Physical and mechanical properties affecting the suitability of black ash wood for W8banaki basketry

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Abstract

Black ash (Fraxinus nigra Marsh) is an important species for the W8banaki Nation, which uses its wood for traditional basketry. This study aimed to identify the wood properties required for black ash splints used in basketry. Eleven logs were selected and pounded into 26 longitudinal groups of annual wood layers, which were then transformed into splints. A quality class (high, medium, or low) was assigned by W8banakiak knowledge carriers to each group of rings. We measured wood density, ring width, modulus of elasticity (MOE), and modulus of rupture (MOR) on samples located at the same radial position in wood bolts collected adjacently to the logs used for pounding. To investigate which wood properties were best related to the assigned wood quality class, we applied a generalized linear mixed model (GLMM). Our model revealed a significant effect of ring width and average ring density on the probability to obtain a given wood quality class. Narrow to medium-sized rings and relatively dense wood offered the best quality for basketry practice. Based on our results, further research on the effects of growth conditions that favour the production of high-quality black ash wood could be conducted to ultimately propose silvicultural treatments and management strategies.

Keywords: Basketmaking, wood properties, cultural values, Fraxinus nigra, southeastern Québec

1. Introduction

Black ash (*Fraxinus nigra* Marsh.) is a unique species with specific properties that allow its wood to be flexible in longitudinal bending, while also being resistant to rupture (Costanza et al. 2017; Diamond and Emery 2011; Emery et al. 2014). Among other things, wood from this species is used for furniture, pulpwood and other non-timber forest products (Benedict and Frelich 2008). In addition, an important use of black ash is for Indigenous traditional basketry, i.e., the manufacture of baskets woven from splints. This practice is shared by several First Nations of North America, including the W8banaki, Mi'kmaq, Wolastoqey, Passamaquoddy, Penobscot, Kanien'kehá ka. For the W8banaki Nation, black ash is a strong symbol of identity (Costanza et al. 2017; Frey et al. 2019; Neptune et al. 2017). In their creation story, humans were born from the ash tree (Frey et al. 2019).

The first step in the basket-making process involves the selection and harvest of black ash trees with a high potential for basketry (Benedict and Frelich 2008; Costanza et al. 2017; Diamond and Emery 2011). Harvested logs are then manually pounded to delaminate annual growth rings into longitudinal wood layers (Frey et al. 2019; Rousseau 1950; Siegert et al. 2023). From these, basket makers produce thin splints, which can be woven into baskets of various shapes and functions (Alarcón et al. 2012; Frey et al. 2019; Pelletier 1982). Two conditions support this practice. On the one hand, black ash wood can be transformed into thin and flexible splints thanks to its exceptional flexibility and mechanical resistance, i.e., its ability to bend without breaking (Alarcón et al 2012; Costanza et al. 2017). On the other hand, W8banakiak basket makers, and more precisely ash pounder, detain traditional and technical knowledges, which allows them to select trees, pound the logs and select wood splints suitable for basketry (Berkes 1999; Neptune et al. 2015). However, for this knowledge to be maintained and passed on to future generations, the W8banakiak must maintain their basketry activities, which in turn depends on the sustained availability of healthy and suitable black ash trees (Costanza et al. 2017).

In recent years, the W8banakiak, like other basket-making First Nations, have been concerned about black ash and the future of basketry, mainly due to the spread of the emerald ash borer (*Agrilus planipennis*; EAB) (Benedict and Frelich 2008; Costanza et al. 2017; Neptune and Neuman 2015; Siegert et al. 2023). The emerald ash borer is an invasive wood-boring beetle that feeds on the phloem of ash trees thus creating galleries that disrupt nutrient and water transport and eventually lead to tree death (Siegert et al. 2023).The EAB was first detected in North America in 2002 (Cappaert et al. 2005; Klooster et al. 2018) and has since spread rapidly through the black ash natural distribution range (Cappaert et al. 2005; Herms and McCullough 2014; Siegert et al. 2023).

Adding to the EAB issue, which represents an important threat, relatively few black ash trees (approximately 5–20%) are suitable for basketry (Benedict and Frelich, 2008). They can be selected by basket makers and ash pounders, who have learned to identify suitable black ash trees for basket making based on several precise criteria and to transform their wood into splints through a unique pounding process (Benedict and Frelich 2008; Costanza et al. 2017; Diamond and Emery 2011; Frey et al. 2019). The fact that only a low proportion of trees are suitable for basketry, and that this population is now under threat, represents an important source of concern for the future of this activity.

There is currently a need to engage into research efforts dedicated to the development of adaptation strategies to ensure a sustainable access to suitable black ash material for basketry (Costanza et al. 2017). Although the relationship between annual ring width and wood quality for basketry has been studied by, or in collaboration with, other First Nations whose territories lie south of Ndakina (territory of the W8banaki Nation) (Figure 1) (Costanza et al. 2017; Diamond and Emery 2011; Frey et al. 2019), other wood properties may be involved in determining wood quality by W8banakiak ash pounders. No studies have so far focused on the links between black ash wood properties and wood suitability variation in the context of W8banaki basketry.

As part of a collective effort led by the W8banaki Nation to ensure the maintenance of traditional basketry, a collaborative research project conducted by academic and community researchers was set up with the aim to better understand and document the physical and mechanical properties of black ash wood that are associated with its suitability for W8banaki basketry. Documenting the wood properties that W8banakiak basket makers are looking for to produce high-quality basketry material is seen as the starting point of a wider research effort that will support the Nation in its adaptation process.

To fulfill this objective, we (1) documented W8banaki knowledge and techniques regarding black ash selection and transformation related to basketry, (2) related this knowledge to wood anatomical characteristics and mechanical properties, and (3) identified a range of wood anatomical characteristics and mechanical properties considered highly suitable for W8banaki basketry. Those objectives were based on three assumptions that resulted from discussion and reflection with W8banaki knowledge carriers: 1) the conjunction of Indigenous knowledge (Berkes 1999) and wood science knowledge will deepen our understanding of black ash wood characteristics; 2) the suitability of black ash wood for W8banaki basketry is influenced by its physical and mechanical properties; and 3) obtaining a better understanding of the relationship between wood properties and suitability for basketry will allow the identification of relevant research efforts and actions regarding black ash and basketry in the future. Throughout the study, we made sure that the objectives, methods, and research processes were in accordance with the Nation protocols, needs and expectations.

