**UNIVERSIDADE FEDERAL DE ALAGOAS**

**INSTITUTO DE CIÊNCIAS BIOLÓGICAS E DA SAÚDE**

**Programa de Pós-Graduação em Diversidade Biológica e Conservação nos Trópicos**

**ROBERTA DE ALMEIDA CAETANO**

# INTERAÇÕES ENTRE O USO DE RECURSOS FLORESTAIS MADEIREIROS E ALIMENTÍCIOS E SUAS IMPLICAÇÕES PARA A CONSERVAÇÃO BIOCULTURAL

**MACEIÓ - ALAGOAS**

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**Tese apresentada ao Programa de Pós-Graduação em Diversidade Biológica e Conservação nos Trópicos, Instituto de Ciências Biológicas e da Saúde. Universidade Federal de Alagoas, como requisito para obtenção do título de Doutora em CIÊNCIAS BIOLÓGICAS, na área da Biodiversidade.**

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**Roberta de Almeida Caetano**

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*À minha amada mãe, que com sua ternura, apoiou-me e guiou-me pelos caminhos que me conduziram até aqui e*

*À minha querida avó materna (in memoriam).*

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“Desde que me entendo por gente, andava mais a minha vó na mata. A gente sempre colhia cambuí, coco de piaçava, araçá, jenipapo, caju, ingá e massaranduba. A mata sempre foi importante pra gente. Aqui sempre tinha muita água, árvore e muito passarinho. Mas depois que começaram a desmatar, começou a sumir as caças, as frutas... Aí ficou um pouco desvalorizada a nossa mata”.

AJD, morador da comunidade de Retiro, Piaçabuçu - Alagoas.

## RESUMO

As plantas alimentícias silvestres lenhosas têm alto potencial para a segurança alimentar e nutricional, mas podem estar sofrendo pressão do uso madeireiro. Por isso, é importante entendermos se em um contexto de interação de usos, a importância do uso alimentício pode atuar protegendo as plantas lenhosas de usos destrutivos. Esta tese está dividida em dois capítulos, os quais convergem sobre a conservação de plantas lenhosas a partir da interação entre usos distintos, tendo um desses usos um efeito de proteção. No primeiro capítulo, por meio de uma revisão sistemática, buscamos identificar espécies prioritárias para a conservação biocultural que, ao mesmo tempo, são estratégicas para a manutenção da segurança alimentar e nutricional (em termos de composição de micro e macronutrientes) e potencialmente ameaçadas pelos seus múltiplos usos madeireiros. Identificamos 42 espécies com aplicação em todas as categorias de uso madeireiro analisadas neste estudo, sendo consideradas versáteis. A comparação dos dados etnobiológicos e nutricionais revelou oito espécies versáteis para as quais estava disponível informação sobre a composição nutricional, entre as quais, três se destacaram em termos de teor de macronutrientes, nomeadamente *Anacardium occidentale* L., *Bauhinia cheilantha* (Bong.) Steud., e *Eugenia pyriformis* Cambess. Encontramos que, muitas espécies versáteis classificadas como ameaçadas ou em declínio não têm sido foco de estudos nutricionais, o que sinaliza a necessidade de maiores esforços de investigação nutricional. Também destacamos a necessidade de investigar se a importância alimentícia exerce algum efeito protetor sobre estas espécies, reduzindo a pressão do uso madeireiro (hipótese de proteção). No segundo capítulo, conduzimos um estudo de campo em uma comunidade rural dentro da vegetação de Restinga, no nordeste do Brasil. Nesse capítulo buscamos preencher uma lacuna na literatura sobre como a importância doméstica e comercial das plantas alimentícias lenhosas pode protegê-las da exploração madeireira. Para esse fim, examinamos a hipótese da proteção a partir de duas perspectivas distintas (proteção generalizada e proteção direcionada a espécies chave). Nossas descobertas sugerem que não há efeito protetivo proporcional ao uso alimentício das espécies. No entanto, o uso doméstico de espécies-chave para alimentação exibiu um forte efeito protetivo. A disponibilidade e a qualidade percebidas surgiram como preditores importantes para a exploração da madeira. Assim, discutimos estratégias de conservação biocultural que aumentem a importância alimentícia das plantas para garantir a sua proteção, juntamente com medidas para espécies lenhosas não comestíveis sob maior pressão de uso. Por meio dessa tese, descobrimos que espécies alimentícias com potencial nutricional podem estar sofrendo pressão de uso devido a seu emprego madeireiro. No entanto, espécies com alta importância têm o uso madeireiro reduzido, controlando o efeito da qualidade madeireira e a disponibilidade percebidas. Portanto, é necessária a realização do estudo ecológico dessas espécies e a adoção de medidas de conservação que incluam a valorização e o uso sustentável dos recursos vegetais.

**Palavras-chave:** Produtos da sociobiodiversidade. Usos madeireiros. Interação de usos. Conservação biocultural. Manejo tradicional. Etnobiologia

**Abstract**

Wild woody food plants have high potential for food and nutritional security but may be under pressure from wood use. Therefore, it is important for us to understand whether in a context of interaction of uses, the importance of food use can act to protect woody plants from destructive uses. This thesis is divided into two chapters, which converge on the conservation of woody plants through the interaction between different uses, with one of these uses having a protective effect. In the first chapter, through a systematic review, we sought to identify priority species for biocultural conservation that are also strategic for maintaining food and nutritional security (in terms of micro and macronutrient composition) and potentially threatened by their multiple wood uses. We identified 42 species with applications in all categories of wood use analyzed in this study, considered versatile. Comparison of ethnobiological and nutritional data revealed eight versatile species for which nutritional composition information was available, among which three stood out in terms of macronutrient content, namely Anacardium occidentale L., Bauhinia cheilantha (Bong.) Steud., and Eugenia pyriformis Cambess. We found that many versatile species classified as threatened or declining have not been the focus of nutritional studies, signaling the need for greater nutritional research efforts. We also highlight the need to investigate whether the food importance exerts any protective effect on these species, reducing the pressure of wood use (protection hypothesis). In the second chapter, we conducted a field study in a rural community within the Restinga vegetation, in northeastern Brazil. In this chapter, we sought to fill a gap in the literature on how the domestic and commercial importance of woody food plants can protect them from wood exploitation. To this end, we examined the protection hypothesis from two different perspectives (generalized protection and protection targeted at key species). Our findings suggest that there is no protective effect proportional to the food use of the species. However, the domestic use of key food species exhibited a strong protective effect. Perceived availability and quality emerged as important predictors for wood exploitation. Thus, we discuss biocultural conservation strategies that increase the food importance of plants to ensure their protection, along with measures for non-edible woody species under greater pressure of use. Through this thesis, we discovered that food species with nutritional potential may be under pressure from use due to their wood employment. However, species with high importance have reduced wood use, controlling for perceived wood quality and availability. Therefore, ecological study of these species and adoption of conservation measures that include the valorization and sustainable use of plant resources are necessary.

