MECHANICAL PROPERTIES OF JUTE AND HEMP TRAINING STRINGS FROM HOP (*Humulus lupulus* L.) FIELD EXPERIMENTS

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Abstract
The influence of weather conditions, the presence of plants and the treatment of plants on the mechanical properties of selected jute and hemp twines used as hop strings during the 2013 growing season is presented. Twine's operating properties and prices are determined by a raw material from which they are made and by their construction characteristics. The higher the number twists of single yarns and the number of plies are, the better the mechanical properties of twines for hop string will be: higher tensile strength, lower elongation, and less likelihood to cause surface abrasion. For a hop string, plied twines are more appropriate then single yarn twines. As hop strings, coir twines are usually used. In the research, a single yarn twine from hemp fibres used as a hop string deteriorate in mechanical properties during the field experiment much more then plied jute twines. In the field experiments on the deterioration of the mechanical properties of strings, exposure to sunlight had the highest influence, while the development of mould, micro-organisms and plant treatment had minor effects. The tensile strength decreased in the wet state more in the jute twines than in the hemp twine. The two-ply jute twine was more stretchable in the wet state than the three-ply jute twine. With aging, the twines lost toughness; they became less elastic and withstood lower loads. On the basis of the research results, the following conclusions have been made about the expedience of twines for hop strings: twines should be at least two-ply or more to enable higher strength, compactnes and uniformity and lower elongations.
Keywords: hop, *Humulus lupulus*, jute, hemp, twines, training strings, mechanical properties, tensile properties, physical ageing, weather conditions

MEHANSKE LASTNOSTI JUTNIH IN KONOPLJENIH VODIL ZA HMELJ (*Humulus lupulus* L.) IZ POLJSKIH POSKUSOV

Izvleček
V članku so predstavljeni rezultati preučevanja vpliva vremenskih razmer, prisotnosti rastline in postopka pridelave hmelja na spremembo mehanskih lastnosti izbranih jutnih in

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konopljenih vrvic v vlogi vodil za hmelj v rastni sezoni hmelja 2013. Mehanske lastnosti vrvic določajo surovinska sestava in konstrukcijske karakteristike. Čim bolj vite in sukane so vrvice, tem boljše mehanske lastnosti imajo: višjo trdnost, nižjo raztegljivost, manjšo nagnjenost k obrabi. Kot vodila za hmelj so primernejše večnitne sukane vrvice kot enonitne vrvice, največ pa se uporabljajo kokosove. Enonitni vrvici iz konopljenih vlaken, ki je bila uporabljena v raziskavi v poljskih poskusih kot vodilo za hmelj, so se bolj poslabšale mehanske lastnosti kot večnitnim jutnim vrvicam. V poljskih poskusih je bilo ugotovljeno, da na poslabšanje mehanskih lastnosti vrvic vpliva predvsem izpostavljenost sončni svetlobi, medtem ko ima razgradnja vrvic zaradi razvoja plesni in mikroorganizmov ter škropljenja manjši vpliv. V mokrem se je jutnim vrvicam bolj znižala natezna trdnost kot konopljeni vrvici. Bolj vita trinitna sukana vrvica se je v mokrem manj raztezala od manj vite dvonitne sukane vrvice. S staranjem se je vrvicam zmanjšala žilavost; postale so manj raztegljive in manj trdne. Na osnovi rezultatov raziskave so bili postavljeni zaključki, da morajo biti vrvice, ki so primerne kot vodila za hmelj, sukane (dvo ali večnitne), kar jim poveča trdnost, kompaktnost, enakomernost in tudi zmanjša raztegljivost.
Ključne besede: hmelj, *Humulus lupulus*, juta, konoplja, vrvice, vodila, mehanske lastnosti, natezne lastnosti, naravno staranje, vremenske razmere

1 INTRODUCTION

The hop is a climbing plant that needs a training string or a wire to attach its vines as it grows vertically up. The hop training string is strung to a strained steel wire over the plant on a trellis that is permanently kept in the hop field. Until the hop grows enough to hang over the trellis wire, the training string is exposed to the tension of the increasing weight of the growing plant (a mature plant, depending on the cultivar, can attain about 35 kg). During rain and storms with severe winds, the training string is exposed to extra tensile forces, against which it should resist well. Too much stretching or abrading of the string during plant growth leads to weakening and breakage. After the plant reaches the top of the trellis and hangs over it, the string is not so important because the wire takes on the majority of the plant's weight.