2. Methods

2.1 The W8banaki Nation

The W8banaki Nation is a southern Algonquin First Nation of the Québec province. The W8banakiak are represented by about 3000 members living both inside and outside of the two communities of Odanak and W8linak (Treyvaud et al. 2018). There are two band councils (Odanak and W8linak) responsible for political matters, daycare services, public safety, etc. The W8banaki is the Tribal Council regrouping the W8banaki bands of Odanak and W8linak. The Ndakina office is a department of the W8banaki and is responsible for territorial consultations, land claims, as well as environmental and climate change adaptation. The Ndakina office initiated this project based on members' concerns and needs and ensured its alignment with the priorities of the Nation.

2.2 General approach

This study was conducted in partnership with the Ndakina office in accordance with a signed research agreement. Three of us (Michel Durant-Nolett, Luc Gauthier-Nolett, and Danny Gill) are ash pounders with specific knowledge related to the W8banaki Nation, including their context and territory, although some elements might be shared with other First Nations. This knowledge encompasses practices and beliefs that are adaptive and based on the relationship between living beings and the environment (Berkes 1999; Rist and Dahdouh-Guebas 2006; Tengö et al. 2014). It is dynamic and transmitted from one generation to another. More precisely, ash pounders have extensive personal experience in harvesting and working with black ash wood for basketry. Within the context of the W8banaki Nation, tree selection and wood pounding are recognized as specific abilities, and people who practice these steps are called ash pounders. Weaving and basket making involve individuals with a different set of knowledge known as basket makers. They can also be referred to more broadly as knowledge carriers (Trosper et al. 2012).

The importance of Indigenous knowledge and the use of an interdisciplinary approach is now increasingly valued and recognized to respond to the complexity of environmental issues (Kimmerer 2002; McGreavy et al. 2021; Tengö et al. 2014). For this study, we adopted a participatory action research approach (Weber-Pillwax 2009), which provides a space for knowledge systems and people to interact (Kimmerer 2002; Tengö et al. 2014) over an extended period to address specific problems (Smith 2021; Huntington 2000). This approach allowed us to work on a common subject, namely black ash, while respecting each knowledge system (scientific and Indigenous) and considering them on equal footing (Asselin 2015). The research was approved by the ethics committee for research involving humans at Laval University.

2.3 Study area

The study area is the Quebec part of Ndakina, the ancestral land of the W8banaki Nation. Ndakina expands from the Richelieu to the Etchemins rivers from west to east and from the south shore of the St-Lawrence River to the USA border from north to south (Figure 1). Ndakina is located within the natural distribution range of black ash, which expands from northern Ontario to Virginia from North to South and from Newfoundland to Manitoba from East to West. Around 51% of the natural range of black ash is located in Canada and the occurrence of the species is more common in the centre of its natural distribution range (COSEPAC 2018). Ndakina overlaps four bioclimatic domains in Quebec, i.e., sugar maple (*Acer saccharum*)-butternut hickory (*Carya ovata*), sugar maple-American basswood (*Tilia americana*), sugar maple-yellow birch (*Betula alleghaniensis*), and balsam fir (*Abies balsamea*)-yellow birch bioclimatic domains (Saucier et al, 2009).

Black ash trees were sampled in two sites located in Ndakina. The first was located on the Seigneurie de Lotbinière (46° 32′ 00″, 71° 51′ 00″). The average altitude is 81 m, the mean temperature is 5°C and the mean precipitation is 1143 mm. It is part of a public forest estate, that has been used by the W8banakiak as a supply area for black ash since 1990. The second site is on Domtar Corporation's private lands (45° 21 '30 ", 71 °17′ 15″). The average altitude is 417 m, the mean temperature is 4.3°C and the mean precipitation is 1160 mm. This site was identified prior to sampling using Domtar's forest resource inventory data.

2.4 Tree and log sampling

In the summer of 2020, four and seven trees were harvested in the Seigneurie de Lotbinière and Domtar private lands, respectively. Trees were selected based on guidelines from knowledge carriers, which allow them to target standing trees likely suitable for the pounding stage. The guidelines are based on several criteria, including general tree vigour, diameter at breast height (DBH), stem straightness, stem vigour, absence of defects (e.g., dead branches, cracks), and absence of adventitious buds. Bark colour and texture also help knowledge carriers in tree selection, as a thick and spongy bark can be indicative of the suitability of black ash stems for basketry (Costanza et al. 2017, Luc Gauthier-Nolett and Michel Durand-Nolett, pers. observation. July 2020). The best logs (i.e., straight and without defects) that had been selected from the standing trees could then be processed into wood splints at the pounding stage. At each site, some black ash trees with good basketry potential were also deliberately left standing to ensure a supply for future generations.

For each of the 11 harvested trees, W8banakiak knowledge carriers selected one to three logs of 2.0 to 2.5m in length (Figure 2A). A total of 23 logs were sampled with large end diameters ranging from 20 to 28 cm. At both ends of each log, 30-cm bolts were sampled and used for mechanical and physical tests (Figure 2B). Logs were stored in Odanak and the bolts were transported to Laval University's Renewable Material Research Centre (CRMR)

2.5 Pounding process and wood splint sampling

After harvesting trees and selecting logs, we proceeded to the pounding stage which led to the extraction of wood splints (Figure 3). During the pounding stage, knowledge carriers made an evaluation of the suitability of each pounding layer for basketry. This evaluation was made according to two main criteria: 1) annual rings can easily be peeled from the log, 2) the annual rings that are delaminated from the logs are flexible and rupture resistant. Although we had previously selected logs with a high potential for pounding, this did not completely ensure that ash pounders could extract only high quality material from them (Costanza et al. 2017, Luc Gauther-Nolett and Danny Gill, pers. observation. October 2020). In fact, not all black ash annual rings could be transformed into thin and flexible splints because wood anatomical and mechanical properties vary within the stem, from pith to bark and from the stump to the apex of the stem (Luc Gauthier-Nolett and Danny Gill, pers. observation. October 2020). During the pounding stage, knowledge carriers attributed a quality grade to the black ash pounding layers that were delaminated (low, medium, or high). This evaluation process considered the smoothness of the splints, their colour, and the ease of peeling off the splints from the log, among others, which were considered in a holistic evaluation (Asselin 2015).