**Keyword**: Sociobiodiversity products. Wood uses. Use interaction. Biocultural conservation. Traditional management. Ethnobiology

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**Artigo 1**



**Artigo 2**

**SUMÁRIO**

# 1 APRESENTAÇÃO

As plantas alimentícias silvestres têm destacada importância ao redor do mundo do ponto de vista socioeconômico e nutricional (JACOB et al., 2020). Essas plantas podem desempenhar um papel importante em uma dieta saudável como fonte alternativa de minerais, vitaminas e antioxidantes, bem como macronutrientes, como carboidratos, proteínas e lipídios. Por isso, o seu consumo tem sido recomendado como parte de estratégias globais para combater a desnutrição (HUNTER et al., 2019), diversificar a dieta humana e os sistemas alimentares como um todo (BALDERMANN et al., 2016), e gerar renda para pequenos agricultores e extrativistas (DELANG, 2014). Além disso, a extração de partes comestíveis de plantas é, na maioria dos casos, menos prejudicial que a extração de madeira, sendo propícia à aplicação de estratégias de manejo e uso sustentáveis (GAOUE et al., 2016).

No entanto, apesar do grande potencial das plantas alimentícias silvestres para o manejo sustentável, muitas dessas espécies têm múltiplas aplicações, incluindo a extração de madeira, que é uma das principais causas do declínio das populações vegetais (BRUSCHI et al., 2014; ROS-TONEN, 2000; STANLEY et al., 2012). Esta situação é particularmente preocupante para as plantas alimentícias de alta versatilidade para os usos madeireiros, pois podem estar enfrentando maior pressão de uso. E a extinção de espécies representa uma perda irreversível da biodiversidade e do patrimônio cultural. Para evitar esse problema, é essencial desenvolver estratégias a partir de uma perspectiva de conservação biocultural, ou seja, buscando combinar ações de conservação ao conhecimento e uso dos recursos naturais para reduzir a perda da diversidade biológica e cultural (Gavin et al., 2015).

Nesse sentido, conservar o amplo uso dos recursos alimentícios silvestres pode ser estratégico porque as plantas silvestres são encontradas em muitas comunidades locais que ainda enfrentam desafios relacionados à: fome, disponibilidade de alimentos, pouca diversificação da dieta e a eventos climáticos que impactam a produção de cultivos (NASCIMENTO et al., 2012, 2011; JACOB et al., 2020).

No Brasil, vários estudos registraram espécies lenhosas com potencial nutricional (NASCIMENTO et al., 2012, 2011; JACOB et al., 2020; NUNES et al., 2012). No entanto, a maioria dos estudos não conseguiu analisar até que ponto as populações de plantas são ameaçadas por outros usos que não o uso alimentício.

Compreender a sobreposição dos usos das plantas lenhosas é importante porque estratégias de conservação que abrangem diferentes usos dos recursos vegetais podem contribuir grandemente para a segurança alimentar e nutricional.

Além disso, é esperado que o uso de plantas alimentícias seja um provável candidato a conferir um efeito de proteção contra os usos madeireiros. E, dada a natureza especializada do uso alimentício, sua importância na dieta humana e seu potencial econômico, é possível que as comunidades locais protejam estas plantas de danos irreversíveis, como os causados pela maioria dos usos madeireiros, para os quais estão disponíveis espécies vegetais alternativas devido à sua natureza generalista. Inclusive, essa hipótese é testada nessa tese e será apresentada mais adiante.

No contexto de diversas comunidades sul-americanas, os usos especializados são definidos por uma gama mais restrita de plantas adequadas que atendem a requisitos específicos, com a premissa de especialização reforçada por observações de que a disponibilidade de plantas exerce pouca ou nenhuma influência sobre tais usos (RIBEIRO et al., 2014; SOLDATI et al., 2016). Em contraste, os usos generalistas acomodam um espectro mais amplo de espécies, sendo as mais utilizadas, muitas vezes, as mais disponíveis, como acontece com os usos madeireiros (GONÇALVES et al., 2016).

Embora a qualidade também possa ser um importante preditor da importância das plantas para usos generalistas (CARDOSO et al. 2015), a natureza generalista do uso da madeira é apoiada por estudos que investigam a hipótese da aparência (disponibilidade), que postula uma correlação entre a disponibilidade ambiental e a utilização das espécies (GONÇALVES et al., 2016; LUCENA et al., 2013; LUCENA et al., 2007). Portanto, para usos generalistas, há outras opções igualmente vantajosas, o que permitiria às pessoas pouparem certas espécies para usos especializados, como o uso alimentício, para a qual menos espécies podem atuar como substitutas.

Diante desse cenário, a hipótese da proteção foi criada para considerar que plantas de alta importância numa categoria de uso mais especializada (como o uso medicinal) podem experimentar uma redução na sua utilidade para outras categorias de natureza mais generalista, como o uso madeireiro (SILVA et al., 2021). Um estudo que testou essa hipótese demonstrou um efeito pequeno, mas significativo da importância do uso medicinal sobre o uso madeireiro, indicando evidências favoráveis à hipótese, uma vez que as plantas medicinais de maior importância são utilizadas com menos frequência para fins madeireiros. Além disso, foi observado que o efeito protetivo é provavelmente mais forte nas espécies de alta importância medicinal. Nessa tese, as espécies de alta importância, são denominadas de espécies-chave, sendo definidas como espécies alimentícias silvestres de alta importância regional para o consumo e geração de renda.

Investigar como a interação de categorias de uso distintas pode interferir na conservação das espécies vegetais tem se mostrado uma abordagem promissora para entender sobre o efeito de proteção em sistemas socioecológicos (SILVA et al., 2021). Porém, tem sido pouco explorada em estudos dessa natureza, obscurecendo a nossa compreensão sobre como o valor de uma planta para um determinado propósito pode protegê-la de outros usos mais prejudiciais.

É essencial entender se existem interações de uso e como elas se comportam do ponto de vista de conservação, porque, embora o uso madeireiro associado possa representar uma ameaça maior às espécies vegetais do que somente o uso alimentício; por outro lado, a planta que tem uso alimentício, pode ser menos usada para fins madeireiros pelos povos locais do que uma planta de mesma qualidade e disponibilidade e que não tenha uso alimentício associado.

Com base nessas premissas, esta tese está dividida em dois capítulos, os quais convergem sobre a conservação de plantas lenhosas a partir da interação entre usos distintos, tendo um desses usos um efeito de proteção.

O primeiro capítulo é produto de duas revisões sistemáticas que se complementam: uma de natureza etnobiológica e a outra, de natureza nutricional. Nesta revisão sistemática, buscamos identificar espécies prioritárias para a conservação biocultural que, ao mesmo tempo, são estratégicas para a manutenção da segurança alimentar e nutricional (em termos de composição de micro e macronutrientes) e potencialmente ameaçadas pelos seus múltiplos usos madeireiros. De modo geral, nesse capítulo identificamos a partir de estudos etnobiológicos, quais as espécies lenhosas nativas do Brasil utilizadas para propósitos alimentícios são também versáteis para os usos madeireiros (nas categorias combustível, construção e tecnologia) e fornecemos um compilado de informações sobre a composição química dessas espécies, a partir de estudos nutricionais diversos. Além disso, discutimos estratégias de conservação biocultural para essas espécies e fazemos recomendações para estudos futuros sobre lacunas identificadas nos estudos etnobiológicos e nutricionais.

