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Impact of the seeding rate on flax stem stability and the mechanical properties of elementary fibres

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ABSTRACT

Cultivation of flax fibres (*Linum usitatissimun*) for composite reinforcement must provide fibres with good mechanical properties, but also a high fibre yield and lodging stability in order to ensure a stable and satisfactory income for the farmer. This work proposes a study of the impact of the seeding rate on these key parameters. We studied the Aramis variety with 4 different seeding rates (1200, 1500, 1800 and 2500 seeds/m^2). The results indicate the significant impact of the seeding rate on the stem's morphological parameters; its increase induces a progressive decrease of the scutched fibre length and of the stem diameter. At the same time, the higher seeding rates obtained improved the scutched fibre's yield (+11% between 1200 and 2500 seeds/m^2) but, conversely, induced a drop in the elementary fibre's tensile properties and in the flax stem's lodging stability, mainly due to the large decrease in the stem's diameter. This work shows that a compromise must be found to optimize the fibre yield, the mechanical performance and the plant's stability; it underlines the relevance of using a conventional seeding rate, close to 1800 seeds/m^2.

1. Introduction

Over the last few years, we faced significant developments in biocomposites; manufacturers are now considering semi-structural applications for these materials that require the use of vegetal fibres that have efficient and reproducible mechanical properties (Lefeuvre et al., 2014a). In a previous work (Baley and Bourmaud, 2014), we showed that flax fibre, in spite of slight differences from one variety to another, exhibit stable mechanical performances and can compete with glass fibres. Nevertheless, mechanically speaking, some differences exist between fibre batches.

Variations into fibre mechanical properties could be explained by the structure of the fibre and the biochemical composition of the cell walls (Alix et al., 2009; Bourmaud et al., 2013; Roach et al., 2011) and could be due to the flax varieties gene pool (Brutch et al., 2011) but they could also be influenced by environmental stimuli mainly induced by rain or wind (Menoux et al., 1982). The most common features of thigmomorphogenesis on plants are a decrease in elongation growth and an increase in radial expansion (Braam, 2005) but it also has an influence on the quantity and stiffness of strengthening tissues (Biddington, 1986; Telewski, 1995). Furthermore, the stimuli frequency has an impact on the plant acclimation as well as on their specific responses, particularly on the increase of the stem diameter (Martin et al., 2010).

Amongst other indicators, the involvement of calcium in the early events of exterior stimuli sensing and transduction was found (Bush, 1995; Knight et al., 1991). In the case of flax, Verdus et al. (1997) evidenced that the number of meristems produced is strictly dependent on the intensity of the environmental stimuli received; the meristems production being governed by calcium depletion signals. On *Arabidopsis*, Braam et al. (1997) showed that the TCH gene regulation and expression is a response to environmental stimuli and could lead to an increase in xyloglucan crosslinks with cellulose microfibrils and hence cell wall reinforcement of non-growing cells stimulated by touch or wind. In wood cell walls, xyloglucans play a linking role, between the S2 and G layer (Mellerowicz et al., 2008); in flax cell walls, xyloglucans are part of the non-cellulosic polymer matrix and are mainly present in the primary wall (Morvan et al., 2003).

During the flax growing period, environmental stimuli are mainly due to the sun, wind and rain, which can induce plant lodging. The boundary conditions, i.e., the anchorage quality and the soil behaviour are also preponderant parameters for plant stability and the lodging is highly influenced by the stem stiffness, the environmental stimuli and especially the additional water

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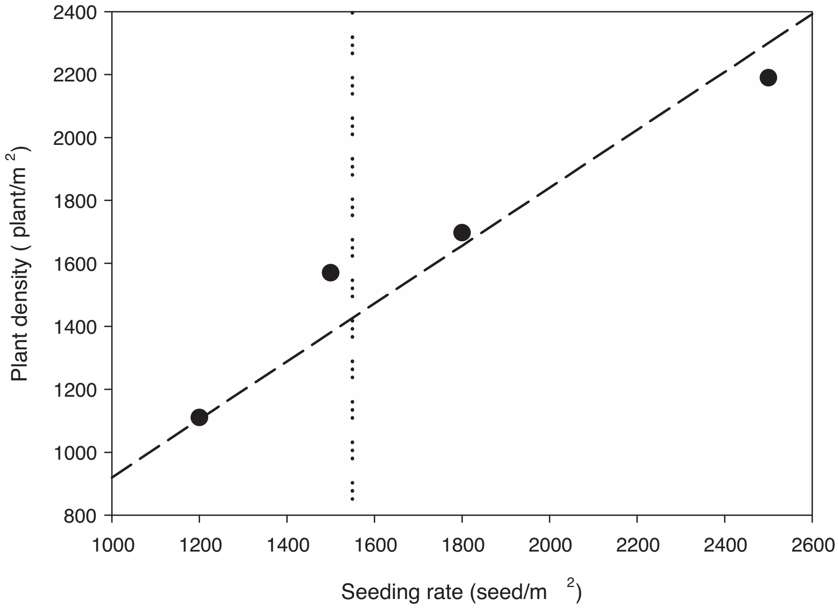