To pound a log and process the wood into thin and flexible splints, the knowledge carrier placed the log horizontally supported by smaller logs placed at both ends, so that the log laid a few centimeters above the ground. The knowledge carrier repeatedly pounded the log with the back of an axe from one end of the log to the other (Figure 3A). If two pounders work on the same log such as in the W8banaki way of pounding black ash, they position themselves on the same side of the log and alternate their pounding motions in a rhythm.

Black ash being a ring-porous hardwood, earlywood contains large vessels that are crushed during the pounding stage. In contrast, the latewood is denser and characterized by smaller vessels, which resist the pounding. As a result, the pounding causes the delamination of annual wood layers that are mainly composed of latewood, since the earlywood has been crushed. These annual wood layers generally come off the log in a group of five (but this may range from three to 15). This group of wood layers is called a pounding layer (Figure 3B). The annual wood layers contained in the pounding layer are generally too thick to be woven. They are then processed with a splinter tool that allows the knowledge carrier to split them into thinner splints. Lastly, individual splints are polished, refined, and rolled up to be stored in anticipation of being used for weaving (Figure 3C).

Our study focused on the pounding stage, during which 27 pounding layers were delaminated from 10 logs and attributed a quality grade. Quality grades were categorized as high, medium, and low quality. This qualitative assessment was based on the general suitability of wood layers contained in one pounding layer for basketry and its general appreciation by log pounders. Splints of different qualities can be used for different types of baskets (Costanza et al. 2017). To be assigned a high-quality grade, the splints contained in a pounding layer had to be easily delaminated from the log and easily divided into flexible but rupture-resistant thinner splints. Such splints are few in number and can be used for the production of fancy baskets, especially if they are extracted in the sapwood area of the log and white coloured (Alarcón et al. 2012). Pounding layers assigned a medium-quality grade are generally used for frames or utility baskets since the splints are usually thicker, less easy to work with, and darker-coloured. Those assigned a low-quality grade are considered unsuitable for basketry as they often break at the pounding stage and are hard to divide into splints. As the quality assessment was done at the pounding layer level, the pounding layers were used as the sampling unit for the analyses. The pounding stage took place from October to November 2020. The remaining material was stored for the future needs of the Nation for basketry.

2.6 Physical wood properties

Densitometry analyses were used to produce profiles of annual ring width, density and proportion of latewood and earlywood, which may all influence the flexibility-related properties (Alteyrac et al. 2006) that are key for W8banaki basketry. From each bolt extracted from the ends of the pounded logs, a radial pith-to-bark segment was cut (Figure 2B) and air dried in a conditioning chamber maintained at 65 % relative humidity and at 20°C until they reached ~12 % moisture content. From these segments, radial pith-to-bark strips (1.6 mm thickness, 25 mm width) were extracted for densitometry analyses (Figure 2B). Wood density profiles were obtained by scanning radial strips with a QMS Tree ring analyzer densitometer (QTRS-01X) with a resolution of 20 µm. During this process, an X-ray beam passes longitudinally through the strip while the sample is progressively moved along its radial direction (Quintek Measurement Systems Inc., Knoxville, TN, USA). Density profiles were obtained using the image analysis software QMS Tree Ring System (QTRS, version 2.03). Densitometry measurements allowed us to obtain the density (kg/m^3) and width (mm) of each annual ring. Annual rings were visually delaminated following the method developed by Mothe et al. (1998) which is to compute a floating threshold based on the minimal and maximal densities in the ring. This allowed us to obtain width of earlywood and latewood within each ring. We then averaged these variables for each pounding layer previously prepared by Danny Gill. So, for each pounding layer, we had the average earlywood and latewood widths, the average ring width, and average density of all the rings it contained.

2.7 Mechanical wood properties

For the static bending tests, we used small clear specimens of 10 x 10 x 160 mm in the radial, tangential, and longitudinal directions, respectively (Figure 2B). Samples were prepared following the methodology described in Torquato (2014) and Waldron et al. (2020). From each bolt extracted from the ends of the logs, a pith-to-bark slab was sawn and air-dried in the same conditioning chamber as the wood strips until they reached a constant mass indicating that the samples had reached ~ 12 % moisture content. The slabs were then reduced to a 10 mm thickness using a planer. We then drew successive 10-mm-wide and 160-mm-long specimens directly on the slab. Small, clear wood specimens were extracted from the bark to the pith, aligned parallel to the grain and spaced 3 mm apart to accommodate the thickness of the saw cut, while avoiding defects such as knots (Figure 2B). By doing so, we ensured consistency with the pounding technique, which also delaminates annual rings from bark to pith. We counted and identified the number of annual rings to position small clear specimens in the log, allowing us to associate the mechanical properties with the characteristics of each pounding layer extracted by the W8banaki knowledge carriers.

Mechanical properties were measured in longitudinal static bending using an adaptation of the ASMT D-143 standard for smaller specimens. First, the depth, width, and length of the specimens (mm) were measured using calipers. Upon testing, specimens were placed pith upwards in the horizontal position for a three-point longitudinal static bending test with a span of 140 mm. An increasing load was then applied on the samples at a speed of 2 mm/min while the resistance force was measured by a 5kN load cell. The bending test was performed below the elastic limit and until the rupture of the specimen. The modulus of elasticity (MOE) and the modulus of rupture (MOR) were then measured from pith to bark with a variable number of observations that depended on the log radius.

2.8 Statistical analyses

To investigate which wood properties were related to the wood quality assessments made by W8banaki knowledge carriers, we applied a generalized linear mixed model (GLMM) in the form of a mixed ordinal regression model with a cumulative logit link function. This process allowed us to work with fixed and random effects and assess which variables showed the best performance in predicting wood quality classes. The regression was computed with the procedure GLIMMIX of SAS software, version 9.4.

The response variable corresponding to the quality class was assessed by the knowledge carriers on the pounding layer. The quality was coded as an ordered factor with levels high, medium, and low corresponding to 1, 2, and 3, respectively. Four variables were selected as candidate predictors: ring width, ring average density, MOE, and MOR. The predictors were measured at different scales (ring width and density measurements were made at the ring level, while MOE and MOR were measured on small clear specimens consisting of several annual rings). Because quality classes corresponded to pounding layers, all variables were averaged at this scale. We also added a tree-level random intercept, as there was more than one pounding layer per tree. The final dataset consisted of 27 pounding layers originating from 10 different logs.