O segundo capítulo é um estudo de caso conduzido em uma comunidade rural dentro da vegetação de Restinga, no nordeste do Brasil. Nesse capítulo buscamos preencher uma lacuna na literatura sobre como a importância doméstica e comercial das plantas alimentícias lenhosas pode protegê-las da exploração madeireira. Para esse fim, examinamos a hipótese da proteção a partir de duas perspectivas distintas (proteção generalizada e proteção centrada nas espécies chave). Nosso estudo é o primeiro a testar a hipótese da proteção considerando o uso alimentício como efeito protetor para espécies lenhosas e contribui com estratégias de conservação biocultural que buscam ampliar a importância alimentícia das espécies para garantir a sua proteção, juntamente com medidas para espécies lenhosas não comestíveis sob maior pressão de uso. Adicionalmente, apresenta alguns desafios e perspectivas do teste da hipótese da proteção para estudos futuros.

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# 2 REVISÃO DA LITERATURA

## 2.1 Impactos da extração de produtos florestais madeireiros e não madeireiros

Os Produtos Florestais Não-Madeireiros (PFNM) ou produtos florestais não-lenhosos, podem ser definidos como produtos vegetais ou animais provenientes de florestas naturais ou manejadas, com exceção da madeira e suas diferentes finalidades (SOLDATI, ALBUQUERQUE, 2008). No entanto, existe uma questão terminológica e conceitual associada aos PFNM que pode causar confusão. Na literatura inglesa a tradução do termo “timber” pode significar “madeira para construção” ou “viga” e “madeira bruta”. Outro termo utilizado ao tratar desse tema é “wood”, que em geral, incorpora a madeira em um sentido mais amplo. Em relação à questão conceitual relacionada às variações nos termos, é possível encontrar estudos sobre produtos florestais não-madeireiros que incluem produtos de origem madeireira que, ora utilizam o termo “non-timber” (DEREBE; ALEMU, 2023; LAARIBYA, 2023), ora o termo “non-wood” (PURWESTRI et al., 2020; MUSA et al., 2023) e ainda, os que utilizam “non-timber” desconsiderando usos madeireiros (SOLDATI, ALBUQUERQUE, 2008). É possível que a utilização de termos distintos (“non-timber” e “non wood”) como sinônimos nesses estudos resulte da confusão conceitual que esses termos geram. De acordo com o site da Organização das Nações Unidas para Alimentação e Agricultura (FAO, 2024), o termo “non-wood”, exclui todas as matérias-primas lenhosas. O termo “non-timber”, por sua vez, geralmente inclui lenha e pequenas madeiras como ferramentas, equipamentos domésticos e esculturas.

Enquanto não há uma definição global dos PFNM, é necessário ter clareza sobre quais abordagens estão sendo consideradas pelos pesquisadores para não generalizar equivocadamente resultados favoráveis ou desfavoráveis à conservação de espécies associadas ao uso desses produtos. No primeiro capítulo dessa tese, embora tenha sido utilizado o termo “timber”, todas as categorias de usos madeireiros estão sendo consideradas. Além disso, assim como a definição de Soldati e Albuquerque (2008), o conceito adotado para produtos florestais não-madeireiros nesse estudo não inclui os recursos madeireiros.

### 2.1.1 Uso e conservação de produtos florestais não-madeireiros

Em se tratando dos aspectos ecológicos associados ao uso de PFNM, este é considerado como uma forma alternativa de uso da terra, com impactos menores sobre a cobertura florestal quando comparado à exploração madeireira ou à agricultura comercial. Isso porque os produtos comercializados podem ser frutas, fibras vegetais, óleos, resinas, plantas medicinais, sementes, (NAKAZONO; MAGNUSSUM, 2016) e mel (LOWORE, 2020), entre outros.

Além de serem importantes componentes para a subsistência de famílias, mitigação ou redução da pobreza e geração de renda a partir da comercialização, eles fornecem uma rede de segurança em tempos de dificuldades econômicas (DECARLO; ALI; CERONI, 2020), como a melhoria da segurança alimentar, principalmente em períodos adversos, além da manutenção das tradições e conhecimentos culturais (SHACKLETON, 2015). Um reforço à importância econômica de plantas alimentícias e de subsistência para as populações locais pode ser encontrado no estudo de Adam, Pretzsch e Pettenella (2013) que foi realizado na localidade de Rashad, no Sudão, para analisar o papel dos PFNMs em estratégias de subsistência no desenvolvimento rural. Os resultados revelaram que as funções desses produtos iam desde ajuda às famílias para garantir o abastecimento de alimentos, até acumular capital financeiro, de modo que a venda dos frutos de *Adansonia digitata* representava uma estratégia de subsistência para a maioria das famílias de coletores e uma estratégia acumulativa para a maioria das famílias de comerciantes. Por outro lado, a venda dos frutos de *Ziziphus spina-christi* e *Balanities aegyptica* era uma estratégia de subsistência para a maioria das famílias de coletores e comerciantes. Essas estratégias tinham relação com o acesso aos mercados e o valor de mercado de tais produtos.

Os múltiplos benefícios socioeconômicos e socioambientais dos produtos florestais não-madeireiros, como mencionados acima, fizeram com que estes fossem visados fortemente a partir dos anos 90 como impulsionadores do manejo sustentável dos recursos florestais (SHACKLETON; SHACKLETON, 2004; SHANLEY, 2011). Tendo como principal premissa que, se a floresta apresentasse valor econômico para as comunidades locais, as pessoas estariam mais propensas a mantê-las (EVANS, 1993).

Desde então, vários estudos baseados na premissa de que os produtos florestais não madeireiros são um caminho sustentável para explorar as florestas, têm avaliado os impactos ecológicos da extração de diversos produtos florestais não-madeireiros. Dentre esses estudos, aqueles focados na coleta de frutos com importância econômica e/ou para a subsistência  têm encontrado resultados positivos (ZUIDEMA; BOOT, 2002; OLIVEIRA; SCARIOT, 2010; BRUSHI et al., 2014; GIROLDO; SCARIOT, 2015) e negativos (SINHA; BAWA, 2002; AVOCÈVOU-AYISSO et al., 2009) a respeito da sustentabilidade do uso desse recurso vegetal. Na maioria dos casos, a coleta de PFNMs não leva à morte dos indivíduos coletados, pois para várias espécies vegetais, esses produtos são removidos pelas pessoas locais na própria planta (GAOUE et al., 2016), sem necessidade de cortes ou poda. No entanto, em situações em que a espécie-alvo é danificada ou morta durante o processo, a extração parece ser geralmente insustentável (SINHA; BAWA, 2002). Além disso, o impacto da exploração vai depender da parte da planta que é explorada e do potencial de regeneração da espécie (CAMPOS et al., 2018). Por exemplo, a extração de frutos tem sido considerada menos impactante e mais sustentável quando comparada com a extração de folhas, cascas e raízes (HALL; BAWA, 1993; GAOUE;TICKTIN, 2007; STANLEY; VOEKS; SHORT, 2012).