Fig. 1. Relationship between the seeding rate and the plant density. The dashed line represents the case of an emerging plants rate of 92% and the dotted line the recommended plant density (Bert, 2013).

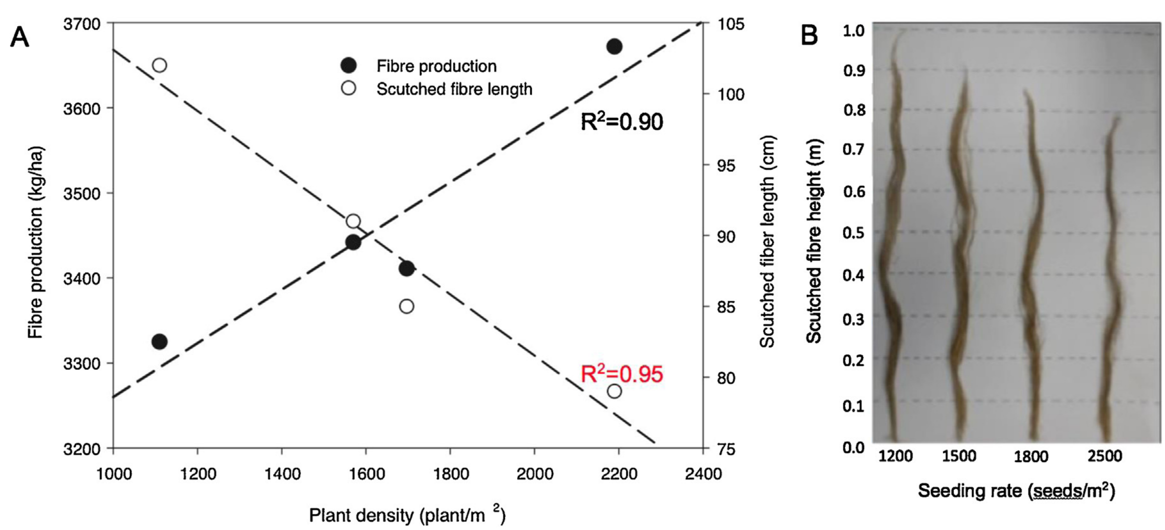

Fig. 2. Impact of the plant density on the scutched fibres yield and stem height (A) and illustration of the scutched fibre length evolution (B).

Table 1
ANOVA one way parameters *P* values indicating the statistical differences between each plant density for elementary fibres Young's modulus, strength and elongation at break. Bold values are significantly different ($P < 0.005$).

Compared plant densities	Young's modulus Tukey prob value	Strength at break Tukey prob value	Elongation at break Tukey prob value
1570-1110	2.54×10^{-1}	9.63×10^{-1}	9.68×10^{-1}
1697-1110	7.81×10^{-1}	4.27×10^{-1}	2.35×10^{-1}
1697-1570	8.44×10^{-1}	1.86×10^{-1}	4.48×10^{-1}
2190-1110	$\mathbf{3.34 \times 10^{-3}}$	$\mathbf{2.54 \times 10^{-3}}$	3.60×10^{-1}
2190-1570	3.48×10^{-1}	$\mathbf{1.03 \times 10^{-2}}$	1.43×10^{-1}
2190-1697	8.14×10^{-2}	$\mathbf{7.57 \times 10^{-6}}$	$\mathbf{2.99 \times 10^{-3}}$

weight. Consequently, the distribution of water drops on the plant increases its mass and, with windy conditions, the risk of instability becomes even more significant. The work of varietal selection aims to develop new varieties to increase the production of fibres or seeds but also concerns the behaviour of lodging or disease resistance, which are primordial parameters in order to ensure a sufficient income for the farmers. In a previous work (Bourmaud et al., 2015), we evidenced that the lodging stability of flax was correlated to the supporting tissues mechanical properties. The lodging stability criteria, which could be optimized during the work of varietal selection, could be assimilated to an indicator of the flax fibre's mechanical performances. Furthermore, the varieties hav-