Prior to developing the models, correlations among variables were checked using Pearson’s correlation coefficients (Figure 4) as well as variance inflation factor (VIF) indices (Zuur et al. 2010). Correlation coefficients between variables were below 0.6 in all cases and VIF indices below 5, which indicated that they could all be included as candidate variables in the same model. Correlation and multicollinerarity indices were computed in the R environment (R Core Team 2019).

Throughout the analysis, the statistical significance threshold was set at $p < 0.05$. Two variables were found to be statistically significant: ring width and density measurements. Predicted values were generated for the three quality classes based on a model that included these significant variables. These values were calculated for regular coordinates of the fishnet within the convex hull of our observed dataset. To produce predicted values of the probability of side effects for each observation, the OUTPUT statement was used in PROC GLIMMIX. Using these predicted values, we were able to create a map computed in the R environment, allowing us to better visualize the results (R Core Team 2019).

3. Results

3.1 Variables influencing black ash wood quality for W8banaki basketry

We built a generalized linear mixed model using four candidate variables to predict the quality classification of 27 pounding layers that have been processed and assessed by W8bankiak ash pounders. Results showed a significant effect of both ring width and ring average density on wood quality with p-values of 0.007 and 0.0474, respectively (Table 1). The effects of MOE and MOR were not statistically significant ($p > 0.05$). As revealed in the multicollinearity analyses ran prior to model development, there was a positive correlation between our two predictor variables. This correlation can be seen in our observed data as a gradient ranging from thin, medium-density rings to wide, denser rings (Figure 5). High-quality pounding layers were clustered around the centre of the point cloud, characterized by narrow to medium-sized rings of relatively high wood density (Figure 5).

Within the observed range of ring width and density, we used the model predictions to map the probability of pounding layers to be classified as either high, medium or low quality for basketry (Figure 6). There was a high probability for the pounding layers to be classified as of high quality when they were composed of thin to medium sized rings and high density, as indicated by the dark blue areas in Figure 6A. In contrast, the probability to obtain a low-quality pounding layer was high when rings were wide and dense, or narrow and of low density (Figure 6C). The predicted probability of being classified as of medium quality was more diffuse and generally low (Figure 6B). The maximum probability of having a pounding layer of medium quality reached only 50% (Figure 6B), whereas those of high and low quality reached the maximum (Figure 6A, C).

4. Discussion

4.1 Relationship between wood properties and wood quality

By combining W8banaki knowledge and wood science, we identified the wood properties that influenced wood quality for basketry. While previous studies reported that ring width is an important determinant of wood quality for basketry (Benedict and Frelich 2008; Costanza et al. 2017), our results suggest that wood density also plays a key role.

Within the gradient of ring width and density that we observed in our black ash samples, we identified upper part of the distribution of ring width and density, two variables that were observed to be positively correlated in our samples, as offering the highest probabilities for being highly suitable for basketry. Ring width and density are closely related to wood flexibility (the opposite of stiffness) and resistance to rupture (Green et al. 1999, Garrat 1931), two properties that must be balanced in black ash splints for basketry. Indeed, splints need to be flexible enough to be bent, but resistant enough not to break during the splinting and weaving process (Danny Gill and Luc Gauthier-Nolett, pers. observation. June 2020). Accordingly, rings of narrow to medium width and relatively high density seemed to offer the best balance between flexibility and resistance to rupture. In contrast, the lower part of the distribution, i.e., large rings or narrower rings of low density, were generally associated with low-quality pounding layers. The fact that no part of the distribution was clearly associated with the medium quality grade likely arises from the sparse occurrences of pounding layers classified as medium quality by the knowledge carriers. In general, our results are in accordance with previous reports of narrow and wide ring widths being of lower quality for basketry use (Benedict and Frelich 2008; Costanza et al. 2017), although in our study narrow rings of high density were generally considered suitable.

Our study added a component to the initial observation whereby density also appears to influence wood suitability for basketry.

The relationship between ring width and density is directly related to the anatomy of black ash wood. Ring-porous hardwoods, such as black ash, are characterized by the succession of earlywood and latewood that are of contrasting width and density. Earlywood is produced before leaf development (Hacke and Sperry 2001; Takahashi et al. 2013) and is characterized by large vessels with thin cell walls that allow high hydraulic conductivity (Zhu et al. 2021). Latewood is denser than earlywood because of its smaller vessels and thick-walled fibre material, which provides mechanical strength to the material (Rao et al. 1997). Whereas black ash earlywood width is relatively constant from year to year, latewood width varies much more, given that it is more sensitive to environmental conditions of the growing season (Tardif 1996; Tardif and Bergeron 1997). Therefore, wide rings usually have a higher latewood content – and a higher density – whereas narrow rings generally have a lower latewood content – and a lower density. Such relationship leads to an increased stiffness in wide rings and a lower mechanical strength and resistance in narrow rings. This positive correlation between ring width and wood density is specific to porous hardwood species (Panshin and De Zeeuw 1980).

Within this relationship, there remains variation in density for a given ring width, which is likely associated with the differences in quality, as suggested by the fact that quality was best predicted by both ring width and density. While annual ring density is generally related to the width of the ring, it can also be affected by changes in earlywood and latewood density as well as by slight changes in earlywood width, although the latter is much more constant than the width of latewood (Tardif 1996; Zhu et al. 2021). Due to such variations, two annual rings of a similar width may have different densities. A narrow ring (~0.9 cm) may be of high quality if its density is high (~600 kg/m^3), but of low quality if its density is low (~450 kg/m^3). Similarly, medium sized rings (~2.0 cm) with a higher density (~650 kg/m^3) showed an increased suitability for basketry compared to those with a lower density (~500 kg/m^3). Among wider rings (~3.0 cm), the reduced range of variation of wood led to all rings generally being of low suitability of basketry. Therefore, when pounding layers in which rings have reached a certain width, it is possible to notice that the probability of high-quality rings is consistently low (Figure 6). Wide rings with higher density usually have a higher latewood proportion, which may result in splints that are not flexible enough for basketry use. In addition to variations in the thickness of each section (Figure 7), variations in the density of the latewood section itself may also have similar effects.