Sinha e Bawa (2002) realizaram um estudo nas florestas de Biligri, na Índia, visando avaliar o impacto das técnicas de coleta dos indígenas Soligas sobre as espécies frutíferas *Phyllathus emblica* e *Phyllanthus indofischeri* e a susceptibilidade das árvores a infestação por plantas hemiparasitas da família Loranthaceae. Os autores identificaram que as atuais técnicas de coleta utilizadas pelos Soligas estão impactando negativamente o recurso que lhes serve de sustento, uma vez que para a espécie *Phyllathus emblica,* a poda dos ramos reduziu a produção de frutos no ano seguinte e, de forma geral, o corte das árvores está comprometendo o uso sustentável de longo prazo de *Phyllanthus spp*. No entanto, eles descobriram que a infestação por plantas hemiparasitárias também tem impacto negativo na produção de frutos das espécies, sustentando o argumento de que eventos naturais também precisam ser incluídos nessas avaliações.

Outro aspecto a considerar sobre as práticas de coleta e produção de frutos é que algumas espécies de frutíferas, mesmo sujeitas a diferentes distúrbios antropogênicos e extrativismo em escala comercial, conseguem se manter produtivas.

Em uma investigação conduzida em uma área de Cerrado *lato sensu*, Giroldo e Scariot (2015) realizaram um estudo de estruturação populacional. Eles avaliaram se haveria alguma evidência de mudança no recrutamento no nível de paisagem em populações de uma espécie frutífera com importância comercial, *Caryocar brasiliense*, a qual está sujeita a diferentes usos e manejos da terra. Giroldo e Scariot (2015) descobriram que as populações de *Caryocar* são afetadas pelo uso e manejo da terra, mas a pressão atual da coleta de frutas nas populações da espécie não comprometia o recrutamento de mudas na paisagem, concluindo que a coleta de frutos é sustentável. Essa espécie já foi relatada como tendo coleta máxima sustentável de frutas de cerca de 90% (OLIVEIRA; SCARIOT, 2010). No entanto, essa informação não pode ser generalizada, pois estudos têm indicado que a sobrexploração de frutas tem mostrado impacto na dinâmica de regeneração de árvores frutíferas silvestres (AVOCÈVOU-AYISSO et al., 2009; ALMEIDA, 2014). Algumas pesquisas vem apontando que a insustentabilidade da extração de frutos em algumas comunidades locais está associada, muitas vezes, ao abandono de estratégias e técnicas de coleta tradicionais como medida de maximização do retorno econômico (SINHA; BAWA, 2002) e a superexploração de uma espécie-alvo mediante baixos retornos (CROOK; CLAPP, 1998).

Neste sentido, um estudo realizado por Gaoue *et al*. (2016) avaliou as taxas ótimas de coletas de produtos florestais madeireiros e não madeireiros, considerando dados de pesquisa em ecossistemas tropicais e integrando fatores socioeconômicos e ecológicos. Os autores classificaram essas coletas, respectivamente, como coleta letal e coleta não letal. Com base em seus resultados, eles demonstraram que as estratégias de colheita ideais incluem começar com a coleta não letal de PFNM e adiar a coleta letal de madeira para começar após alguns anos, embora uma redução drástica da população seja causada pela coleta letal em todos os cenários de controle do estudo. Por fim, o estudo indicou que para manter uma população com um declínio inferior a 10% da sua densidade inicial, as taxas ótimas de coleta letal e não letal, não devem exceder 40% da densidade populacional total.

No entanto ainda existe um dilema no que diz respeito à sustentabilidade entre o manejo florestal direcionado de espécies de interesse alimentício e coleta sem manejo. Por um lado, estudos com PFNM (entre eles as espécies alimentícias) vem mostrando que a extração sem manejo tem mais chances de trazer consequências negativas para as populações alvo (KUSTERS et al., 2006). Por outro lado, espécies que experienciaram aumento da demanda nos últimos anos e que tiveram estabelecidas formas de manejo *in situ* (ex: plantio em áreas de vegetação nativa), embora mantenham suas populações, podem trazer impactos para a comunidade como um todo (FREITAS, 2019; FREITAS et al., 2015; BARROS et al., 2023). Um exemplo disso é o caso da espécie *Euterpe oleraceae* Mart**.** (açaí), cujo aumento do valor de mercado em escala nacional, impulsionou a intensificação do cultivo da espécie *in situ*, o que tem levado à diminuição da diversidade de espécies na floresta estuarina amazônica (FREITAS, 2019; FREITAS et al., 2015; BARROS et al., 2023).

Como observado, alguns estudos têm sugerido que a coleta de recursos florestais não madeireiros nem sempre se dá de forma sustentável (BROKAMP et al., 2014; AVOCÈVOU-AYISSO et al., 2009). Adicionalmente, há o dilema da sustentabilidade entre a coleta com manejo (KUSTERS et al., 2006) e coleta sem manejo (FREITAS et al., 2015) atrelada a esses produtos. Por outro lado, a extração de produtos florestais não madeireiros, especialmente a coleta de frutos silvestres, em sua maioria, afeta menos a estrutura e a função das florestas do que outros usos (STANLEY; VOEKS; SHORT, 2012) como os madeireiros.

No tópico seguinte (e seus subtópicos) será abordado um conjunto de evidências que fornecerá as bases para reforçar a importância do uso alimentício como fator de proteção. Inicialmente, abordarei sobre evidências históricas de estratégias de manejo vegetal realizadas por populações locais que promovem a proteção de certas espécies com características desejáveis. Em seguida, abordarei sobre a conservação através do uso pautada em produtos florestais não-madeireiros. Por fim, discorrerei sobre evidências a partir da hipótese da proteção, que leva em consideração o efeito protetivo para as espécies lenhosas associado a um uso especializado contra um uso generalista e destrutivo a estas.

## 2.2 Evidências do papel de proteção associados às plantas alimentícias

### 2.2.1 Proteção de plantas a partir do manejo: evidências da domesticação

A literatura vem demonstrando que a relação entre seres humanos e plantas é contrastante. Alguns exemplos de relação desarmoniosa incluem o abandono de estratégias e técnicas de coleta tradicionais como medida de maximização do retorno econômico (SINHA; BAWA, 2002). Adoção dessas novas técnicas podem levar à coleta destrutiva dos produtos florestais, e à superexploração de certas espécies vegetais mediante baixos retornos (CROOK; CLAPP, 1998). Por outro lado, um conjunto de estudos vem demostrando a existência de várias estratégias de manejo que podem trazer benefícios mútuos para as plantas e pessoas (CASAS et al., 1997; FONDOUN; TIKI-MANGA, 2000; CASAS et al., 2001; BLANCAS et al., 2010; Blancas et al., 2013).

