to climate change adaptation strategies other than AF prod-

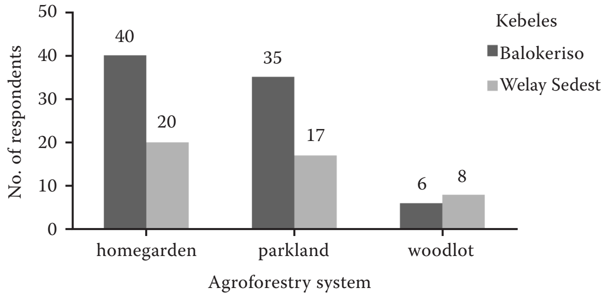

Figure 2. Types of traditional agroforestry system in two selected kebeles

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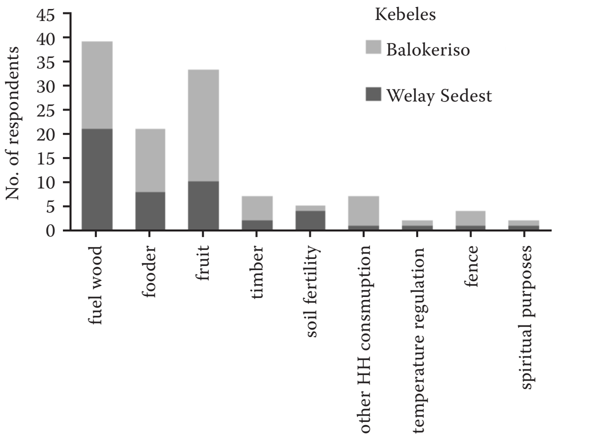

Figure 3. Importance of trees incorporated in agroforestry system for livelihood

HH – household

ucts. The farmers practiced about 8 major adaptation techniques (Figure 4). Livestock sale was amongst the first followed by off-farm activities and government aid. Others such as remittance, migration, product from AF saving are also coping mechanisms. This study also makes sure that the livelihood sources/adaptation methods listed below are basically followed by climate related hazards.

Farmer's perception of climate change. The respondents claimed that drought and flood were the natural hazards that widely occurred in the study areas. 62% and 93% of the respondents in the above-mentioned kebeles, respectively, had perceived the prevalence of climate change (χ^2 = 15.7, P < 0.001). In line with this, 56% and 83% of the respondents claimed that agroforestry could increase crop productivity and coping climate change effect (χ^2 = 9.1, P < 0.01) (Table 3).

Table 3. Farmer's perception on climate change in the two selected kebeles; χ^2 = 15.7; P = 0.001

Perception	Balokeriso		Welay Sedest	
	frequency	%	frequency	%
Perceived	51	62	40	93
Not perceived	4	5	2	4.7
Not sure	27	33	1	2.3
Total	82	100	43	100

Perception on agricultural productivity. The statistical descriptive analysis indicated that out of the total respondents from Balokeriso kebele 56% of the respondents were positive about increasing crop productivity with tree incorporation in farmland and 33% of them perceived decreasing productivity of crops after incorporation of trees in farmland while the rest 11% perceived no change. The same trend was observed in Welay Sedest kebele, 83% of the respondents were positive about increasing crop productivity with tree incorporation in farmland and 12% of them perceived the opposite and the remainder 5% perceived no change. According to the chi-squared statistic test the difference in perception of climate change in the two studied kebeles was significant (χ^2 = 9.1 and P < 0.05) (Table 4).

Climate hazards observed in the study area. In both studied kebeles drought was the most frequently observed climate threat; in Balokeriso kebele the threats were ranked as drought followed by heat wave, flood and strong wind while the most important threats observed in Welay Sedest kebele were flood followed by drought, strong wind and heat wave (Table 5).

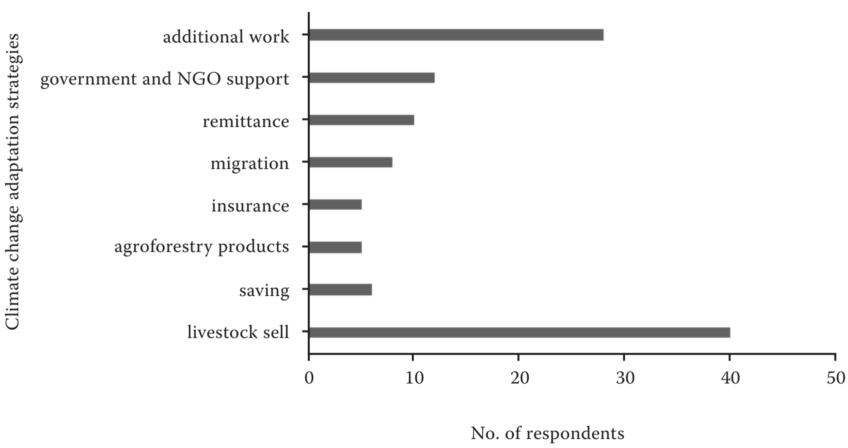

Figure 4. Climate change adaptation strategies of farmers in Silite district, Ethiopia

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Table 4. Farmers perception on agricultural productivity in the two selected kebeles; $\chi^2 = 9.1$; $P = 0.01$

Perception	Balo Keriso		Welay Sedest	
	frequency	%	frequency	%
Increasing	46	56	35	83
Decreasing	27	33	5	12
No change	9	11	2	5
Total	82	100	42	100

Biomass carbon stock. The mean total biomass (*AGB* and *BGB*) carbon stock of studied agroforestry, i.e. parkland, homegarden and woodlot AFS systems, ranged from 2–7 Mg·ha^{-1} across the systems. The result showed that *AGBC* (above ground biomass carbon) and *TBC* (total biomass carbon) among all the AFS was significant at a 5% level of significance and parkland AFS accounts significantly for a higher amount of *TBC* among all studied AFS (Table 6).

Share of carbon stock in homegarden AFS components. Homegarden AFS incorporates trees, coffee plants and enset at once. The tree component (including fruit trees such as papaya, avocado and mango) has taken the major share in the total carbon stock (Figure 5).

Table 5. Climate hazards observed in the study area

Climate threats observed	Number of respondents	
	Balokeriso (total = 79)	Welay Sedest (total = 50)
Drought	28	12
Flood	15	22
Heat wave	22	6
Strong wind	14	10

Table 6. The mean (± SD) carbon stocks in different agroforestry systems

Biomass components	Land use systems		
	woodlot	homegarden	parkland
AGBC	1.28 ± 1.0[a]	2.14 ± 0.85[b]	5.40 ± 1.24[c]
BGBC	0.73 ± 0.8[a]	0.97 ± 1.74[a]	1.50 ± 0.78[b]
TBC	2.01 ± 2.1[a]	3.11 ± 2.40[b]	7.01 ± 1.40[c]

a, b, c – significant difference among *ABGC*, *BGBC* and *TBC*; *AGBC* – above ground biomass carbon; *BGBC* – below ground biomass carbon; *TBC* – total biomass carbon

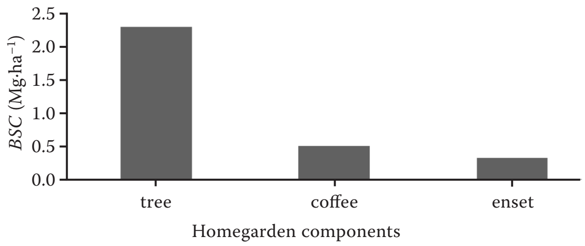

Figure 5. Homegarden AFS components' carbon stock share

BSC – biomass carbon stock; AFS – agroforestry system

DISCUSSION

Biomass carbon stock. This study documented that minimum aboveground biomass carbon stock was estimated in woodlot and homegarden AFS whereas maximum aboveground carbon stock was exhibited by parkland AFS, which can be attributed to continuous biomass accumulation in the woody component. The carbon stock of aboveground biomass is higher compared to belowground biomass (*BGB*) in all studied plots. The average frequency of aboveground biomass (*AGB*) was more important compared to belowground biomass (*BGB*) in the studied sites. Aboveground, belowground carbon and total biomass carbon in general followed virtually the same trend.