Beyond these general trends, we observed some mismatches between our model results and the classification made by the knowledge carriers. Indeed, some samples that were in the middle of the ring width and density ranges would have been attributed a high or medium quality by our model, although they were classified as low quality by the knowledge carrier. This suggests that other factors not captured by our analysis may be involved in influencing wood quality for basketry. Other variables, such as the proportions of the different cell types in the wood, the cell-wall content and the lumen dimensions are known drivers of the density and strength properties of wood (Lachenbruch et al. 2011; Rao et al. 1997). In addition, the presence of defects such as inserted pin knots could also have affected the quality of the pounding layers.

Surprisingly, MOE and MOR were not identified as important drivers of suitability for basketry despite both properties being direct indicators of wood mechanical strength and stiffness (Fischer et al. 2016; Schlotzhauer et al. 2017). Ash pounders are looking for wood splints that can resist rupture and that are not too stiff, so they can be bent and weaved without problems. A strong yet flexible wood piece would have a high MOR and low MOE, and these two properties are influenced by the microfibril angle in the S2 layer of the cell wall and by wood density (Alteyrac et al. 2006; Auty and Achim 2008). Once the pounders have selected the tree, transformed it, and assessed its suitability for basketry, the resulting splints are sent to women who will weave it into baskets. We could speculate that MOE and MOR are properties that primarily affect the weaving stage, which was not assessed in this study. This may explain why MOE and MOR did not appear as key variables for the pounder, contrarily to wood density and ring width. To obtain a better understanding of the effect of MOE and MOR on wood quality for basketry, more in-depth studies should be carried out among women basket weavers.

4.2 Factors affecting black ash wood properties at different scales

As we identified rings of narrow to medium width and high density as having the highest potential for basketry, our results suggest that factors leading to excessively fast growth rates are likely to be detrimental for wood suitability for basketry in our study region. Because wood properties vary both within and among trees, multiple factors may be involved in determining wood quality for basketry. Among trees, growth conditions including site characteristics and regional climate are known to influence tree growth and wood properties (Auty et al. 2013; Genet et al. 2013). Basket makers and ash pounders of several First Nations (Mi’kmaq, Wolastoqey, Passamaquoddy, Penobscot, Kanien'kehá ka) have been reported to avoid harvesting black ash trees growing in permanent standing water (Benedict and Frelich 2008; Costanza et al. 2017; Diamond and Emery 2011), a practice also shared by the W8banakiak involved in the present study. Prolonged flooding can have a negative effect on tree growth (Tardif and Bergeron 1997), resulting in the formation of thin and porous rings that are associated with poor wood quality for basketry (Costanza et al. 2017). The regional climate also influences tree growth and may lead to differences in the overall properties of the available resource. In turn, these may become prime determinants of the properties locally selected for basketry use. For example, black ash rings of 2-3 mm were previously reported to be preferred for Kanien'kehá ka basketry in the New York State, where narrow (<1mm) and wide (>5mm) rings were considered of lesser quality (Benedict and Frelich 2008). Although a similar pattern applies to the present study, the preferred ranges of ring width differ substantially with much larger rings being preferred in the New England States. Whereas rings of 2-3 mm are representative of an average growth in Maine and neighboring states (Benedict and Frelich 2008), our results show that they would be among the largest rings in Ndakina. The differences between the widths preferred in the two regions are thus likely to be explained by regional climates, with the milder climate of Maine and longer growing season allowing generally faster black ash growth. It is conceivable that differences in pounding techniques among the Nations is also driven by the properties of the locally-available resource.

Within trees, annual time series of ring properties are driven by cambial age but may also be affected by climatic conditions and the occurrence of environmental stressors. As ring-porous trees mature, their growth rate decelerates and the proportion of latewood decreases, leading to an increase in ring porosity (Zhang et al. 1993). Cambial age also influences the anatomical structure of the wood as a decrease in the proportion fibre to the benefit of vessels (Rao et al. 1997), thus leading to lower density. Climatic conditions also influence the earlywood to latewood ratio, although they are not influenced by the same climatic variables (Tardif 1996). Earlywood is influenced by early spring temperature and water stress, while latewood is influenced by June and July temperature, and precipitation (Nolin et al. 2021; Tardif 1996). In both cases, extreme climatic conditions affecting growth (i.e., drought, heat waves, floods, etc.; Nolin et al. 2021; Tardif and Bergeron 1993; Tardif et al. 2021; Zhu et al. 2021) are likely to be detrimental for wood quality by disrupting the balance between ring width and density. As climate change induces more extreme climatic events and conditions (Lucash et al. 2018; McDowell et al. 2020; Seidl et al. 2017), we can therefore expect the properties of black ash wood properties to change over time on Ndakina. Other stressors such as the EAB outbreak (Costanza et al. 2017; Klooster et al. 2018; Palik et al. 2011), will likely exacerbate the issue by causing high mortality rates.

4.3 On the benefits of knowledge dialogue

The results from this study demonstrate how combining traditional ecological knowledge and wood science can contribute to adaptation and resilience to environmental challenges for both human communities and ecosystems (Berkes 1999; Kimmerer 2002; McGreavy et al. 2021, Reid et al. 2020). To ensure this research involved a constructive knowledge dialogue and a respectful partnership, we first recognized the potential negative effects and inequities that can result from such an intercultural project (Asselin and Basile 2012; Smith 2021). Our approach must not be seen as an attempt to validate W8banaki knowledge through the perspective of wood and forest sciences, but rather as work conducted in close collaboration to create a dialogue around black ash that respects the integrity of each knowledge system (Kimmerer 2002; Tengö et al. 2014). The two knowledge types involved in this study fed each other in an iterative manner (Emery et al. 2014; McGreavy et al. 2021; Tengö et al. 2014). We abide by the principle that such partnership needs to be co-developed respectfully and adequately (Smith 2021).

Basketry is a very complex, non-static practice linked to dynamic knowledge (Berkes 1999). The wood quality assessments used in our analysis depend on the experiences and preferences of each pounder (Frey et al. 2019) and are thus expected to vary among W8banaki knowledge carriers and among northeastern Indigenous peoples who practice basketry across the black ash natural distribution range.