A forma de manejo incipiente é um tipo de interação intermediária entre a coleta e a agricultura, que tem sido documentada por alguns pesquisadores (CASAS et al., 1997). Essa forma de manejo inclui as práticas realizadas nos ambientes onde as plantas ocorrem naturalmente, podendo esses ambientes serem as florestas, no caso de plantas silvestres e ambientes antrópicos quando se trata de plantas espontâneas (BLANCAS et al., 2010). Esse tipo de manejo é denominado técnicas de manejo *in situ,* que podem ser diferenciadas em três processos: tolerância, promoção e proteção (CASAS et al. 1997). De acordo com Blancas *et al*. (2010), e, considerando apenas a ocorrência dessas técnicas em florestas, tem-se que: 1) tolerância é uma técnica por meio da qual espécies vegetais úteis silvestres ou fenótipos particulares dessas espécies são deliberadamente deixados sem nenhuma manipulação durante eventos de desmatamento; 2) a promoção ou aprimoramento ocorre quando atividades são realizadas com o intuito de aumentar a densidade populacional e a disponibilidade de espécies vegetais úteis ocorrentes em uma comunidade biótica; e 3) a proteção inclui ações que favorecem a permanência de certas plantas por meio de cuidados especiais, que podem envolver a eliminação de competidores e herbívoros, podas, proteção contra pragas, geadas, radiação solar e outras.

As interações entre humanos e plantas podem ser influenciadas por alguns fatores. como: a) o papel do recurso vegetal na subsistência humana, seja em termos econômicos ou culturais; b) sua disponibilidade em relação à demanda humana; sua qualidade; e c) a viabilidade de manejo dos seus propágulos, suas populações ou comunidades bióticas nas quais esses recursos ocorrem (CASAS et al., 2001). Em um estudo realizado em quinze aldeias, na zona da floresta úmida do Sul de Camarões, Fondoun e Tiki-Manga (2000) identificaram as abordagens tradicionais para a conservação de duas espécies (*Garcinia kola* e *Gnetum africanum*) muito importantes para usos alimentícios, medicinais e econômicos, para geração de renda de pequenos agricultores. Os resultados mostraram que os agricultores estão envolvidos na conservação *in situ* das espécies, usando, dentre outras abordagens, o desmatamento seletivo durante a preparação da terra para cultivo, a coleta sustentável de cascas de populações vegetais silvestres mantendo-as de pé e, evitando o corte de populações das espécies arbóreas durante o desmatamento de áreas florestais. Outro exemplo das práticas de manejo *in situ* que beneficiam as espécies vegetais foi encontrado por Blancas *et al*. (2010) que, ao revisarem um conjunto de estudos etnobotânicos conduzidos em treze aldeias do Vale Tehuacátan-Cuicatlán, no México, identificaram as três técnicas de manejo acima descritas para espécies com usos principalmente alimentício, forrageiro, medicinal e ornamental. Entre as plantas manejadas com múltiplos usos, o uso alimentício foi o mais frequente e 60 plantas alimentícias foram registradas entre as espécies com uso exclusivo, perdendo apenas para as plantas ornamentais.

O tipo e a intensidade e estratégias de manejo de plantas podem variar entre as espécies conforme as necessidades das pessoas locais. Em uma pesquisa etnobotânica, Blancas *et al.* (2013) analisaram a relação entre índices de risco e a intensidade do manejo de espécies vegetais alimentícias usadas em cinco aldeias de Coyomeapan, no México. Os resultados indicaram que as pessoas manejam os recursos vegetais de acordo com o papel que desempenham na subsistência das famílias, ou a quantidade disponível e a qualidade de seus produtos úteis, sobretudo o equilíbrio entre a disponibilidade e a demanda de recursos. Os autores encontraram que, em geral, os menores valores de intensidade de manejo correspondiam a espécies sujeitas a coleta simples ou tolerância. A maioria delas eram plantas anuais abundantes, consumidas ocasionalmente por poucas pessoas. Enquanto os maiores valores de intensidade de manejo foram registrados em espécies com importância econômica, em sua maioria perenes, com variedades reconhecidas, cujo manejo requer o uso de ferramentas e que são protegidas por regulamentação coletiva.

Embora esses estudos tratem sobre o favorecimento deliberado de plantas alimentícias de alta importância econômica e cultural nos seus locais de ocorrência a partir de estratégias de manejo como a tolerância, promoção e proteção, pouco se sabe sobre como a importância da planta para um fim pode protegê-la de outros usos mais destrutivos, ou seja, dos efeitos interativos entre as diferentes formas de aproveitamento das espécies vegetais. Isso limita a nossa compreensão do efeito protetivo em sistemas socioecológicos e de seu benefício econômico para a população humana. Essas informações são essenciais para se entender e estabelecer o arcabouço da conservação biocultural, mostrando os múltiplos benefícios da manutenção de práticas culturais associadas à biodiversidade.

### 2.2.2 Conservação através do uso de PFNM

A promoção dos produtos florestais não-madeireiros tem sido proposta como uma maneira sustentável de explorar as florestas tropicais, intensificando-se a partir dos anos 90 (BELCHER; RUIZ-PÉREZ, 2004). Isso se deve, sobretudo, à possibilidade de coleta de partes da planta, que seria menos destrutiva do que a exploração madeireira e a importância desses recursos para muitas comunidades rurais ao redor do mundo. Além disso, os PFNM têm sido associados ao alívio da pobreza (ZENTENO et al., 2013).

Com a promoção e utilização dos PFNM, muitos pesquisadores incorporaram uma abordagem chamada “conservação através do uso” aos seus estudos. Essa abordagem foi posteriormente denominada hipótese da conservação pela comercialização (EVANS, 1993) e postula que as florestas podem ser conservadas se as comunidades locais obtiverem retorno econômico direto da coleta desses produtos (EVANS, 1993).

No entanto, não é qualquer PFNM que pode alcançar retornos econômicos suficientes e de forma segura do ponto de vista sustentável. O consumo de produtos florestais não-madeireiros ganha visibilidade econômica quando seu valor de mercado é superior ao valor para uso doméstico, possibilitando a geração de renda (VENTER; WITKOWSKI, 2013). Vários fatores podem influenciar o sucesso desta atividade econômica como sistemas de coleta, taxa de regeneração de espécies, disponibilidade, procura, diversificação de produtos, mercado, cadeia de valor, entre outros (SHACKLETON et al., 2024). No contexto de recursos alimentícios como PFNM, para que a comercialização seja disseminada em uma base sustentável, o local deve ter: pessoas que precisem gerar renda, mercados disponíveis e espaço para melhorar a base da dieta. Além disso, as atividades comerciais precisam ser realizadas em pequena escala, serem específicas para o local e considerarem os lucros somente para os produtores (EVANS, 1993).

Exemplos de casos exitosos considerando essa abordagem foram encontrados em vários estudos (PETERS; GENTRY; MENDELSOHN, 1989a; PETERS; GENTRY; MENDELSOHN, 1998b; WADT et al., 2008; CHAGAS et al., 2021). Por exemplo, Zuidema e Boot (2002), realizaram o estudo da demografia de *Bertholletia excelsa* (castanha-do-pará) em duas florestas primárias do norte da Bolívia, das quais a castanha do Pará é extraída há décadas. Os autores concluíram que devido ao contínuo rejuvenescimento da população, o seu tamanho estável, a elevada idade na maturidade e o longo período reprodutivo, a extração da castanha-do-pará poderia durar por décadas. Mais tarde, Wadt *et al*. (2008) analisaram as populações exploradas de castanha-do-pará (*Bertholletia excelsa)* em áreas protegidas no oeste da Amazônia, a partir de um estudo comparativo da estrutura da espécie em três locais com contextos ecológicos e socioeconômicos distintos. Os autores encontraram que a estrutura populacional em todos os três locais foi representada por uma distribuição de classe de tamanho J reversa, tendo maior representação em classes de tamanho menores e representação proporcional ligeiramente decrescente com o aumento do tamanho, uma estrutura que sugere populações demográficas saudáveis. O estudo concluiu que a regeneração é suficiente para a persistência a médio prazo das populações de plantas nesses locais.