The number of planted trees tends to increase the biomass carbon stock of a given area. However, the result in this study was opposite to the above claim proving that parkland AFS accounts for a high amount of carbon stock compared to the other studied AFS having a lower number of individual trees with less diversity. Therefore, the result indicated that the stand structure and number of individual trees in the study area have a greater impact on increasing the carbon stock than the species diversity (Baul et al. 2021). This study also indicated that the species diversity has a significant positive relationship with aboveground carbon. Therefore, the lowest carbon stock recorded for woodlot AFS could be due to the single species-based woodlot agroforestry system.

The biomass carbon stock in a particular land use system depends to a great extent upon its age, structure, functional component and its number and intensity of management. Additionally, the high carbon stock of parkland AFS could be potentially due to its natural reserve of flora and to being a less disturbed AFS. This study also proves that the carbon stock potential highly depends on *DBH* and height rather than on the number of trees.

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The mean total biomass carbon stock of selected AFS observed in this study was comparable with the findings in Vietnam coffee-based AFS (Pham et al. 2018) in Gununo watershed in the Wolayita zone, Ethiopia (Bajigo et al. 2015) and it is also analogous in the range of African tropical dry forest [10–34 Mg(C)·ha^{-1}] (Henry 2010). The biomass carbon storage capacity estimated in our study is lower than in fruit tree-based agroforestry [60 Mg(C)·ha^{-1}] studied in Costa Rica and in other fruit-based agroforestry systems [51.85 Mg(C)·ha^{-1}] in the Northwestern Himalayas (Sanneh 2007). The aboveground tree carbon of the study area was also smaller than in smallholder farms of Vihiga district [36.9 Mg(C)·ha^{-1}] in Western Kenya and smallholder farms of Siaya district [115.9 Mg(C)·ha^{-1}] in Western Kenya (De Stefano et al. 2017). Our study shows higher results than the latest study carried out in Adulala Watershed, Ethiopia, where the mean aboveground total dry biomass of trees was estimated at 844 kg·tree^{-1}, tree density was 5.80 trees·ha^{-1} and 2.45 Mg(C)·ha^{-1} in aboveground biomass and 0.76 Mg(C)·ha^{-1} in belowground biomass (Dilla et al. 2019).

The higher biomass carbon stock recorded in parkland AFS could be due to the species (*F. albida*) morphological characteristics. This species undergoes physiological dormancy and sheds its nitrogen-rich leaves during the early rainy season, which makes it very suitable to be incorporated under parkland AFS and for the growth of crops under the tree canopy. This suggests that agroforestry systems sequester a considerable amount of carbon stock, which makes it appropriate for climate change mitigation in addition to its socio-economic contribution by being a means of income generation for smallholder farmers.

Perception of climate change. The results further showed that the perceived effect of agroforestry on soil fertility, perceived effect of agroforestry on drought control, farm size, and association membership were the positive determinants of agroforestry technique adoption among respondents in the study area.

This study shows that the majority (more than 50%) of the respondents perceived some abnormal changes in their local climatic changes in both studied kebeles; this is in line with the study by Adesina and Baidu-Forson (1995), Hitayezu et al. (2017) and Asrat and Simane (2018).

Climate change threats and adaptation strategies. The study of farmers' perceptions toward the most important climatic hazards reveals that drought and water shortages, when considering their occurrence, intensity, negative impact and severity to cope with, are the most important climatic hazards the future production system and livelihood are facing. Although climate change is a global issue, its impacts differ from one place to another. Rain and water shortage, pest and disease outbreaks (Niles et al. 2016), extreme temperatures and change in precipitation patterns and decreasing yields and erratic rain have already been considered as the most important impacts of climate change.

The hydrological cycle is intimately linked with changes in atmospheric temperature and radiation balance. Increased temperatures in the study area may increase precipitation intensity and variability, which are expected to increase the risks of flooding and drought. According to IPCC (2008), the frequency of intense precipitation events (or the proportion of total rainfall from intense falls) will likely increase over most areas during the 21st century, resulting in the risk of floods. At the same time, the proportion of land surface in extreme drought is also projected to increase. The same study was found in the Gedio zone in Ethiopia (Bishaw et al. 2013), in Burkina Faso (Callo-Conch 2018), tropical Africa (Paeth et al. 2008) and Africa (Sanchez 2002). The threats caused by changing climate hinder productivity, thus a simple solution could be to increase tree density within the AFS and carbon sequestration. Also the inclusion of trees for timber or wood production could increase the revenue and carbon sequestration potential without complementing maintenance costs significantly. These recommendations are an easy and possible solution to turn the AFS feasible without incurring further costs.

CONCLUSION

The selected indigenous agroforestry systems of this study area are very important carbon sinks which directly provide a climate change mitigation option in addition to their socio-economic contribution to smallholder farmers. This study shows that parkland AFS accounted for a significantly higher amount of biomass carbon stock than the other studied AFS which was considerably higher than in the same studies carried out in different parts of tropics. Generally, this study provides information about the carbon stock potential of AFP in the southern part of Ethiopia. This study also

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implies that incorporating trees into a daily cropping system supports the environment by being one means of the climate change mitigation option. Larger carbon projects need a higher amount of carbon and farmer participation than ever. Local small-scale farmers are less aware of environmental benefits of the system. But these days a very large number of parkland AFS have been re-established in different parts of the world; this could be a motivation factor for the carbon stock benefit gained from the system. The study as a whole supports the impression of the higher recognition of AFS as one of the best climate change mitigation options considering the fact that agroforestry can contribute to food security through the provision of edible products such as fruits, roots and seeds. Trees can also improve soil fertility by fixing nitrogen from the air and recycling nutrients, thereby helping to increase crop yields. Trees in the agroforestry system provide valuable supplemental fodder for animals to enhance livestock production and household energy for cooking, heating, and light.

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Vegetation dynamics and soil properties following low-intensity wildfire in loblolly pine (*Pinus taeda* L.) planted forest in Northern Iran

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Abstract: Vegetation dynamics, soil properties, and the correlation between them following a wildfire are crucial to understanding the recovery of forest (natural or planted forest) ecosystems. We compared species composition and soil properties in two burned (Br) and unburned (UBr) sites of loblolly pine (*Pinus taeda* L.) stand in Northern Iran. We detected 39 plant species including 22 (56.4%) species that were common in both sites, 13 (33.3%) species specifically in the Br site, and 4 (10.3%) species specifically in the UBr site. Although species abundance was significantly higher in the UBr site, species richness was significantly higher in the Br site. Species composition was significantly different (F = 16.25, P-value = 0.001) between Br and UBr sites. Rarefaction-extrapolation revealed consistently and significantly higher species diversity in Br site compared to UBr site for all three Hill numbers. Only sand (t = 2.23, P-value = 0.030), pH (t = 2.44, P-value = 0.018) and electrical coductivity (t = 2.98, P-value = 0.004) were significantly higher (P-value ≤ 0.05) in the Br site due to the demobilization of base cations in burnt vegetation. In the Br site, the wildfire did not cause any marked changes in C and N stocks.

Keywords: forest management; ground flora; litter thickness; soil organic matter; species composition

Globally, the overall area of planted forests has been estimated at 294 million ha, which is 7% of the world forest area, and it increased by 123 million ha between 1990 and 2020 (FAO 2020). Planted forests are crucial renewable sources of raw material, both in environmental as well as social and economic terms. Also, tree plantations can provide other significant ecosystem services like regulation of water flow, improvement in soil fertility, and carbon sequestration (Humpenöder et al. 2014). One of the main reasons for planted forests around the world is to reduce the pressure on natural forests (slow or reverse deforestation and forest degradation) by providing profitable wood products for

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the market, e.g. lumber, fuelwood, pulp, and paper (FAO 2001; Guedes et al. 2018). To this subject, fast-growing species are mainly considered because of their capability to produce a mean annual increment of at least ten cubic meters per hectare under favourable site conditions.