Different types of twines could be used as hop training strings. Generally, a twine is a sort of twisted (laid) cordage, normally with a diameter of less than five millimetres. It is made from textile fibres, assembled into a structure that compacts the fibres into a structure of various constructional forms (Teminology, 2013). The process of manufacturing the twine comprises combing selected fibres into a long ribbon (sliver) that is later twisted into a single yarn. Two, three, or more single yarns can be twisted together (Figure 1) into a plied (folded) yarn that can be referred to as a twine.

Fibres in a twine are laid in a helical position. The direction of the twist, as seen in Figure 1, is Z (or S) if the twine held vertically has fibres that slope in the same direction as the middle part of the letter Z (or S) (Terminology, 2009). Twine's operating properties and prices are determined by the raw material used and by their construction characteristics.

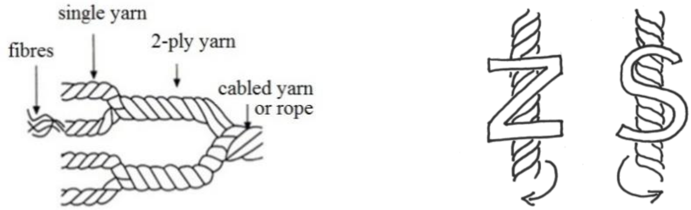

Figure 1: Construction of a plied yarn and a twisting direction scheme.
Slika 1: Konstrukcija sukane preje in shema smeri vitja.

In Slovenia, training string twines from synthetic polypropylene or polyethylene fibres are used, while in the rest of the world, steel wires and twines from coir fibres (from coconuts husks of palm *Cocos nuciferia*) (Koralage …, 2012; Rogue, 2013) are also used. In addition to twines from other bast fibres could be used as hop training strings: from sisal fibres, extracted from *Agava sisalana* plants (WNC, 2010), abaca (manila) fibres from *Musa textilis*, flax fibres from *Linum usitatissimum*, hemp fibres from *Cannabis sativa* (Dewey, 1931) and jute fibres from the jute plant *Corchorus capsularis* (Fisher, 2001).
Synthetic twines have excellent mechanical properties and chemical resistance, do not absorb water, and do not rot and mildew. They can be used for more than one season, but in the existing technology of hop cultivation, they are replaced each season (*Handbook*, 2000). However, the problem with today's production technology is that, after the picking of cones, the hop vines and leaves are usually composted together with the remains of the twine. Over time, the material is converted into compost, which, in the case of using synthetic strings, contains undegraded twine fibres and yarns, which can hinder later the cultivation of the soil by the accumulation of fibres around machine parts at ploughing if the compost is not sieved before it is spread on the field. This is why it should be sieved before spreading to exclude polypropylene and avoid later difficulties in tillage. In any case, when using polypropylene training strings, we gain a lot of waste, which must be handled in an appropriate way to minimize the environmental burden.
On the other hand, strings from natural fibres have significantly lower strength than twines from synthetic fibres, they absorb water, they rot and mildew and they are biodegradable (Handbook, 2000). Hemp and jute fibres are prone to biodegradation by microorganisms in soil, so they would be a good substitute for polypropylene, which is used in Slovenian hop production nowadays, but their proper quality for this purpose should be defined first. Training strings should be sufficiently resistant to weather conditions during the growth season to carry the hop plant weight until

harvest and still not be so strong at harvest that tearing them from the trellis does no damage to the wires.

During hop growth, training strings are exposed to different weather conditions and tensile forces. The aim of our research was to determine the deterioration of twine properties from natural fibres, used as a training string in one growth season. For these purposes, in previous years, jute, hemp, sisal, coir and polypropylene twines have been tested in field experiments, and two types of jute twines and one type of hemp twine have proved to be the best until now. They are included in a detailed analysis of structure and mechanical properties presented in the paper.