Outro exemplo da conservação através do uso é destacado por Chagas *et al*. (2021). O estudo foi realizado em áreas da Mata Atlântica brasileira e avaliou a estrutura e a dinâmica populacional de *Euterpe edulis* Mart. (palmeira juçara), em três tipos de florestas: florestas secundárias protegidas, florestas secundárias manejadas e agroflorestas. Também foram realizadas avaliações financeiras e ecológicas da produção da polpa da fruta e palmito para comparar os resultados da colheita de frutas nessas áreas florestais. Os resultados revelaram que árvores frutíferas maduras eram mais comuns em florestas secundárias e agroflorestas do que em áreas protegidas, apesar da falta de plantas de tamanho intermediário. As projeções demográficas com dados de campo, indicaram que a produção manejada de frutas em florestas secundárias e agroflorestas tem resultados de longo prazo superiores na dinâmica populacional de *E. edulis*, lucratividade e disponibilidade de frutos para *wildlife*, em comparação com a maioria dos cenários de coleta de palmito. As conclusões do estudo indicam que agroflorestas e florestas secundárias são eficazes na conservação e restauração das populações de E. edulis, enquanto geram lucro sustentável para os agricultores. A coleta de frutos é destacada como uma estratégia que maximiza tanto a conservação quanto os benefícios financeiros, demonstrando um equilíbrio entre objetivos de conservação e econômicos.

Com o passar do tempo, no entanto, a partir de revisões da literatura, com base nos estudos de caso realizados, algumas análises e críticas surgiram, contestando a viabilidade das atividades de coleta dos PFNM (CROOK; CLAPP, 1998; BELCHER; RUIZ-PÉREZ, 2004; NEWTON, 2008). Esse contexto crítico inclui: desconsiderar que os lucros a partir da venda desses produtos muitas vezes não são diretamente destinados aos extrativistas, mas divididos com intermediários; desconsiderar perdas após a colheita e o impacto nos preços dos produtos diante da intensificação nas atividades extrativistas; desconsiderar restrições relacionadas à posse da terra que pode limitar o acesso ao recurso, a escala comercial desses produtos, entre outras (CROOK; CLAPP, 1998).

A partir disso, um conjunto de soluções e desafios foi posto em perspectiva para obtenção de sucesso na promoção e venda dos PFNM pelos povos locais. Esse conjunto inclui: conhecimento técnico sobre conservação, processamento e armazenamento de produtos sazonais (ex. frutos), educação financeira, estratégias de marketing, certificação dos produtos, coleta sustentável, utilização de parte dos retornos para ações práticas de conservação destinadas a combater outras ameaças às espécies, etc. (EVANS, 1993; NEWTON, 2008). Isto resultaria em maiores retornos financeiros, os quais seriam incentivos à conservação das áreas florestais ou espécies vegetais.

Entretanto, é preciso atentar sobre qual conceito de PFNM é assumido pelo pesquisador, porque há muitos estudos que consideram, além de frutos, alimentos silvestres como carne de caça e de outros animais e até a extração de madeira de alto valor como parte desses produtos, muitas vezes incluindo mais de um tipo desses PFNM. Por exemplo, na revisão de Newton (2008) são exemplificadas dez espécies arbóreas de interesse para a conservação em vários estudos, nos quais a exploração madeireira é mais citada do que a obtenção de produtos resina, nozes, folhas e flores cuja extração é menos destrutiva. Em nove desses estudos a coleta de madeira foi considerada insustentável ou pouco sustentável, enquanto o uso de nozes, folhas e flores foi considerado sustentável.

Diante das críticas associadas à abordagem da conservação através do uso de PFNM, faz-se necessária a realização de estudos que usem ferramentas sistemáticas para colocar em prova a ideia de conservação pelo uso. Uma das principais hipóteses a serem testadas, nesse sentido, é a hipótese da proteção. O próximo subtópico, fornece argumentos sobre como a interação de usos especializados e generalistas pode ser importante para estudos voltados à conservação de espécies lenhosas.

### 2.2.3 Evidências da hipótese da proteção

Quando se compara usos alimentícios a usos madeireiros quanto ao número de espécies disponíveis para uso e o grau de dano em termos do impacto da coleta das partes usadas, tem-se que o uso alimentício é considerado pela literatura como especializado e com menores impactos nas populações vegetais. Já os usos madeireiros costumam ser considerados generalistas e causadores de maiores impactos à estrutura vegetal (MEDEIROS et al., 2011), devido a coletas geralmente destrutivas. Os usos especializados são definidos por uma quantidade restrita de plantas adequadas que atendem a requisitos específicos. A ideia de especialização é reforçada, pelo fato de a disponibilidade das plantas possuir influência menor ou nula sobre esse uso (RIBEIRO et al., 2014; SOLDATI et al., 2016).

Uma evidência empírica favorável ao efeito de proteção de usos especializados sobre usos generalistas foi registrada por Silva *et al.* (2021), que testou a hipótese da proteção para a qual a importância de usos medicinais (usos especializados) tinha um efeito de proteção sobre usos madeireiros (usos generalistas). O estudo demonstrou um efeito pequeno, porém significativo da importância do uso medicinal sobre o uso madeireiro (lenha) para espécies da Caatinga.

Assim, de um lado, a alta importância das plantas alimentícias para as populações locais (consumo direto e geração de renda) pode impulsionar as pessoas a protegerem e a manterem essas espécies que tem uma forte especialização. Do outro, usos madeireiros podem causar danos estruturais às populações de plantas lenhosas que também fornecem recursos alimentícios de elevada importância. Entretanto, como o uso madeireiro é generalista, há outras opções de espécies igualmente vantajosas que podem ser usadas pelas pessoas, permitindo poupar certas espécies vegetais para utilização exclusivamente alimentícia. Tendo em vista isso, as plantas alimentícias com importância doméstica e/ou comercial se constituem como um modelo viável para testar o efeito de proteção desse uso sobre usos madeireiros.

Para melhor compreender as diferenças dos usos alimentícios e madeireiros, discutirei no tópico a seguir sobre os usos e impactos ecológicos nos recursos florestais madeireiros.