Loblolly pine (*Pinus taeda* L.) is one of the world's most important commercial species (Prestemon, Abt 2002). This species is native to the southeastern United States and is economically valuable because it can grow remarkably well outside its native range (Wallinger 2002) in differently textured soils, from deep sands to heavy-textured clays. It has rapid regeneration, substantial yields per hectare, and numerous marketable products (Fox et al. 2007). In addition to the United States (Perdue et al. 2017), *Pinus taeda* is widely cultivated in Brazil (Dobner, Campoe 2019), China (Jin et al. 2019), Mozambique (Guedes et al. 2018), Uruguay (Leites et al. 2013), Argentina (Martiarena et al. 2011), Iran (Picchio et al. 2020) as an exotic (non-native) fast-growing species. Therefore, as an exotic species planted in many countries, it is expected to be more impacted by natural disturbances.

Natural disturbances such as fire, insect outbreaks, ice storms, or windthrow are globally increasing mainly due to current and feature global changes (climate changes, land use and land cover changes, social changes) (Dobner, Campoe 2019). Wildfires are one of the most significant primary abiotic disturbances in different ecosystems (Barreiro, Díaz-Raviña 2021) and are the result of high fuel availability, low humidity, high temperature, and high wind speed (Leite et al. 2015). In many territories of the world, wildfires are influential contributing factors that explain habitat structure, ecosystem functioning, and community composition (Bond et al. 2005). Fire influences natural ecosystems by burning plants and changing the succession pattern. Its impact on the ecosystem plays a determining role in the present species and dynamics of forest ecosystems. However, in many cases, surface fire (the height of flames is roughly 10 cm to 30 cm under standard humidity and fuel conditions) occurs and specifically impacts understorey plant species and soil in the planted forests (Peterson, Reich 2008).

Planted forests supply habitats for wildlife and provide conditions for recolonization by native plant species that help the conservation of biological diversity (Chamshama et al. 2009). Biological diversity or biodiversity is crucial for the functionality of ecosystems. Nutrient cycling, resilience, and succession are meaningful ecological roles of plant diversity in forest ecosystems (Poorbabaei, Poor-Rostam 2009). Biodiversity provides essential food and habitat resources for many wild species, including insects, birds, and deer (Felton et al. 2018). The loss of vegetation is the most direct impact of a wildfire, but additionally, the soil ecosystem is also severely affected by the fire and hence there may be a loss of soil quality. The physical and chemical properties of soil are affected by fire severity, which is related to several environmental factors such as moisture content of dead and alive combustibles, wind speed, and site topography (Certini 2005). The principal direct effect of fire on soil physical properties is related to the combustion of organic matter (Mataix-Solera et al. 2011).

Recently, different reviews have addressed the impact of fire on vegetation (Stavi 2019) and soil physicochemical properties (Minervini et al. 2018). It emphasizes the importance of predicting the impact of natural factors and management regimes on biodiversity and soil (Balvanera et al. 2006). Although there is a great deal of published information on the initial stages and long-term fire recovery of understorey species in *Pinus taeda* planted forests (e.g. Iglay et al. 2014; Matusick et al. 2020; Westlake et al. 2020), there is less published information on the two years recovery after wildfire compared with non-fire affected *Pinus taeda* planted forests. From this point of view, our study looked for the influence of surface wildfire on soil properties and understorey vegetation. Specific objectives of the study were (*i*) how species abundance and richness change two years after wildfire, (*ii*) how soil properties are affected by low-intensity wildfire, (*iii*) what of the stand or soil properties mainly determines the species abundance and richness.

MATERIAL AND METHODS

Study area. The study area is located in Saravan Forest, Guilan Province (37°09'12''N, 49°35'40''W – Northern Iran), in the temperate climate conditions which are characterized by high precipitation with a strong seasonal pattern. Mean annual rainfall is 1 189 mm. 67% (796 mm) of the rain occurs in the autumn-winter periods and 33% (393 mm) during spring and summer. Mean annual temper-

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ature is 15.9 °C and the air temperature typically ranges from 14.5 °C (mean minimum temperature of the coldest month) to 28.3 °C (mean maximum temperature of the hottest month). A forest site was identified which was affected by low-intensity wildfire on July 21st, 2017, with an area of approximately 5 ha. Simultaneously, the burnt (Br) site was situated in close proximity to the unburned (UBr) site selected as control. Site conditions (topography, altitude, soils, etc.) were similar among the selected sites. The age of plantations with the same planting distance (4 m × 4 m planting distance) was 24 years. Table 1 shows the plantation characteristics of tree density, basal area, *DBH* (diameter at breast height) and canopy cover.

Data collecting. Sixty plots (1 000 m^2) were established using a random systematic 100 m × 200 m grid. Edge effect was minimized by placing plots at least 30 m from the site boundary and roads. Within each plot, a subsampling technique was employed based on the minimal area method and Whittaker nested plot sampling protocol. Thus, the percent cover of each ground flora was measured using 8 m^2 subplots (centre of each plot). All ground flora individuals were identified, and those that could not be identified to species in the field were transported to the laboratory where they were pressed, dried, and identified by experts. Live standing trees larger than 9 cm in diameter at breast height (*DBH*, 1.37 m) were recorded in each plot. Basal area ($m^2 \cdot ha^{-1}$) was calculated from standing trees > 9 cm in diameter at *DBH*. The forest survey and vegetation measurements were conducted from May to August during the growth season, two years after the wildfire.

Soil sampling and analysis. Soil samples were taken from the first 20 cm of the topsoil with a 7.5 cm diameter soil core at the centre of each plot (a total of 60 soil samples for both sites). To ensure homogeneity in soil samples, we manually removed the soil organic layer before sampling the mineral layer, allowing for a direct comparison of the soil properties between the UBr and Br sites. Soil samples were placed in Ziploc bags before transfer to the lab. Litter depth was measured at the four corners of 8 m^2 subplots. All soil samples were sieved through a 2 mm sieve to remove roots and rocks and air-dried for physical and chemical analysis. The hydrometric technique was used to determine the percentages of clay, sand, and silt (Bouyoucos 1962). A subsample was oven-dried at 105 °C for 24 h to calculate the soil sample water content. Soil samples were soaked in distilled water with soil : water of 1 : 2.5 was stirred sufficiently and left to sit for 30 min until translucent suspensions. Soil pH and EC (electrical conductivity) were determined using an Orion Ionalyzer Model 901 EC and pH meter (Thermo Orion, USA). Soil bulk density was measured by the clod method (Soleimany et al. 2021). Soil porosity was calculated by the formula [1 – (bulk density/particle density)]. Organic carbon (OC) was measured by dichromate oxidation (Allison 1965) and N by wet oxidation using the Kjeldahl method.

Data analysis. All statistical analyses were conducted in R (Version 3.6.3, 2020), and significance was accepted at $P < 0.05$. To analyse the effects of wildfire on species communities, we used the general linear model (GLM) in the MASS package (Version 7.3-55, 2021). We used non-metric multidimensional scaling (NMDS) to visualize and test differences within the species community composition between Br and UBr sites (Oksanen et al. 2013). To compare diversity between Br and UBr sites, we used a framework published by Chao et al. (2014), implemented in the R package "iNEXT" (Hsieh et al. 2016). This framework unifies interpolation and extrapolation approaches with Hill numbers, which allows analysing rare to dominant species in a common framework. We calculated diversity for the diversity of rare (q = 0), common (q = 1), and dominant species (q = 2) (Chao et al. 2014). Significant differences in estimated diversity between sites were judged by non-overlapping confidence intervals (Schenker, Gentleman 2001). Two-sample t-test was used to compare the means of soil variables between sites. All figures are made by using the ggplot2 package (Version 3.3.5, 2021). Significant differences are indicated in the tables by P-values along with the significance level (*significant at 5%, **significant at 1%, ***significant at 0.1%).