The hemp and jute twines included in our research are agricultural plant fibres that serve the plants as stemming tissue. The quality of the extracted fibres depends on the growth conditions and the process of separating the fibres from the stems. The fibres have a multicellular structure where single fibres are connected with a pectin into long bundles that are prone to splitting after extraction. Jute and hemp are lignocellulosic fibres. Jute contains 58−63 percent cellulose, 20−24 percent hemicellulose, 12−15 percent lignin and some small quantities of fats, waxes, pectin, aqueous extract and inorganic matter (Wang et al., 2008). Hemp fibres contain 55−70 percent cellulose, 7−19 percent hemicellulose, 2−5 percent lignin and small quantities of waxes, fats, aqueous extract and inorganic matter (Thomsen et al., 2005).

Jute fibres have lower density then hemp fibres: 1.46 g/cm^3 for jute fibres and 1.48 g/cm^3 for hemp fibres (Wambua, 2003). Hemp fibres have better mechanical properties, i.e. higher tensile strength and a higher modulus of elasticity then jute fibres. The higher moisture content of jute fibres (12%) yields a softer touch and a lower modulus of elasticity than those of hemp fibres, with an 8% moisture content (FAO 2013). Hemp fibres are more than two times stiffer than jute fibres.

In an experiment (Arshad and Mujahid, 2011), it has been shown that, after three months, jute has been biodegraded more than hemp fibres. Jute and hemp fibres are sustainable and, as such, highly suitable for use in agriculture. Jute plants also need very little fertilizer and pesticides for growth. Jute fibres are one of the most inexpensive vegetable fibres, as prices fell sharply at the beginning of the 2010/11 season (Current, 2011). They are the most important lignocellulose fibres, with a global production of 3.46 million tons in the 2011/12 season (World, 2012). The biggest producer of jute fibres is India, followed by Bangladesh, China, Nepal, Myanmar and Thailand.

2 MATERIALS AND METHODS

Selected twines from hemp and jute fibres, which were indicated as the most appropriate among those investigated in previous years, were used as hop training strings in field experiments at the Slovenian Institute of Hop Research and Brewing in Žalec during the 2013 season, from April (training) to the end of August

(harvest). They were exposed to weather conditions in a field with growing plants, and some of them were exposed without plants. The weather conditions in the 2013 season are presented in Figure 1.
Twines from spools were designated as No. I, II and III. Twine No. I was made from hemp fibres imported from Hungary. The other two twines, designated as No. II and III, were made from jute fibres and imported from China.
After cone harvest, the twines were removed from the hop vines. The twines were designated as follows (Table 1):

- Twines extracted from plants in an SN2 field (integrated hop production) were designated as No. I plant, No. II plant and No. III plant.
- Twines extracted from plants used in an ECO field (organic hop production) were designated as No. II plant eco.
- Twines exposed to weather conditions without plants in an SN2 field were designated as No. I bare, No. II bare and No. III bare.

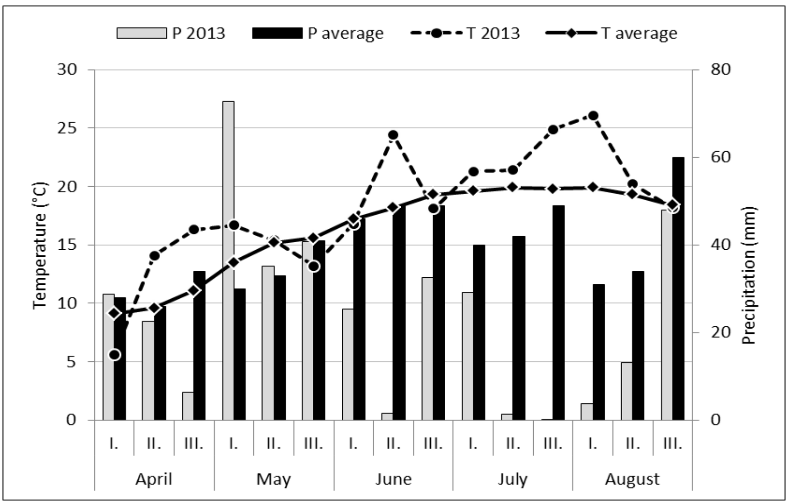

Figure 1: Amount of precipitation and ten days average temperatures from April to September within the 2013 hop growth season in comparison to the 40-year average (Agrometeorological, 2013).
Slika 1: Količina padavin in povprečne dekadne temperature od aprila do septembra 2013 v primerjavi s 40-letnim povprečjem (Agrometeorological …, 2013).