5. Conclusion

In this study, we associated black ash wood quality for basketry as assessed by W8banaki knowledge carriers. This was done with the larger aim to identify relevant research efforts and actions regarding black ash and basketry’s future, and thus support the W8banaki Nation in its adaptation process regarding the issues affecting black ash. We highlighted the fact that wood quality for basketry was mostly related to ring width and ring average density, with the best quality being found in rings of narrow to medium width and high density. Such ring characteristics appear to provide the material with a good balance between wood flexibility and resistance to rupture, which are essential to the quality of pounding layers for basketry. In contrast, wide rings may be too stiff to be bent, whereas narrow rings of low density may not be strong enough. Such results suggest that further research on growth conditions could be used to support the implementation of silvicultural treatments and land management strategies that favour wood of better suitability for basketry by creating optimal conditions to promote the appropriate growth rate. Such practices could participate in supporting basketry and ensuring the production of high-quality black ash wood for future generations. Yet, as climate is changing and EAB is continuing to spread through the species' range, more intercultural and collaborative research are needed to ensure future basketry practices.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data generated or analysed during this study are available from the corresponding author upon reasonable request

Community involvement statement

This research project was conducted with a strong emphasis on community involvement and engagement throughout all stated of the study. Prior to initiating any research activities, the project was approved by the W8banaki research coordination committee. The project has received the UNESCO Chair - Cultural transmission among Indigenous peoples as a dynamic for well-being and empowerment seal of approval.

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7. Figure captions

Figure 1. Location of the two sites where black ash logs were collected in 2020 (stars): Seigneurie de Lotbinière (1) and Domtar (2) on Ndakina, the W8abanaki ancestral land (encircle area). Figure was created using QGIS version 3.22.16 and assembled from the following data sources: Ndakina contour line (Ndakina Office 2023), map showing the native range of black ash (Silvics of North America (Wright and Rauscher, 1990)). Figure was built by the authors.

Figure 2. The process involves the preparation of black ash specimens and wood splints as follows: A) Preparation of logs (2.0 to 2.5m in length) and pounding stage. B) Preparation of wood bolt (30 cm) and wood samples for densitometric testing (radial pith-to-bark segment) and for the static bending test used to evaluate MOE and MOR (using 10-mm-wide and 160-mm-long specimens). Image : Sarah Desrosiers-Vaillancourt

Figure 3. Process preparation of black ash splints for W8banaki basketry from the pounding stage to the storage of the material. A) Danny Gill and Luc Gauthier-Nolett pounding a black ash log at Laval University for a basketry demonstration held in 2022. B) The detachment of a pounding layer after log pounding. C) The long wood layers detached from the log before they are process with the splinter tool. D) Black ash splints rolled up and ready to be stored and woven. Photograph : Laurence Boudreault

Figure 4. Correlation matrix for the following variables: ring width (RW_mm), ring average density (RA_Density), modulus of elasticity (MOE), and modulus of rupture (MOR).

Figure 5. Observed quality for each pounding layers determined by knowledge carriers whether they were of high quality (green), medium quality (yellow) or low quality (red) for basketry.

Figure 6. Probability of pounding layers to be classified as of high quality for basketry (top left panel), medium quality for basketry (top right panel) and low quality for basketry (bottom left panel) depending on ring width and ring average density. Probability ranges from low (dark blue) to high (light blue).

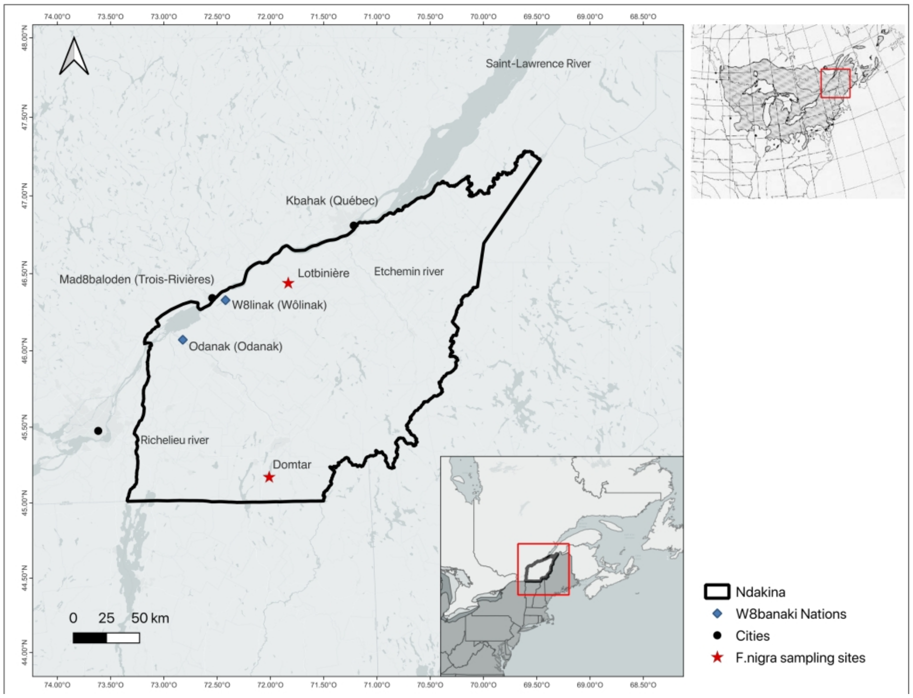
Figure 7. Three pounding layer exemplars with different ring widths that influence wood quality for basketry: (A) narrow rings of high quality, (B) medium annual ring associated of medium quality, (C) wide rings associated with low quality. Images were taken at the transversal section with a Keyence microscope (Quebec, Canada). Scale bar = 1000 μm. Image : Laurence Boudreault

8. Table captions

Table 1. P-value and confidence interval for our GLIMMIX model which consider ring average density, ring width, MOE and MOR.

Effect	Quality	Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept	1	-15.9516	7.4531	9	-2.14	0.0610
Intercept	2	-13.7673	7.2622	9	-1.90	0.0905
MOE		0.000940	0.000603	12	1.56	0.1449
RW_mm		-3.0915	0.9514	12	-3.25	0.0070
RA_Density		0.03540	0.01603	12	2.21	0.0474
MOR		-0.08932	0.06666	12	-1.34	0.2051

Table 1. P-value and confidence interval for our GLIMMIX model which consider ring average density, ring width, MOE and MOR.