Table 1. Stand characteristics (mean ± SD) of burned (Br) and unburned (UBr) sites

Variables	Br	UBr	P-value
Tree density ($n \cdot ha^{-1}$)	265.2 ± 32.8	277.3 ± 31.4	0.153
DBH (cm)	22.8 ± 4.7	24.2 ± 6.3	0.124
Basal area (m^2)	10.9 ± 3.0	13.2 ± 5.6	0.062
Canopy cover (%)	45.8 ± 11.4	53.4 ± 15.7	0.072

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RESULTS

We detected 39 plant species including 22 (56.4%) species that were common in both sites, and 13 (33.3%) species specifically in the Br site, and 4 (10.3%) species specifically in the UBr site. Species abundances (Figure 1A) were significantly higher in the UBr site, whereas species richness (Figure 1B) was significantly higher in the Br site (Table 2).

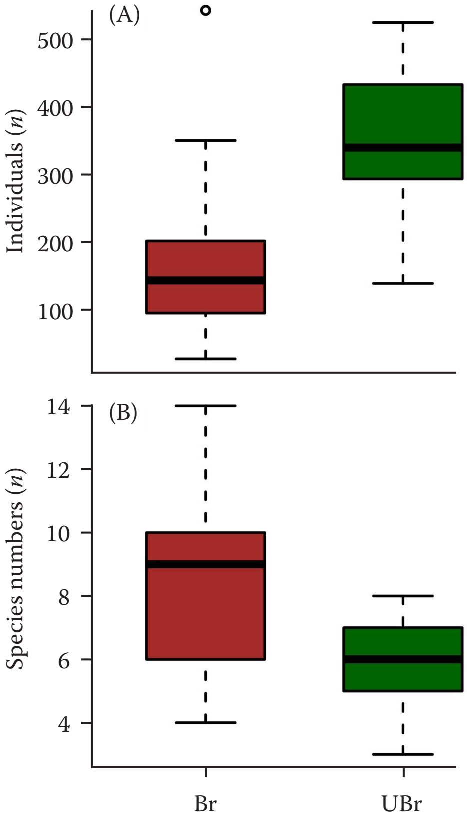

Figure 1. Mean individuals (A) and species numbers (B) per plot sampled across 60 Br and UBr plot

Br –burned; UBr – unburned

Table 2. Results of generalized linear model with abundance and species richness as response variable and sites as predictor

Response		Estimate	SE	*Z*-value	*P*-value
Abundance	intercept	5.106	0.014	359.40	< 0.001***
	sites (UBr)	0.788	0.017	46.00	< 0.001***
Species richness	intercept	2.128	0.062	33.78	< 0.001***
	sites (UBr)	−0.358	0.098	−3.65	< 0.001***

***significant at the 0.001 level (2-tailed); UBr – unburned

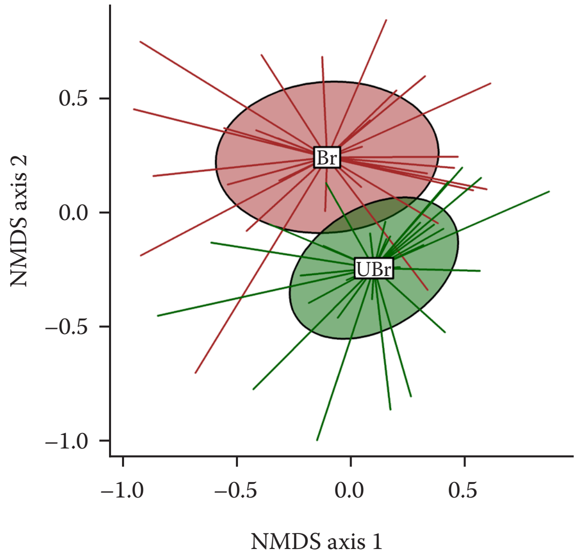

Figure 2. Non-metric multidimensional scaling of species composition sampled in Br and UBr sites (stress = 0.245)

Br –burned; UBr – unburned; NMDS – non-metric multidimensional scaling

Table 3. Pearson correlation between species abundance and richness, and variable types of stands and soil in two Br and UBr sites

Variables	Br		UBr	
	abundance	richness	abundance	richness
Abundance	–	0.661**	–	0.569**
Canopy cover	−0.495**	−0.777**	−0.334	−0.540**
Clay	0.219	0.106	−0.069	0.160
Silt	−0.247	−0.159	0.001	−0.203
Sand	0.011	0.122	0.155	0.142
Saturation moisture	−0.116	−0.019	0.096	0.043
Temperature	−0.312	−0.280	−0.291	−0.080
Balk density	−0.002	0.087	−0.219	−0.097
Porosity	−0.069	−0.235	0.192	0.085
EC	0.046	0.042	0.274	0.003
pH	−0.331	−0.417*	0.351	0.136
Organic carbon	−0.144	−0.064	−0.127	−0.165
N	0.046	0.042	0.274	0.003
C/N	−0.128	−0.002	−0.208	−0.099
Carbon stock	−0.175	−0.041	−0.158	−0.178
N stock	0.036	0.077	0.268	−0.002
Litter thickness	−0.467**	−0.734**	−0.375*	−0.511**

*;**significant at the 0.05 and 0.01 level respectively (2-tailed); EC – electrical conductivity; Br – burned; UBr – unburned

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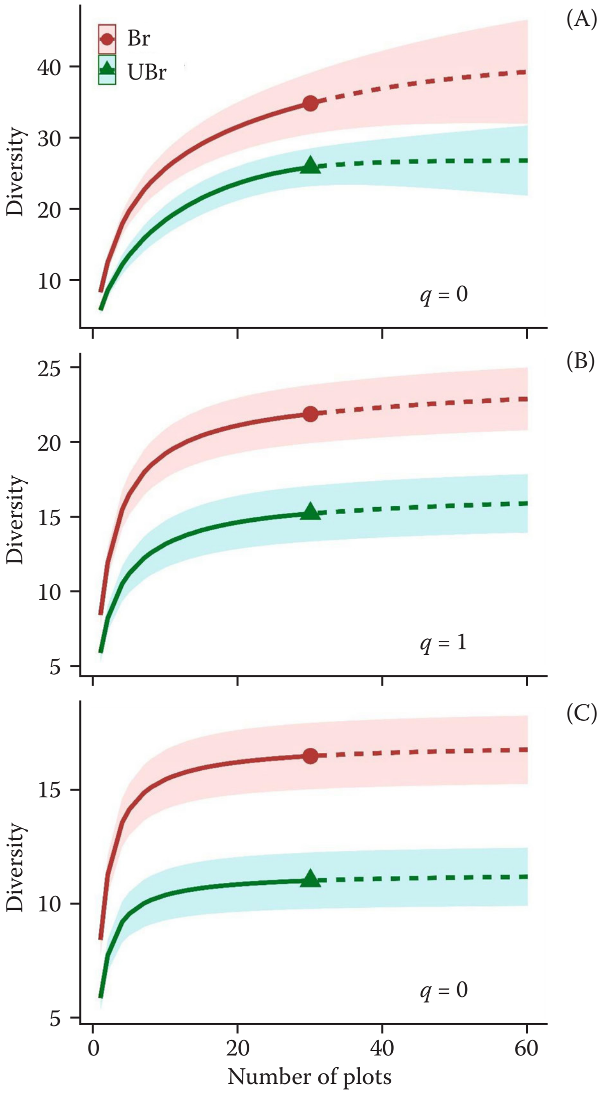

Figure 3. Sample-based rarefaction (solid lines) and extrapolation (dotted lines, up to twice the actual sample size) species diversity in Br and UBr sites, for (A) rare ($q = 0$), (B) common ($q = 1$), and (C) dominant ($q = 2$) species

Br –burned; UBr – unburned

Species composition was significantly different between the Br and the UBr site ($F = 16.25$, P-value = 0.001) (Figure 2). Rarefaction-extrapolation revealed a higher species diversity in Br site compared to UBr site consistently and significantly (non-overlapping confidence intervals of the rarefaction and extrapolation curves) for all three Hill numbers (Figure 3A–C). Soil texture shows insignificantly higher clay content in the Br site and silt content in the UBr site. However, sand content was significantly higher in the Br site ($t = 2.23$, P-value = 0.030) (Figure 4).