The twist direction and the number of twists per metre was determined with the help of a twist counter according to the standard SIST EN ISO 2061 (Textiles, 2002a). A specimen length of 500 mm was used for ply yarns and of 250 mm for single yarns.

The tensile properties of the twines were measured on a Instron 5567 dynamometer (Instron, Great Britain) in accordance with the standard SIST EN ISO 2062 (Textiles, 2002b). To measure the tensile properties in the wet state, the twines were first immersed in distilled water at room temperature (at 23 ºC) for 24 hours and then carefully rinsed on a paper and immediately measured.

Table 1: Twine descriptions and designations.
Preglednica 1: Opisi in oznake vrvic.

Description	Designations of sample No. according to treatment			
Hemp, natural, single yarn	I	I bare	I plant	
Jute, natural, 2-ply yarn (2,200 tex x 2)	II	II bare	II plant	II plant eco
Jute, natural, 3-ply yarn (1,100 tex x 3)	III	III bare	III plant	

A longitudinal view of the twines and measuring diameters were done using a stereomicroscope Leica EZ4 D equipped with the software Leica Application Suite Ver. 2.3.0 R2 (Leica Mycrosystems, Switzerland). The fineness of the twines was determined gravimetrically on 500 mm twine cuttings and calculated by equation 1:

$$T_t = \frac{mass\ (g)}{0.50\ m} \times 1000\ (tex) \qquad (1).$$

The number of measurements (N) was determined according to used standards. Statistical analysis of variance was made with the Statgraphics Centurion XV, Ver. 15.1.02 programme for the tensile properties by a multiple range test. The method used discriminates among the means in Fisher's least significant difference (LSD) procedure. With this method, there is a 5.0% risk of calling each pair of means significantly different when the actual difference is equal.

3 RESULTS AND DISCUSSION

3.1 Properties of twines from spools

Twine No. I was a single yarn composed of hemp fibres of the average length of 150 mm; twine No. II was a 2-ply yarn made from two single yarns composed of jute fibres of a length of about 120 mm; and twine No. III was a 3-ply yarn made from three single yarns, composed from jute fibres of an average length of 140 mm. The structures of the twines from spools are given in Figure 2.
The fineness of the twines ranged from 2,610 to 3,344 tex (Table 2). The most uniform was twine No. III, while twine No. II was the least uniform. The

uniformity of the twine's fineness influences their tensile strength. Twines with higher uniformity of fineness usually attain higher tensile strength.
The diameter of the twines (Table 2) was measured indirectly in stereomicroscopic pictures (see Figure 2, No. III jute 3-ply yarn). The average diameter of the twines was between 2.1 mm (No. III) and 3.4 mm (No. II).

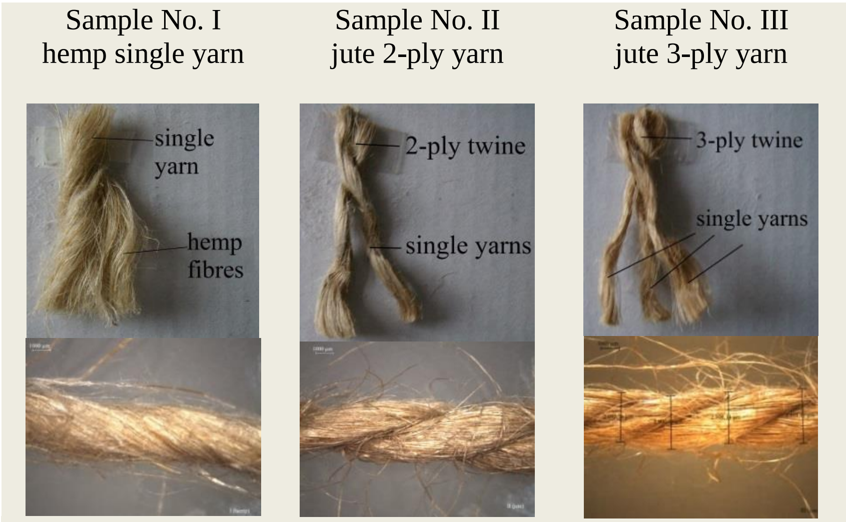

Figure 2: Twine structures.
Slika 2: Struktura vrvic.