Caption : Figure 1. Location of the two sites where black ash logs were collected in 2020 (stars): Seigneurie de Lotbinière (1) and Domtar (2) on Ndakina, the W8abanaki ancestral land (encircle area). Figure was created using QGIS version 3.22.16 and assembled from the following data sources: Ndakina contour line (Ndakina Office 2023), map showing the native range of black ash (Silvics of North America (Wright and Rauscher, 1990)). Figure was built by the authors.

296x209mm (300 x 300 DPI)

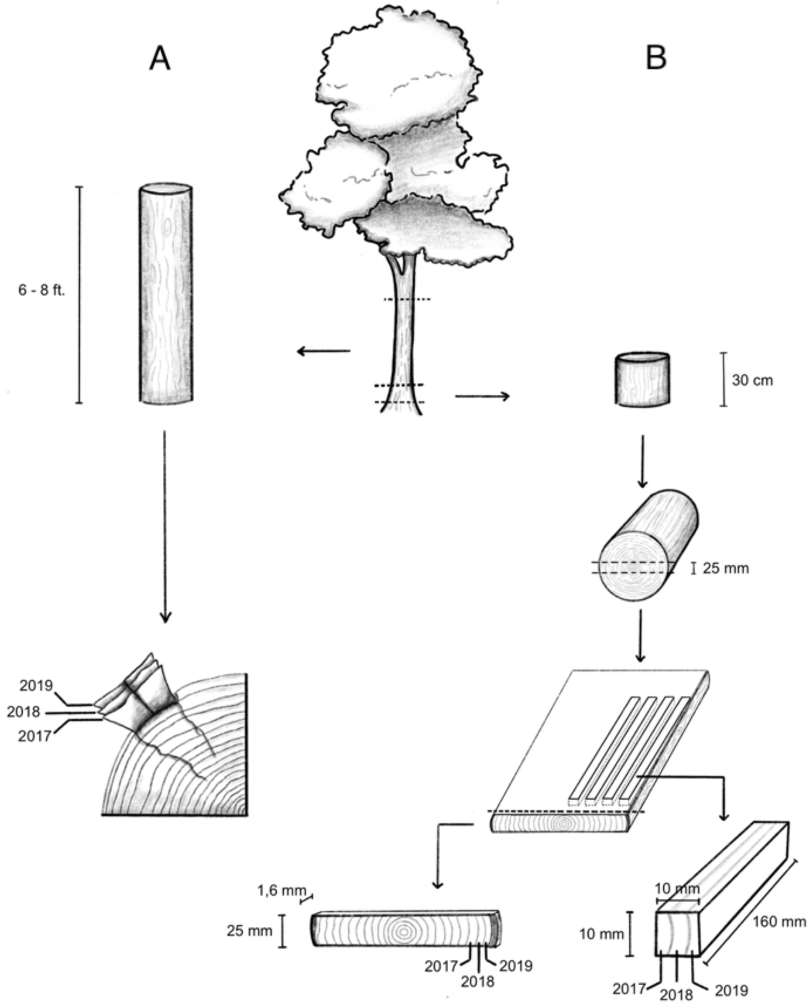


Figure 2. The process involves the preparation of black ash specimens and wood splints as follows: A) Preparation of logs (2.0 to 2.5m in length) and pounding stage. B) Preparation of wood bolt (30 cm) and wood samples for densitometric testing (radial pith-to-bark segment) and for the static bending test used to evaluate MOE and MOR (using 10-mm-wide and 160-mm-long specimens). Image : Sarah Desrosiers-Vaillancourt

717x928mm (28 x 28 DPI)


A
B
C
D

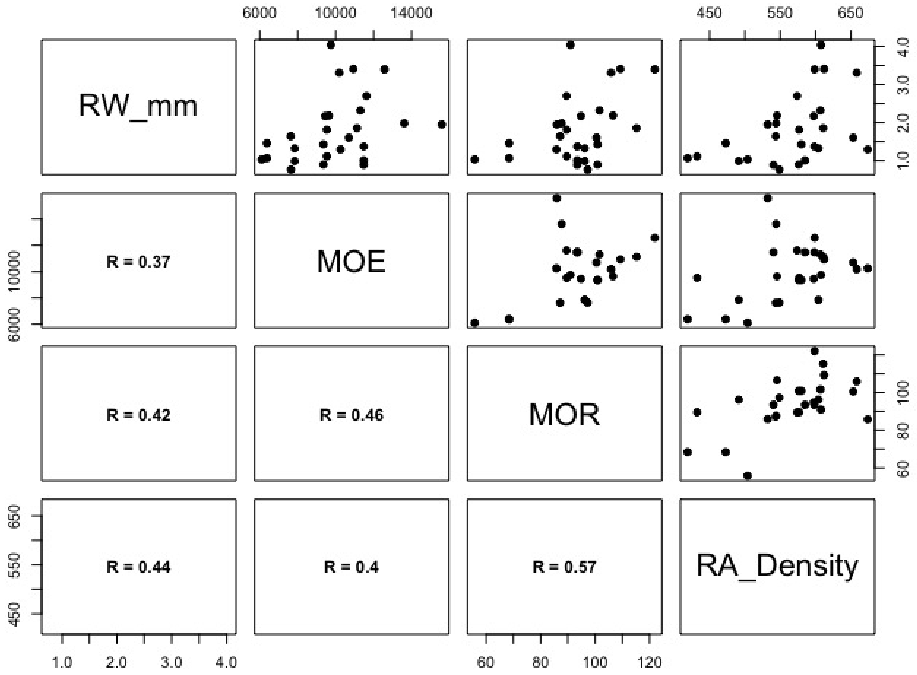


Figure 4. Correlation matrix for the following variables: ring width (RW_mm), ring average density (RA_Density), modulus of elasticity (MOE), and modulus of rupture (MOR).