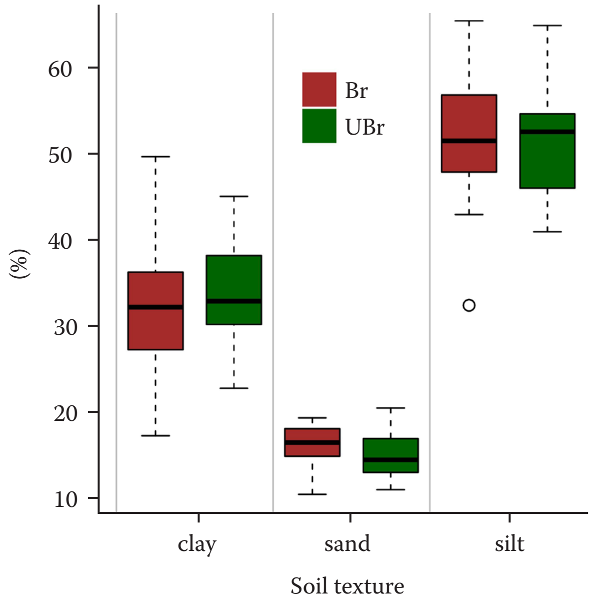

Figure 4. Soil clay, sand, and silt percentage in Br and UBr sites

Br –burned; UBr – unburned

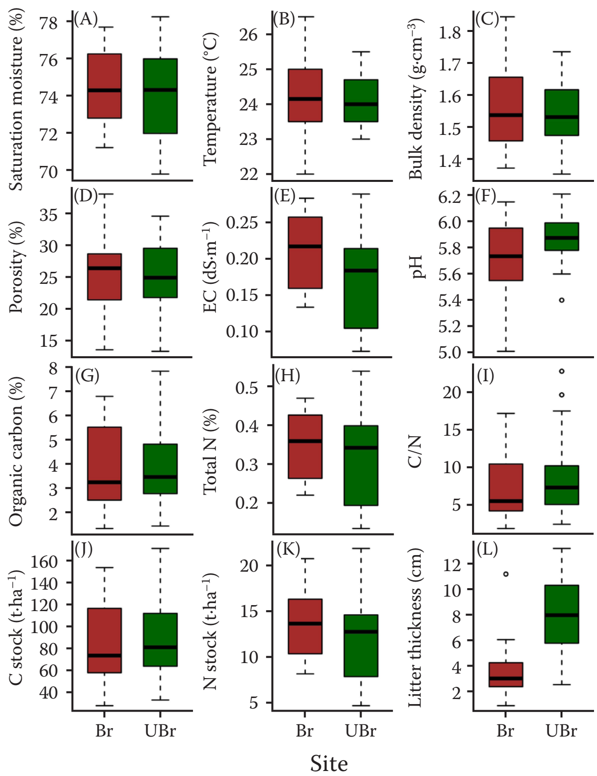

Figure 5. Soil variables of (A) saturation moisture, (B) temperature , (C) bulk density, (D) porosity, (E) EC, (F) pH, (G) organic carbon, (H) total N, (I) C/N, (J) carbon stock, (K) N stock and (L) litter thickness in Br and UBr sites

Br – burned; UBr –unburned

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Soil variables of saturation moisture (Figure 5A), temperature (Figure 5B), bulk density (Figure 5C), porosity (Figure 5D), EC (Figure 5E), pH (Figure 5F), organic carbon (Figure 5G), total N (Figure 5H), and N stock (Figure 5K) were higher in the Br site compared to the UBr site but differences were significant only for pH (t = 2.44, P-value = 0.018) and EC (t = –2.98, P-value = 0.004). Although C/N (Figure 5I) and carbon stock (Figure 5J) were slightly higher in the UBr site, these differences were not significant. Litterfall thickness was significantly higher in the UBr site compared to the Br site (t = 6.99, P-value = 0.000) (Figure 5L).

A negative relationship was found between species abundance with canopy cover and litter thickness in the Br site and only litter thickness in the UBr site (Table 3). Although species richness was positively related to the species abundance in both sites, it was negatively correlated with canopy cover, pH, and litter thickness in the Br site and canopy cover and litter thickness in the UBr site (Table 3).

DISCUSSION

The results show that the fire caused an increase in species richness, but it decreased the species abundance after two growing seasons. These results are in line with the findings of Brewer (2016) and Ürker et al. (2018), indicating that the richness index is higher in the burned stands. Also, Karimi et al. (2019) found that many pioneer species appeared in areas 1 to 3 years after the fire. Barefoot et al. (2019) reported slightly higher species richness in burned than in unburned areas. The species abundance in the Br site was significantly lower than in the UBr site, but it can gradually increase based on Delitti et al. (2005). Furthermore, fire altered the species community composition. Similarly, Xiang et al. (2015) found significantly different species compositions in burned and unburned forests. Richter et al. (2019) found a positive correlation between the species richness and average thickness of litterfalls. It matches our findings since litter thickness in the Br site is significantly lower compared to the UBr site. Although these differences could also be linked to the density of tree overstorey, we observed a similar density of overstorey trees. However, it has been reported as a significant determinant of understorey variation in many studies due to its influence on light transmittance, soil insolation, moisture content, and nutrient cycling (Felton et al. 2010).

The main link between plant species and soil properties is the quantity and quality of nutrient sources. In this study, the fire altered the soil texture by increasing the sand and silt contents and reducing the clay content. We believe the fire intensity was not high enough to cause significant changes in soil texture. Changes in soil texture can occur at temperatures above 250 °C (Giovannini, Sun 2012) by forming silt and sand particles from fine clay particles, which might not happen in this study. Similarly to our result Kara and Bolat (2009) found a higher sand content and lower clay content in burnt soil in Turkey.

In this study, the fire increased soil bulk density but it was not significantly different in comparison with the UBr site. Similarly, Hubbert et al. (2006) found the increased soil bulk density after a fire in an oak forest in Middle Tennessee, USA. Arunrat et al. (2021) indicate that lower clay content is mainly related to higher soil bulk density, which was the case of our study. Soil pH is a critical soil feature that determines the availability of plant nutrients. Therefore, pH changes will have subsequent impacts on soil nutrients (Prendergast-Miller et al. 2017). Wildfire increased soil pH and EC two years after the fire that were significantly different from the levels observed in the UBr site. Muñoz-Rojas et al. (2016) found a significant increase in pH and EC after the fire. Similarly, Fachin et al. (2021) mentioned that soil pH increased after the fire. These results are related to the high amounts of ash and wood charcoal and the slow release of alkaline cations into the soil (Certini 2005). The findings of Knicker et al. (2007) comply with our results, reporting significantly higher EC values in the burnt compared to the unburnt plots, mainly due to increased levels of major cations in the soil. Although our result indicates these variations two years after the fire, Fonseca et al. (2017) observed that pH and EC values after thirty-six months from fire were similar to those seen before the fire.

The soil moisture variations were not significant in both studies, perhaps due to the recovery period after the fire. On the other hand, Arunrat et al. (2022) indicated that the reason for non-significant changes in soil moisture was most likely because the fire intensity was low to medium as it took place in the present study. Based on Keeley (2009), fire intensity refers to the energy or heat released during various phases of fire. Santín et al. (2016b) mentioned that moisture content and fire inten-

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sity depend on the extent of litterfall consumption by fire. Although the soil temperature was higher in the Br site compared to the UBr site, but with a non-significant difference, in our observation, the surface in the Br site can absorb more sunlight due to dark looks because of necromass such as burned leaves, litter, and partially burned branches. Accordingly, Alexis et al. (2007) found an insignificant increase in soil temperature in prescribed fires.