Table 2: Fineness of twines.
Preglednica 2: Finoča vrvic.

Sample No.	N	$\bar{x}$ (tex)	SD (tex)	RSD (%)	x_{min} (tex)	x_{max} (tex)
I	20	2,609.7	249.0	9.5	2,217.4	3,141.4
II	20	3,344.0	425.7	12.7	2,700.6	4,024.8
III	20	2,989.0	168.6	5.6	2,715.8	3,247.2

Twines No. II and III have an alternating plying (Table 4). The 3-ply and the 2-ply yarns had a similar number of twists, but the 3-ply twine was made from more twisted single yarns than the 2-ply twines (Table 4). Higher twists cause the twine to be more compact, harder and stronger. Both the plied twines were very compact, especially the 3-ply twine. The hemp twine, No. I, was, in contrast, soft and compressible and as such is very suitable as a binder twine, too.

Table 3: Twine diameter.
Preglednica 3: Premer vrvic.

Sample No.	N	$\bar{x}$ (mm)	SD (mm)	RSD (%)	x_{min} (mm)	x_{max} (mm)
I	18	2.95	0.59	19.9	2.25	4.31
II	8	3.39	0.56	16.5	2.36	4.38
III	6	2.07	0.62	29.8	1.64	3.13

Table 4: Twists.
Preglednica 4: Vitje.

Sample No.	N	Twist direction	Number of twists per meter				
			$\bar{x}$ (m^{-1})	SD (m^{-1})	RSD (%)	x_{min} (m^{-1})	x_{max} (m^{-1})
I: single yarn	54	Z	70.4	9.1	25.4	8	32
II: single yarn	96	S	27.6	6.7	24.3	12	40
III: single yarn	18	S	49.1	5.1	10.4	40	56
II: ply yarn	30	Z	56.1	8.0	14.2	40	68
III: ply yarn	20	Z	60.4	6.35	10.5	52	72

The mechanical properties of twines depend on the selected fibrous material and composition, which refers above all to the number and direction of twists and the number of subsequent twisting operations. The strength of a twine depends greatly upon the strength and length of the fibres from which it is made (Verrill, 2004). Alternating plying of twines, i.e. Z/S or S/Z, is assumed to be stronger than for non-alternating cordage, i.e. ZZ or SS, because the alternation of a level locks the previous level. The higher the numbers of yarns and ply are, the stronger the cord will be: a ply yarn twine is assumed to be stronger than a single yarn.
The tensile properties of twines No. I, II and III are presented on in Figure 3. All three twines had a tensile strength over 40 kg. The highest tensile strength, near 50 kg, was exhibited by the twine No. III.
The high tensile strength of single twine No. I in comparison to jute plied twines should be a consequence of the much stronger hemp compared to jute fibres (Wambua, 2003). The higher tensile strength of jute twine No. III in comparison to jute twine No. II can be explained by the higher number of twists of single yarns in twine No. III (Table 4).
Water influenced the tensile strength of all three twines: the tensile strength of wet twines decreased in comparison to dry twines by 23.1% for twine No. I, 42.2% for twine No. II and 25.4% for the twine No. III. The tensile strength of vegetable fibres is always higher in wet fibres than in dry fibres, but alongside of the strength

of the fibres, friction forces between the fibres in single yarns and between the single yarns in ply yarns have a significant influence on the tensile strength of twine. In the wet state, the frictional forces were reduced by water trapped between fibres and between single yarns.