## 2.3 Uso e conservação de produtos florestais madeireiros

A madeira pode ser usada para diversos fins e os principais usos madeireiros estão distribuídos principalmente nas categorias combustível, construção e tecnologia (RAMOS; MEDEIROS; ALBUQUERQUE, 2010). Na categoria combustível está a madeira que é destinada à geração de energia para o cozimento de alimentos, aquecimento da água ou de ambientes (RAMOS; MEDEIROS; ALBUQUERQUE, 2010). Nesse caso, a madeira é utilizada na forma de lenha ou carvão. Os elementos de madeira que são parte de uma estrutura para delimitação territorial, moradia ou abrigo de animais e armazenamento de objetos fazem parte da categoria construção. Nessa categoria, a madeira é utilizada para a construção de cercas, mourões, linhas de casa, caibros, ripas, portas, janelas, entre outros (RAMOS; MEDEIROS; ALBUQUERQUE, 2010). A categoria tecnologia, por sua vez, comporta os elementos que sofrem manipulação, contudo, não são destinados para delimitar espaços. Entram nessa categoria, os cabos de ferramentas, bancos, mesas, cadeiras, canoas, remos etc. (RAMOS; MEDEIROS; ALBUQUERQUE, 2010).

Esses recursos florestais madeireiros representam grande importância para as populações locais, com destaque para o uso combustível, principalmente em países subdesenvolvidos. Por exemplo, no nordeste da Índia, Saha e Sundiyal (2012) registraram que a dependência de recursos florestais foi de 100% para a lenha e para materiais de construção de casas. Na aldeia de Santiago Quiotec de Oxaca, no México, 464 toneladas de lenha são extraídas anualmente para cocção (PÉREZ-NEGRÓN; CASAS, 2007). A lenha representa a principal fonte de energia doméstica para a população de Muda, em Moçambique (BRUSCHI et al., 2014). Além disso, a biomassa de madeira extraída nessa região para a produção de carvão vegetal é de cerca de 26.000 m³ por ano, sendo um dos principais responsáveis pelos índices de desmatamento da região. No Brasil, a lenha ainda tem utilização significativa pelas pessoas com maior vulnerabilidade social (HORA et al., 2021; GONÇALVES et al., 2021; BRITO, 1997). Particularmente no semiárido, as estratégias de sobrevivência das populações rurais dependem de espécies lenhosas que fornecem material para construção e usos tecnológicos (ALBUQUERQUE; ANDRADE, 2002).

Embora o uso da madeira seja de grande importância para as populações locais, sobretudo para as que se encontram em países subdesenvolvidos, ela é o produto cuja extração é mais danosa às populações vegetais. Avaliando os padrões de coleta e uso de madeira entre as diferentes categorias, Medeiros *et al*. (2011) observaram que esses padrões diferiam substancialmente, de modo que a categoria combustível abrangia grandes quantidades de madeira, apresentava curto tempo de reposição e a coleta era baseada em galhos, troncos e em indivíduos mortos e vivos. As categorias construção e tecnologia, no entanto, apresentaram tempos de reposições longos e a coleta era baseada em troncos de indivíduos vivos, com um maior volume de madeira utilizada para construção do que para tecnologia.

A maioria dos estudos sobre produtos florestais madeireiros tem considerado ora a avaliação conjunta de várias categorias de uso e seus impactos na conservação dos recursos vegetais, ora especificamente o uso combustível devido ao fato de ser o uso madeireiro mais difundido em diferentes comunidades. No estudo etnobotânico com amostragem da vegetação de Miombo (floresta tropical), realizado por Bruschi *et al*. (2014) em quatro comunidades de Muda-Serração, em Moçambique, as plantas lenhosas mais citadas, depois das plantas alimentícias, foram as plantas artesanais (38 espécies) e domésticas (37 espécies), que foram relatadas como tendo coletas destrutivas, como cortes de galhos de árvores ou caules principais de madeira. As plantas classificadas como artesanais são utilizadas, em sua maioria, como postes para construção, objetos domésticos e carpintaria. Dentre os usos domésticos, está o uso de lenha (10 espécies) e carvão (11 espécies). Os autores indicaram que os principais riscos para a conservação dos recursos vegetais estão concentrados nos usos para fins madeireiros, sobretudo de lenha, carvão e carpintaria, que apresentam um forte impacto tanto pela sobre-exploração de espécies quanto por terem coleta destrutiva. Estudos sobre o uso e preferência de lenha em comunidades rurais, revelaram que as pessoas selecionam e utilizam as espécies pela qualidade madeireira percebida, ao analisarem as propriedades físicas da madeira das plantas mencionadas como preferidas pelas pessoas locais (RAMOS et al., 2008; CARDOSO et al., 2015). Quando essa preferência associada ao uso efetivo se concentra em um pequeno número de espécies pode comprometer a sustentabilidade do uso dessas espécies a longo prazo.

Esses usos também têm sido tratados na literatura como causadores de distúrbios antropogênicos crônicos, referindo-se a distúrbios relacionados aos usos de recursos florestais em proporções pequenas, mas contínuos que vão se acumulando a longo prazo, ao ponto de seus impactos ecológicos se tornarem visíveis (RIBEIRO et al., 2019; GONÇALVES, MEDEIROS, ALBUQUERQUE, 2021). Um exemplo disso é o estudo de Gonçalves, Medeiros e Albuquerque (2021) realizado no Parque Nacional do Catimbau, em Pernambuco. Os autores descreveram os padrões de coleta de lenha e construção de cercas e avaliaram os efeitos da coleta de madeira para esses usos na estrutura da comunidade arbórea. Eles encontraram que as pessoas tinham um comportamento generalista na coleta de lenha, mas um comportamento mais especializado na coleta de madeira para construção de cercas. Embora, de modo geral, a coleta de madeira doméstica tenha demostrado pouco impacto na estrutura da comunidade, os autores alertam que a coleta de madeira para construção de cerca pode afetar a estrutura populacional das espécies mais usadas no futuro, devido ao caráter especializado da sua coleta.

Muitas vezes as plantas lenhosas podem ter múltiplos usos e isso pode influenciar na avaliação do status de conservação de tais espécies. Por exemplo, Oliveira *et al*. (2007) sugerem que os índices de prioridade de conservação podem ser fortemente influenciados pelo fato de que usos medicinais estão associados com usos concorrentes de madeira. É possível imaginar que o mesmo aconteça para plantas lenhosas que também sejam úteis para a finalidade alimentícia, uma vez que os usos madeireiros por serem mais danosos, podem estar reduzindo o uso alimentício, como sugerido por Brushi *et al*. (2014). Contudo, os usos madeireiros têm sido classificados na literatura como sendo generalistas. Para usos generalistas há um repertório maior de espécies úteis e, geralmente, uma relação forte com a disponibilidade. Desse modo, as espécies mais usadas são justamente as mais disponíveis, como ocorre com a maioria dos usos madeireiros (MEDEIROS et al., 2011; GONÇALVES; ALBUQUERQUE; MEDEIROS, 2016). Essa característica possibilita outras opções igualmente vantajosas de espécies lenhosas para propósitos madeireiros relacionados às necessidades das pessoas locais, o que permitiria que certas espécies fossem poupadas para usos nos quais dificilmente há equivalentes para substituição (SILVA et al, 2021), como o uso alimentício.