Soil organic matter is a significant soil property that increases soil resource availability and water-holding capacity and improves the soil structure. (Reynolds et al. 2003). Meanwhile, fires can modify the amount of soil organic matter and change the structure and composition of plant communities (Nghalipo, Throop 2021). We found no significant changes in OC between Br and UBr sites, most probably because of the low fire intensity (the heat was not strong enough to impact significantly) and low mineralization rates. Our findings are consistent with Nave et al. (2011), who observed that the prescribed fire had no significant effects on OC. Lucas-Borja et al. (2019) highlighted the low-intensity fire to explain the stable levels of OC and N stocks. An increment of total carbon concentration in soils of boreal forests was reported by Santín et al. (2016b) after a fire occurred. In other ecosystems, Nichols et al. (2021) reported a decrease of C after a fire in sagebrush steppe ecosystems of the Columbia Basin. Soil C is a strong predictor of plant communities due to its influence on soil water-holding capacity and nutrient retention and availability. Our results indicate that the low-intensity fire has no impact on ecosystem functioning through changes in the soil C stock. An insignificant slight decrease of the C stock was observed at the Br site two years after the fire, most likely it was associated with leaching from this upper to deeper soil layers (Jones et al. 2020). All subsequent changes emanated from the movement of carbon compounds under the influence of water. In contrast to our findings, Fairman et al. (2022) found a significant decrease in carbon stocks at 10 cm soil depth in a eucalypt forest after a wildfire. We observed insignificantly higher N and N stock in the Br site. These findings are consistent with the study of Xiang et al. (2015), who reported a non-significantly higher content of available nitrogen one-year after a wildfire in a Chinese boreal forest. Alteration of soil N cycling was found following the fire disturbance in different ecosystems (Ball et al. 2010; Stephan et al. 2015; Prendergast-Miller et al. 2017). The N cycle in forest soil is an internal cycle between the vegetation and the pool of N. Arunrat et al. (2022) mentioned that fire is not the main factor affecting N, but also N was likely impacted by plant uptake.

It is reasonable to observe a decrease in the litter thickness of the Br site after the fire. We found a significant 57.6% reduction of litter thickness in the Br site compared to the UBr site. Litter is the primary fuel for starting and spreading fire, especially in low-intensity surface fires (Volkova et al. 2019). Although we did not examine the litter biomass, Espinosa et al. (2018) found a reduction between 59 and 77% of litter biomass in mixed stands of *Pinus nigra* and *Pinus pinaster* and pure stands of *Pinus nigra* in central-eastern Spain after prescribed burning. Nevertheless, depending on the forest ecosystem type (natural or planted forest), litterfall reaches pre-fire levels in two to seven years (Dymov et al. 2017).

Dymov et al. (2021) indicated that the soil chemical composition was similar to that before the fire two years after the fire. This can probably be explained by the renewal of ground cover plants and the influx of fresh litter contributing to an increase in the mobility of organic compounds in soil. An important aspect to be considered with post-fire recovery and longevity of fire impacts is the type of ecosystem involved (Prendergast-Miller et al. 2017). The differences in C or N stock in the mineral layer are significantly affected by species difference between aboveground litterfall inputs and decomposition, primarily controlled by the quality of the litter (Li et al. 2012; Rafiei Jahed et al. 2017). The effects of tree species in a planted forest on soil C and N stock changes after the afforestation were reported by Li et al. (2012). Consequently, more C accumulates in the mineral layer for conifer species, notably pine (Li et al. 2012). However, previous studies have reported a wide variability in soil chemicals and nutrients within and among different ecosystems (Allen et al. 2011; Santín et al. 2016a), mainly due to fire intensity (Bird et al. 2015).

CONCLUSION

This study research provides a better understanding of dynamics and changes in vegetation cover and soil properties which have a relevant role in forest management planning. Here we studied the species diversity and composition, and

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most fire-affected soil properties following wildfire in *Pinus taeda* stands as an alien species in the temperate area of Northern Iran, Central Asia. Our findings indicated that fire altered the species composition. Moreover, although species abundance was negatively affected in the Br site, species richness increased dramatically within two years after the fire. There were significant differences in species diversity based on rarefaction-extrapolation between Br and UBr sites. Due to the influence of a low-intensity fire on soil, the number of soil properties (saturation moisture, temperature, bulk density, porosity, EC, pH, organic carbon, total N, and N stock) increased within two years after the fire. However, only pH and EC were found significantly different between Br and UBr sites. We showed that a single low-intensity fire in *Pinus taeda* stands improved species richness and diversity by reducing litterfall thickness. Finally, as we have not found a significantly negative impact of wildfire after two years, we suggest the prescribed fire (considering fire intensity) as a potentially effective mechanism to decrease the litterfall thickness and promote species richness and diversity in similar ecosystems. However, long-term monitoring of vegetation and soil fertility in the planted forest in future studies is needed.

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Evaluation of selected growth parameters of *Paulownia cotevisa* plantation in the Danubian Lowland

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Abstract: The main objective of this study was to assess the growth of the established *Paulownia cotevisa* plantation during an extended time period and compare it with values reviewed in the literature. Seven years after planting, mean diameter at breast height and height of the aboveground part of *P. cotevisa* 2® (*P. cotevisa*) plantation were similar to values reported in the literature and they reached 21.5 cm and 11.2 m, respectively. Besides the crown damage caused by wind, development of the *P. cotevisa* plantation established in the Danubian Lowland was not affected by any other harmful environmental factor or biological pest. The results suggest that *P. cotevisa* could be used to a larger extent in diversification of biomass production on abandoned arable lands of the Danubian Lowland.

Keywords: agroforestry systems, arable lands; biomass production; fast-growing tree species

In Slovakia, current climate change as well as ongoing extension of restrictions related to nature conservation make the production of main commercial tree species with cutting age exceeding 80 years more difficult (Kovalčík et al. 2012; Hlásny et al. 2021). Thus, the demand for a stable and safe source of wood biomass provokes interest of land managers also in the cultivation of plantations with markedly shortened production period (Dimitriou, Rutz 2015; Yavorov et al. 2015). In the lowlands of Slovakia, the attention was focused primarily on the native tree species including poplars and willows and utilization of the maximum production potential of these tree species through hybridisation (Bartko 2011; Kohán 2012). However, a distinctively more efficient mechanism of carbon integration during photosynthesis ensuring the ability to reach a diameter of 27.3–39.6 cm and a height of 9.9–13.2 m within the 10-year period (Wang, Shogren 1992) makes from non-native *Paulownia* sp. one of the most prominent objects of interest (Yavorov et al. 2015; Jankovič et al. 2016). Regarding its high adaptation ability to a wide range of climatic conditions as well as its still non-invasive character (Franz 2007; Buzan et al. 2018), *Paulownia* sp. is also considered suitable for the improvement of abandoned agricultural lands or for land rehabilitation, where the main intention is not focused on the biomass production (Yadav et al. 2013; Buzan et al. 2018).

Thus the establishment of a *Paulownia* plantation in the Danubian Lowland in 2015 offers a unique opportunity to study the production characteristics

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of this non-native tree species in the new environment. The main objective of this study was to assess the growth of the established *Paulownia cotevisa* 2® (*P. cotevisa*) plantation during an extended time period and compare it with values reviewed in the literature.

MATERIAL AND METHODS

The study site was situated in the SW of Slovakia, cadastral area of the Búč municipality (47.79°N, 18.45°E) located in the Danubian Lowland. The plantation was established in the spring 2015 on a flat site at an altitude of 108 m a.s.l. that had been cleared of natural vegetation and ploughed. The soil of the study site is classified as sandy loam Calcari-Haplic Chernozem (FAO 2015). Mean annual air temperature at the study site is 10.4 °C and mean monthly temperature for the warmest month (July) is 20.8 °C and for the coolest month (January) –1.1 °C. Annual precipitation averages 540 mm and is evenly distributed across the seasons (SHMI 2021b).