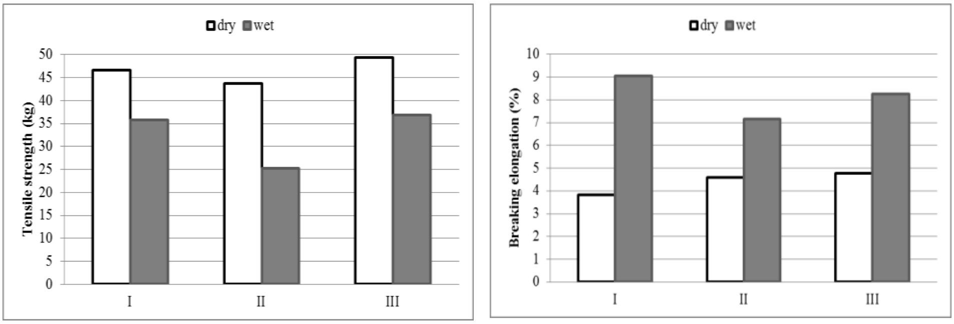

Figure 3: Tensile strength and breaking elongation of twines from spools in dry and wet conditions.
Slika 3: Pretržna sila in pretržni raztezek vrvic z navitkov v suhem in mokrem stanju.

The breaking elongation of twines (Figure 3) was determined in the tensile test as a relative value in percentage of the deformation of twine in the moment before breaking, considering the initial length of the tested twine. The breaking elongation for twine No. I was 3.84%, 4.58% for twine No. II and 4.76% for twine No. III. In the wet state, the breaking elongation more than doubled for twine No. I. The jute twines showed a lower increase in the breaking elongation in the wet state than the hemp twine.

3.2 Properties of twines from the field experiments

The twines from the field experiments were 3.7 to 5.7 m long. Some twines were broken when they were picked from the trellis. Because of solar degradation, mildew and rotting the twines changed colours in the field from reddish to greyish (twines No. II and No. III) and from tawny (twine No. I) to greyish. Figure 4 shows that twines extracted from plants had abraded surfaces and pronounced hairiness.
The tensile properties of twines from field experiments in a dry state are presented in Tables 5, 6 and 7. They show the influence of weather conditions, growing plants and treatment processes on the twine's degradation during the field experiments.
The remaining breaking strength of twines from the field experiments (Table 5) was 24–25 kg for twine No. I bare/plant, 35–36 kg for twine No. II bare/plant and 34 and 41 kg for twine No. III bare/plant. The hemp twine lost about ½ of the

tensile strength of the twine from the spool, the jute twines lost about of 1/5 of the tensile strength of the twines from the spools.

Figure 4: Twine structure after hop harvest at the end of the season.
Slika 4: Struktura vrvic ob koncu rastne sezone hmelja v letu 2013.

Table 5: Tensile strength of samples from field experiments in a dry state.
Preglednica 5: Natezna trdnost v suhem stanju za vzorce iz poljskih poskusov.

Sample No.	Tensile strength in dry state				
	$\bar{x}$ (kg)	SD (N)	RSD (%)	x_{min} (kg)	x_{max} (kg)
I bare	24.19	7.04	29.11	10.71	32.84
I plant	25.38	4.17	16.41	18.15	31.20
II bare	36.20	4.80	13.25	31.08	37.48
II plant	35.54	7.375	20.75	22.48	46.505
II plant eco	35.02	4.33	12.37	25.56	41.89
III bare	34.17	2.68	7.85	29.30	35.58
III plant	41.08	3.06	7.45	36.73	47.28

The influence of the plants on the tensile strength was different (Table 6), insignificant for twines No. I and No. II, but for the jute 3-ply twine, the tensile strength was almost 20% higher than for bare twine (Table 5). At the beginning of the hop plant growth the twines were bare until the plants covered them with leaves and protected them against solar degradation. From the results, it can be concluded that solar degradation is the most influential cause for the decreasing tensile strength of twines. Different treatments of plants, i.e. the integrated and eco treatment, had no influence on the tensile strength of the twines (Table 6).

Table 6: Changes in the tensile strength of twines in the dry state.
Preglednica 6: Spremembe trdnosti vrvic v suhem stanju.

Sample No.	Changes in tensile strength in dry state (%)		
	Spool/plant	Bare/plant	Plant/plant eco
I	-45.54	-4.92	-
II	-18.67	-1.82	-1.46
III	-16.67	+20.20	-

The remaining breaking elongation of the twines from field experiments was about 2.5% for twine No. I plant/bare and about 4% for twine No. II bare/plant and No. III bare/plant (Table 7).

Table 7: Breaking elongation of samples from field experiments in a dry state.
Preglednica 7: Pretržni raztezek v suhem stanju za vzorce iz poljskih poskusov.