241x183mm (72 x 72 DPI)

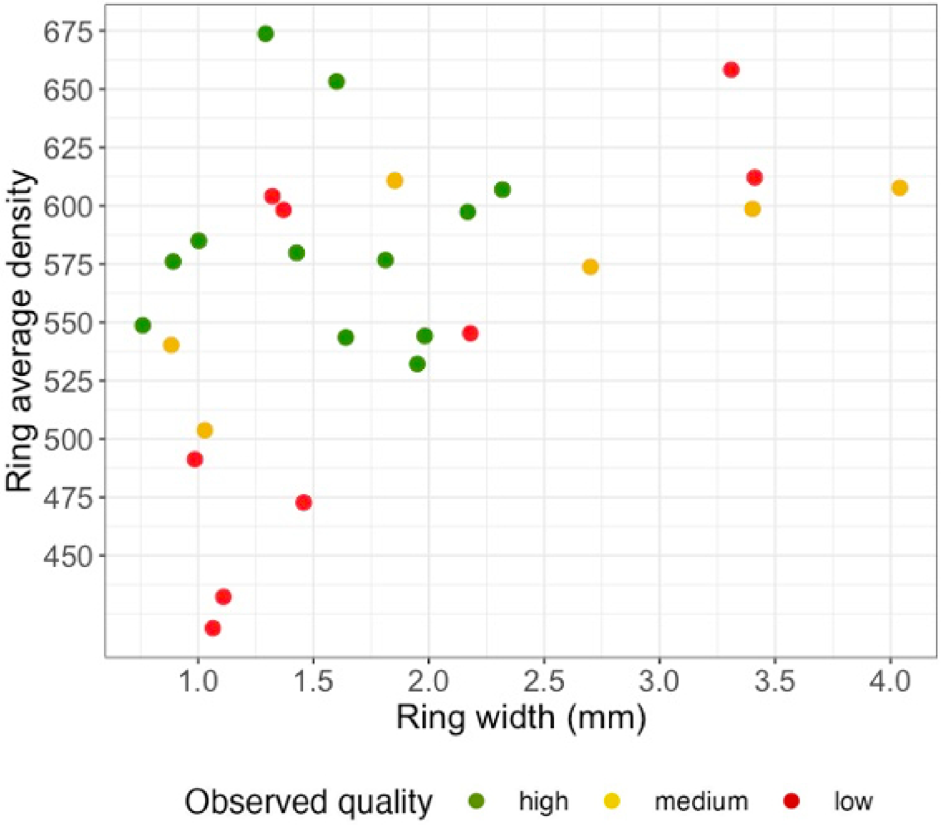


Figure 5. Observed quality for each pounding layers determined by knowledge carriers whether they were of high quality (green), medium quality (yellow) or low quality (red) for basketry.

212x180mm (72 x 72 DPI)

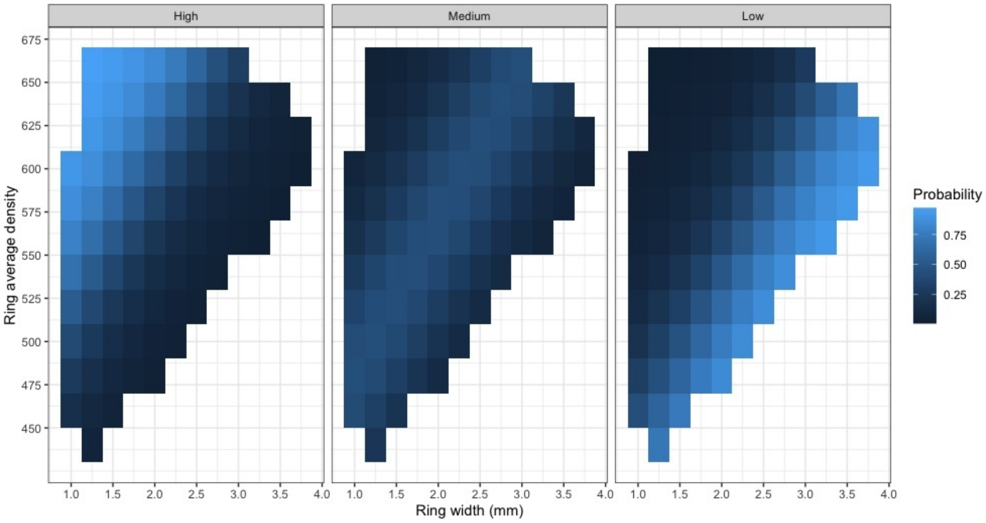
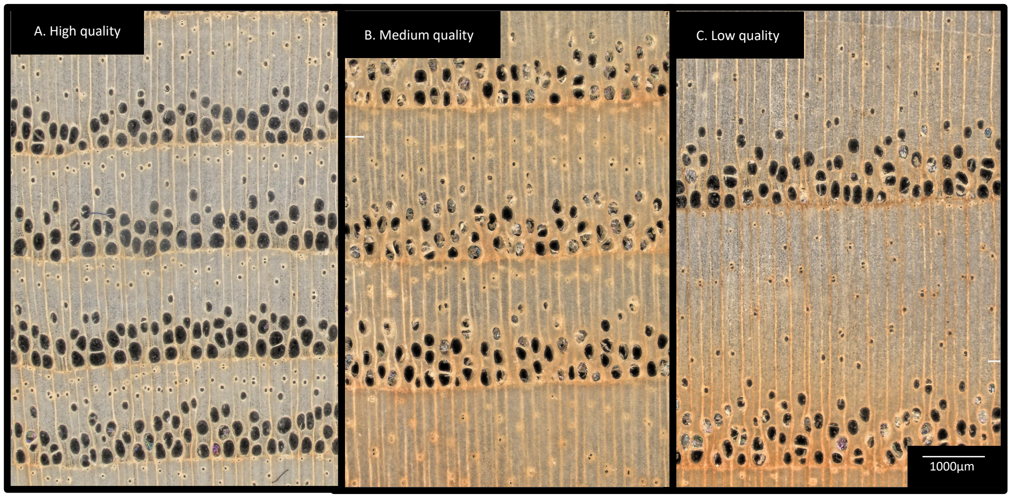


Figure 6. Probability of pounding layers to be classified as of high quality for basketry (top left panel), medium quality for basketry (top right panel) and low quality for basketry (bottom left panel) depending on ring width and ring average density. Probability ranges from low (dark blue) to high (light blue).

349x185mm (72 x 72 DPI)


A. High quality
B. Medium quality
C. Low quality
1000µm