Air temperature and precipitation over seven consecutive years of plantation monitoring were recorded daily by a meteorological station of the Slovak Hydrometeorological Institute in Hurbanovo (SHMI 2021a) situated approximately 15 km NW of the study site at the similar altitude.

Two hundred one-year-old containerized seedlings of the hybrid *P. elongata* × *fortunei (P. cotevisa* 2®) (iPaulownia, Sueca, Spain) obtained from a private nursery were planted in rows at spacing of 4 × 4 m (625 seedlings·ha^{-1}). One year after planting, seedlings were cut to the ground in order to recruit one straight healthy stem from among the multiple sprouts that emerge from the stump at the start of the second growing season. Post-planting care included ploughing and disking of soil between the lines of trees twice a year (spring and autumn). No protection of the plantation from damage by game (fencing, individual protection) was installed.

The established plantation was evaluated after the fifth, sixth and seventh year from outplanting. Recorded data included diameter at breast height (*DBH*), tree height (*H*) and visual assessment of damage (biotic/abiotic factors). Collected data for *DBH* and *H* were sorted into diameter (interval: 2 cm) and height (interval: 2 m) classes, and histograms for *DBH* and *H* of the *Paulownia* plantation were constructed. *DBH* and *H* increments were calculated as a difference between the mean values of selected growth parameter for each consecutive year.

RESULTS AND DISCUSSION

In this study, the plantation of *P. cotevisa* established in the Danubian Lowland reached mean *DBH* 21.5 cm and mean *H* 11.2 m seven years after planting (Figure 1). Dimensions of the largest individuals exceed 28 cm for *DBH* and 12 m for *H*, the smallest individuals had *DBH* lower than 16 cm

Figure 1. *P. cotevisa* plantation after 5th, 6th and 7th year after planting in the locality of Búč, Danubian Lowland (Slovakia) (photo: Jankovič)

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and *H* not exceeding 10 m (Figures 1 and 2). In the fifth, sixth and seventh year, the annual average increment reached 3.4 cm for *DBH* and 2.3 m for *H*. The standard 10-year period used for the cultivation of *Paulownia* in the country of origin, China, enables trees to develop *H* 8–12 m and *DBH* 30–40 cm, with crown radius 3–5 m (Wang, Shogren 1992). In Europe, the ability of *Paulownia*

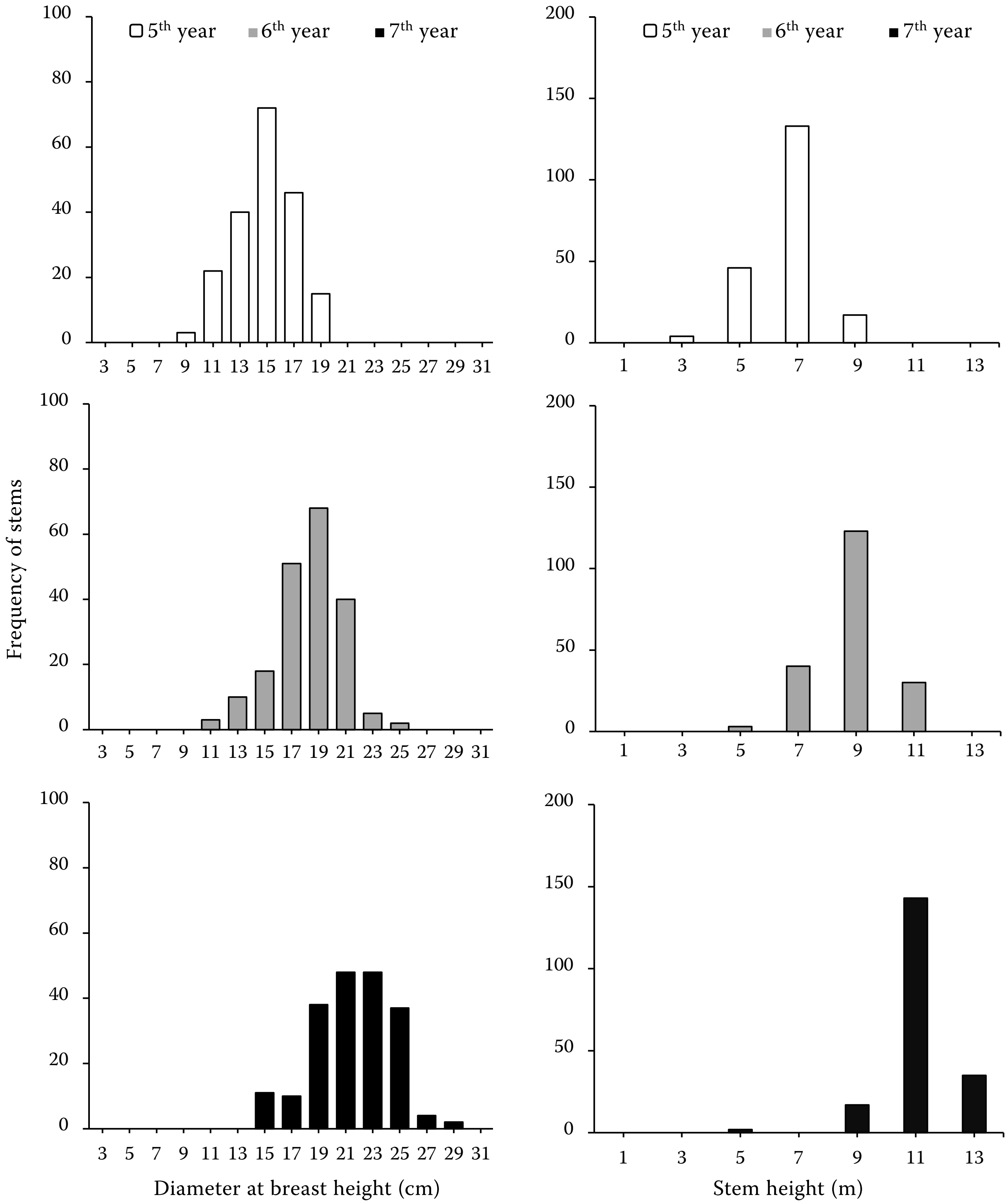

Figure 2. Diameter at breast height and stem height distribution of individuals of *P. cotevisa* after 5th, 6th and 7th year after planting in the locality of Búč, Danubian Lowland (Slovakia)

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to exhibit similar field performance has been observed in several studies, but only on sites located in southern parts of the continent (Table 1). In Romania, 30-years-old individuals reached *H* 15–16 m and *DBH* 40–58 cm (Buzan et al. 2018). Similarly, Ayrilmis and Kaymacki (2013) reported that samples of wood used in their study were from an 8-years-old solitaire of *P. elongata* with DBH 65 cm (Table 1). On the other hand, *Paulownia* plantations established in the USA on an abandoned agricultural field in Virginia (Johnson et al. 2003) or in the Southern Appalachians in North Carolina (Bergman 2003; Berg et al. 2020) as well as in Ireland (Olave et al. 2015) showed much worse results (Table 1). Johnson et al. (2003) and Berg et al. (2020) described serious problems with the preservation of established plantations, when the overall survival of *Paulownia* plantations did not exceed 30% seven years after planting. Weak performance of *Paulownia* plantations reviewed in Table 1 was attributed predominantly to unusual weather events (low freezing temperatures, drought and strong winds) or diseases during the early years of plantation development. According to Olave et al. (2015), especially freezing temperatures during exceptionally cold winters might be the most important factor limiting the successful growth of *Paulownia* sp. in northern latitudes. In this study, the lowest daily winter temperature of –13 °C was recorded in January 2017 two years after planting. Except of winter 2017/2018, winter temperatures (December–February) ranged only