Sample No.	Breaking elongation in dry state				
	$\bar{x}$ (%)	SD (%)	RSD (%)	x_{min} (%)	x_{max} (%)
I bare	2.50	0.36	14.52	1.57	3.22
I plant	2.60	0.31	11.8	2.01	3.22
II bare	3.95	0.64	16.3	3.02	4.83
II plant	3.66	0.55	15.0	2.82	4.63
II plant eco	3.55	0.29	8.3	3.02	4.02
III bare	4.33	0.79	18.3	3.23	5.83
III plant	3.52	0.49	14.0	2.82	4.03

Influence of plants during the field experiments on the changes in the breaking elongation in comparison to the twines from spools (spool/plant), to the twines without plants (bare/plant) and to the treatment process (plant/plant eco) are minimal (Table 8).
The influence of water on the remaining tensile properties of twines is given in Tables 9 and 10.

Table 8: Changes in breaking elongation of twines in a dry state.
Preglednica 8: Spremembe pretržnega raztezka vrvic v suhem stanju.

Sample No.	Changes of braking elongation in dry state (%)		
	Spool/plant	Bare/plant	Plant/plant eco
I	1.34	-0.1	-
II	0.63	0.29	0.11
III	0.4	0.81	-

Table 9: Tensile strength of samples from field experiments in a wet state.
Preglednica 9: Natezna trdnost v mokrem stanju za vzorce iz poljskih poskusov.

Sample No.	Tensile strength in wet state				
	$\bar{x}$ (kg)	SD (kg)	RSD (%)	x_{min} (kg)	x_{max} (kg)
I bare	31.37	9.25	29.49	15.55	47.46
I plant	27.96	8.74	31.26	17.70	41.80
II bare	18.15	2.27	12.52	14.18	20.84
II plant	16.78	2.06	12.30	9.29	17.62
II plant eco	13.67	2.73	20.00	13.55	22.53
III bare	16.87	1.20	7.10	15.24	18.80
III plant	22.96	3.09	13.46	18.86	28.44

Table 10: Breaking elongation of samples from field experiments in a wet state.
Preglednica 10: Pretržni raztezek v mokrem stanju za vzorce iz poljskih poskusov.

Sample No.	Breaking elongation in wet state				
	$\bar{x}$ (%)	SD (%)	RSD (%)	x_{min} (%)	x_{max} (%)
I bare	5.51	1.33	24.05	1.97	6.84
I plant	5.90	0.58	9.80	5.23	7.04
II bare	7.23	1.04	14.3	5.64	8.66
II plant	7.25	1.24	17.1	5.64	9.46
II plant eco	6.67	0.78	11.7	5.23	8.05
III bare	5.84	0.45	7.80	4.83	6.45
III plant	5.86	0.78	13.3	4.83	6.84

The influence of water on tensile strength is statistically significant for both jute twines, but not for the hemp twine. The influence of water on the breaking elongation is statistically significant for all three twines.
The tensile strength/elongation curves of twines from the spools and the field experiments are presented in Figure 5. The curves have a similar shape for all twines. At very low loads, i.e. a cca under 2 kg, the twines showed a very short elastic deformation of under 1%. Increasing the load over 2 kg influences plastic causing unrecoverable twine deformation. At the same load, the twines from spools show higher elongations. Twines from the field experiments are less tough than the twines from spools.