Table 1. Growth of *Paulownia* sp. plantations under various conditions

Site location	Mean air temperature (°C) warmest month	Mean air temperature (°C) coldest month	Mean annual precipitation (mm)	Species	Age (years)	*DBH* (cm)	*H* (m)	Reference
China	–	–	–	*Paulownia* sp.	10	30.0–40.0	8.0–12.0	Wang and Shogren (1992)
Romania	0.0	25.0	623	*Paulownia* sp.	4	7.7	6.2	Buzan et al. (2018)
					30	40.0–58.0	15.0–16.0	
Ireland	6.8	16.9	715	*P. elongata*	3	NA	1.5	Olave et al. (2015)
				P. fortunei			1.5	
				P. elongata × *fortunei*			1.0	
				P. elongata × *fortunei* × *tomentosa*			0.4	
New Zealand	13.8	22.6	625	*P. tomentosa*	5	30.7–34.0	11.3–11.5	Barton et al. (2007)
Turkey	2.9	27.2	510	*P. elongata*	2	30.0	6.0–7.0	Ates et al. (2008)
Turkey	1.7	30.9	693	*P. elongata*	8	65.0	NA	Ayrilmis and Kaymacki (2013)
USA (North Carolina)	2.3	22.5	1 214	*P. tomentosa*	9	2.5–28.7	10.4–12.0	Berg et al. (2020)
				P. elongata		3.0–28.7	2.1–14.0	
				P. fortunei		1.0–34.0	2.0–14.5	
USA (Virginia)	–4.3	16.1	787	*P. tomentosa*	7	7.8–9.1	3.8–4.0	Johnson et al. (2003)
Italy (Sardinia)	14.3	30.8	428	*P. tomentosa*	2	4.4	4.3	Puxeddu et al. (2012)
Albania	4.0	29.0	723	*P. tomentosa*	13	38.0–40.0	10.0	Icka et al. (2016)
				P. tomentosa	1	5.2	4.3	

DBH – diameter at breast height; *H* – height; NA – not assessed

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from −8 °C to +8 °C during plantation monitoring, without any negative effect on the *Paulownia* plantation development (Figure 3).

Observations of Berg et al. (2020) suggested that strong winds might also be another factor affecting the development of *Paulownia* plantation. Barton et al. (2007) observed that the breakage of young stems and branches of *Paulownia* trees occurred when the wind speed exceeded 40 $km \cdot h^{-1}$. Higher susceptibility of *Paulownia* to damage caused by wind was observed partially also in our study. Five years after planting almost 25% of planted individuals of *Paulownia* showed signs of crown damage (broken branches or central stem). However, the observed level of damage had no marked effect on further development of assessed *Paulownia* individuals. Besides the registered crown damage caused by wind, the individuals of *P. cotevisa* in this study were not affected by any other negative environmental factor (high temperatures, water shortage) or biological pest (insect, rodents, ungulates etc.).

In lowlands of Slovakia, Kohán (2012) reported that the most commonly used fast-growing hybrids of poplars can reach *H* 20 m and *DBH* ranging from 19 cm to 26 cm already after a 10-year period.

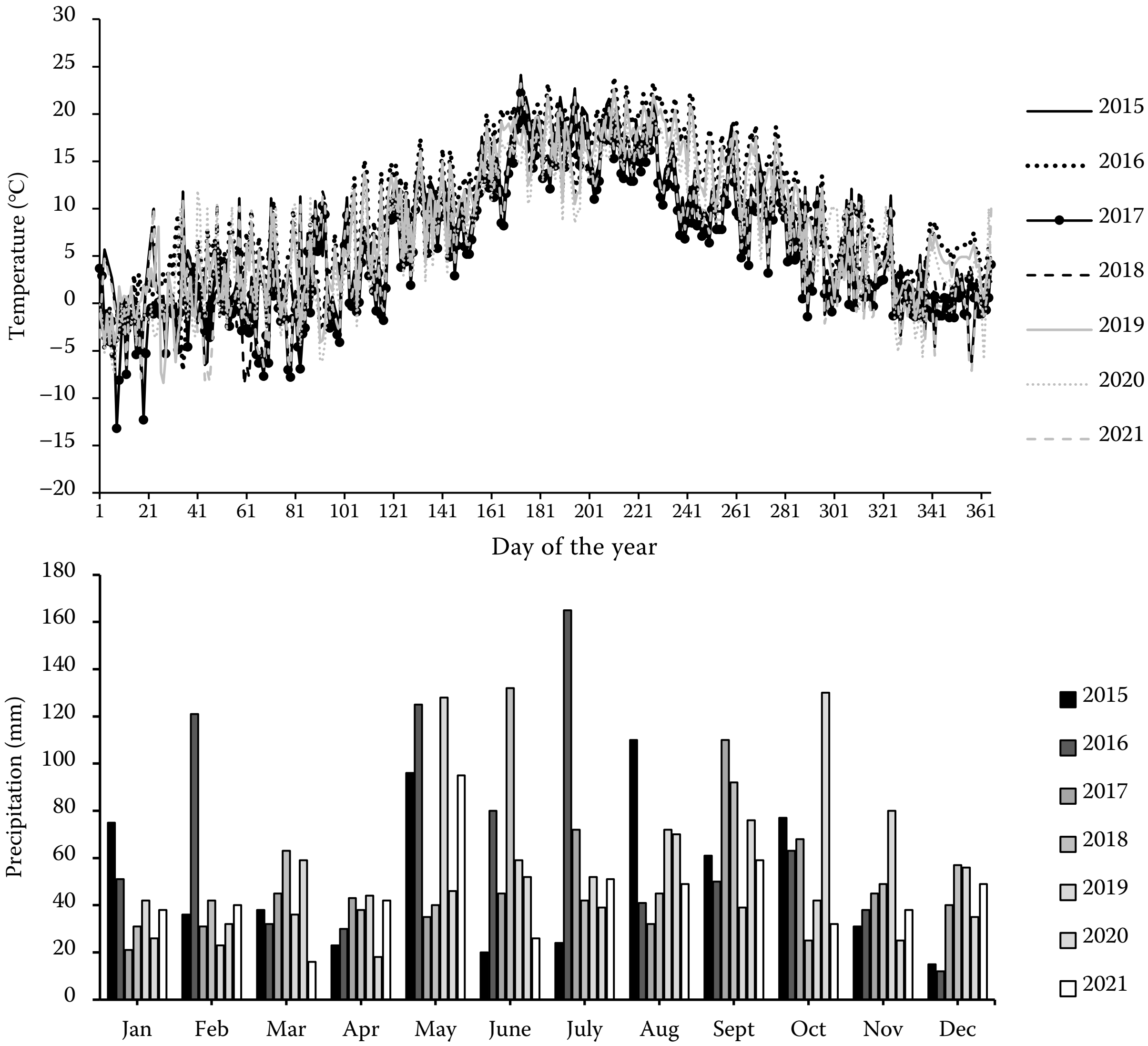

Figure 3. Minimal daily air temperature and monthly precipitation totals over seven consecutive years of *P. cotevisa* plantation development recorded by meteorological station of Slovak hydrometeorological institute in Hurbanovo (SHMI 2021a) situated 15 km NW of the study site

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The ability of the assessed *P. cotevisa* individuals to reach approximately similar values of evaluated growth characteristics in this study indicates that this tree species could contribute to the expansion of the wood biomass resource base, without any considerable production losses.

CONCLUSION

The preliminary results of this study suggest that the hybrid *P. cotevisa* 2® could be used for the purpose of wood production in conditions of the Danubian Lowland. Seven years after planting, mean *DBH* and *H* of the assessed *P. cotevisa* plantation reached 21.5 cm and 11.2 m, respectively. Besides the crown damage caused by wind, development of the evaluated plantation established in the Danubian Lowland was not affected by any other harmful environmental factor or biological pest. However, the results presented in this study are restricted only to the examined material and described conditions of the selected site and further research including comparison of different environmental scenarios or experimental treatments is needed.

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