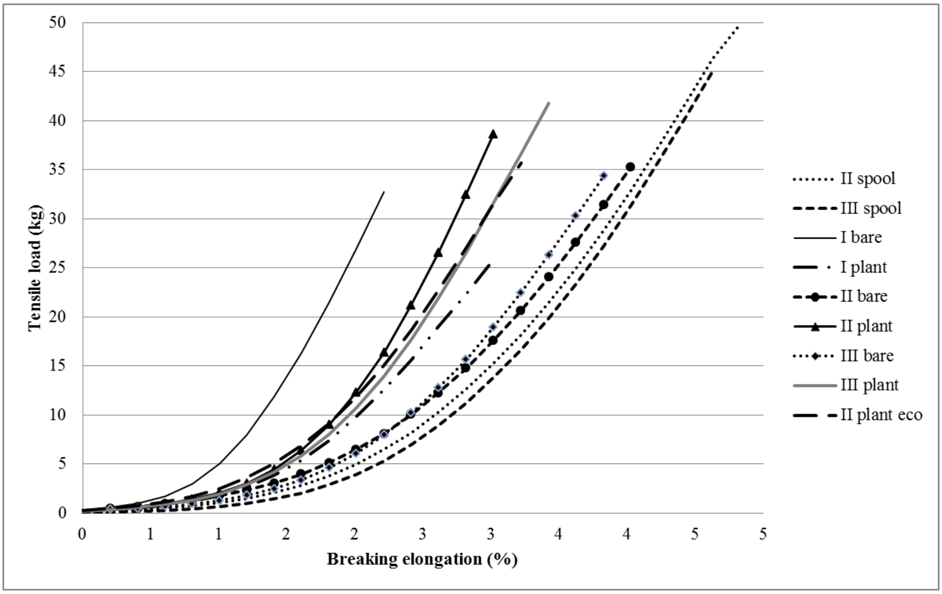

Figure 5: Tensile load from elongation curves for bare twines from field experiments.
Slika 5: Krivulje natezna trdnost/raztezek za vrvice iz poljskih poskusov.

The influence of the distance of the twines from the ground to the metal wire on tensile strength (Figure 6) shows that the positions have no significant influence. This means that the degradation of twines is more or less similar along the twine. Twines always break at the wire because of the very strong plant stems that do no break generally. Because of this, the most stressed point of the twine is there where it is attached to the metal wire. In addition, the rubbing of twine against the wire can have some influence.

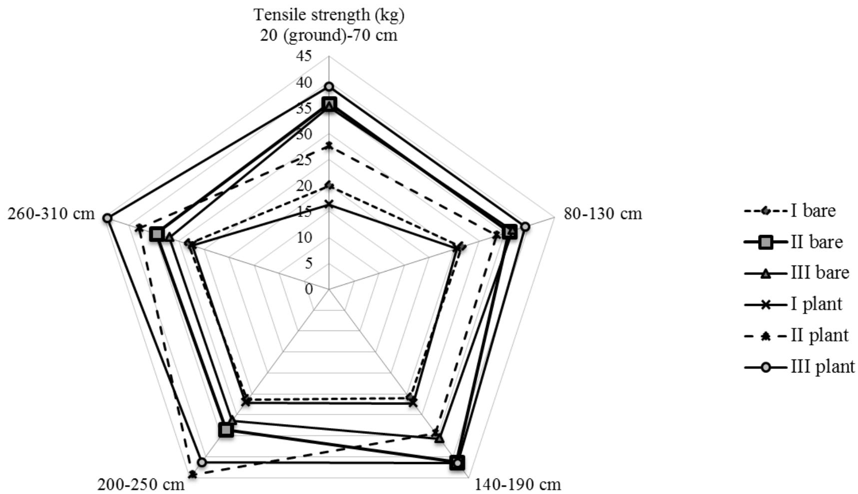

Figure 7: Dependence of the tensile strength of the twines from a distance between 0 cm and 270 cm along the twine, i.e. from the point where the twines are attached to the ground and the point near where the twines attached to the metal wire.
Slika 7: Odvisnost natezne trdnosti vrvic od njene pozicije med 0 in 270 cm vzdolž vrvice, to je od točke, kjer je vrvica pritrjena na podlago (tla) do točke, kjer je pritrjena na kovinsko žico.

4 CONCLUSIONS

On the basis of the research results, the following conclusions can be given:

- Single hemp yarn twine from a spool had comparable mechanical properties as jute 2-ply and 3-ply twines from spools.
- After exposure to weather conditions in field experiments, the mechanical properties of the hemp twine deteriorates much more than the jute twines.
- For all three twines used as hop strings, it was found out that sunlight had the highest influence, while the development of mould, micro-organisms and plant treatment had a minor impact.
- In the wet state, the tensile strength of twines decreased and their breaking elongation increased.
- The 2-ply jute twine was more stretchable in the wet state than the 3-ply jute twine.
- With age, the twines lost toughness; they became less elastic and withstood lower loads.

The following conclusions have been made about the suitability of twines for hop strings: twines should be at least 2-ply or more to enable higher strength, compactness and uniformity, and lower elongations.

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