As evidências empíricas da maioria dos estudos com produtos florestais madeireiros e não madeireiros explanadas acima, indicam a comum característica da dependência das populações locais sobre esses recursos vegetais e a notável distinção em termos da sustentabilidade do uso desses recursos pelas populações locais. No entanto, ainda são necessários estudos nos remanescentes da Mata Atlântica que possam contribuir para a ampliação das informações sobre sustentabilidade dos usos madeireiros e usos alimentícios. Além disso, em um contexto em que a grande parte das plantas conhecidas e usadas apresentam múltiplo usos, destaca-se a importância de investigações com vistas à conservação que avaliem o impacto de um uso sobre outro. Ou seja, estudos que considerem a interação entre usos de plantas lenhosas, os quais podem indicar, além da possível influência negativa de certos usos sobre outros, o potencial efeito de proteção que essa interação pode promover.

No próximo tópico serão explanados alguns fatores que influenciam na seleção de espécies usadas para fins madeireiros.

### 2.3.1 Critérios de seleção de plantas madeireiras

Um conjunto de estudos etnobiológicos realizados em distintos contextos socioambientais têm mostrado que a seleção de plantas madeireiras pelas populações humanas pode ser influenciada por fatores socioeconômicos (RAMOS et al., 2008a; ARRUDA et al., 2019; CRUZ et al., 2020), físicos e ecológicos (RAMOS et al., 2008a,b; CARDOSO et al., 2015; SILVA et al., 2017; HORA et al., 2021; CRUZ et al., 2020). Dentre esses fatores, a qualidade e a disponibilidade têm se destacado em termos de maior poder preditivo entre os estudos.

A qualidade vem sendo estudada em termos de suas propriedades físicas (RAMOS et al., 2008; CARDOSO et al., 2015) e da percepção local (HORA et al., 2020; SILVA et a., 2017). A disponibilidade, por sua vez, vem sendo estudada a partir da percepção local e/ou sendo aferida por meio de ferramentas ecológicas (HORA et al., 2020; GALEANO, 2000; ALBUQUERQUE; LUCENA, 2009). Muitos estudos avaliaram a influência da disponibilidade ambiental (aferida por parâmetros fitossociológicos) a partir da hipótese da aparência e, ora foi encontrada relação entre a disponibilidade ambiental e o uso de plantas madeireiras (GALEANO, 2000; GONÇALVES et al., 2016), ora não (ALBUQUERQUE; LUCENA, 2005). E ambos os fatores são avaliados ou isoladamente, ou em conjunto, sendo a categoria de uso combustível a mais presente nesses estudos.

As propriedades físicas da madeira são indicadores da sua qualidade. Componentes físicos da madeira como densidade, teor de água, teor de umidade, teor de cinzas e valor calorífico são aferidos como determinantes da combustibilidade de uma planta. Geralmente, a combustibilidade é estimada por meio do Índice de valor Combustível (IVI). Alguns trabalhos sobre uso e preferência de lenha que utilizaram esse índice como indicador de qualidade da madeira, identificaram que as espécies com maiores valores de IVI são as preferidas pelas pessoas locais, sugerindo que as pessoas selecionam e utilizam as espécies pela sua qualidade (RAMOS et al., 2008; CARDOSO et al., 2015). Silva *et al*. (2017) examinaram a influência da qualidade na seleção de recursos madeireiros. O estudo foi realizado em uma comunidade quilombola no município de União dos Palmares, em Alagoas. O estudo testou a influência da qualidade percebida sobre o uso de lenha em ambiente de Mata Atlântica com escassez florestal. Os autores encontraram que a qualidade percebida exerce influência sobre a frequência de uso, mas não sobre o número de usuários de plantas para lenha. Eles inferiram que o contexto de escassez florestal interfere mais fortemente no número de pessoas que utilizam recursos de alta qualidade do que na frequência de uso desses recursos por pessoas que podem acessá-los. Assim, evidenciou-se a necessidade de que as estratégias de conservação levem em conta o acesso diferencial a recursos de alta qualidade em contextos de escassez.

Uma pesquisa realizada por Hora *et al*. (2021) em uma comunidade rural do município de Altinho, em Pernambuco, avaliou a influência de fatores ecológicos (percepção da dificuldade de aquisição e disponibilidade ambiental) e de fatores biológicos (dentre eles, a qualidade percebida geral) no uso de plantas para fins combustíveis. O resultado revelou influência da disponibilidade ambiental, qualidade percebida (geral) e durabilidade da madeira no uso da lenha. Os fatores que exibiram influência no uso de carvão foram a qualidade percebida (geral) e a durabilidade. O estudo mostra a importância de avaliar diferentes fatores de forma combinada para obter uma resposta mais completa sobre o comportamento de coleta de plantas para fins combustíveis e, consequentemente direcionar estratégias de conservação mais realistas.

Embora o efeito das variáveis disponibilidade e qualidade sobre o uso de plantas para fins madeireiros esteja sendo amplamente estudado em diferentes contextos socioecológicos, a literatura científica carece de estudos que considerem interações entre categorias de uso ao avaliar os critérios de seleção dos recursos vegetais. Isso é importante para entender até que ponto múltiplos fatores podem atuar como impulsionadores ou não da seleção de plantas lenhosas usadas para fins alimentícios e madeireiros. Além disso, esses estudos também poderão informar quando a importância de uma planta para determinado fim supera o seu uso potencial para outro fim.

Diante de todas as evidências e argumentos apresentados nesta revisão, neste estudo busquei investigar as interações entre os usos alimentícios e madeireiros e suas implicações para a conservação biocultural. Esse estudo é o primeiro framework a testar a hipótese da proteção para plantas alimentícias silvestres e a utilizar ferramentas sistemáticas para isso.

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**CAPÍTULO 1**

# 3. WILD FOOD PLANTS WITH THE POTENTIAL TO IMPROVE FOOD AND EXTRACTION: A SYSTEMATIC REVIEW OF THE BRAZILIAN CONTEXT

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## Significance Statement

The interaction of uses is an important tool to capture potentially threatened woody plants. However, it has been little explored in studies on biodiversity conservation. Our systematic review provides a compilation of ethnobiological and nutritional information on versatile food woody plants for the main timber uses, uses considered to be the most destructive to the structure of plant populations. We indicate food species native to Brazil that are strategic for food and nutritional security, due to their high nutritional potential and, at the same time, strategic for conservation, due to the probable risk of loss of their natural populations by logging. We discuss possible biocultural conservation strategies for these species. We also make recommendations for future studies on identified gaps in both ethnobiological and nutritional studies.

**Abstract**

Wild food plants can contribute to improving the food and nutrition security of local populations by promoting diet diversification and increasing the intake of micro- and macronutrients. However, many of these plants are also used as timber. Wild food species need to be identified and their food–wood use interactions need to be well understood for the development of conservation strategies, as species with the potential to improve food and nutrition security may be threatened by destructive extraction. This systematic review recorded and compiled nutritional information on woody plant species native to Brazil that are used by local populations for food and timber purposes, seeking to identify which species have a high overlap between food and timber uses as well as a high nutritional potential. A total of 635 woody species with timber and/or food uses were identified. Of this total, at least 42 species find application in all timber use categories analyzed in this study, being considered versatile. Comparison of ethnobiological and nutritional data revealed nine versatile species for which nutritional composition information was available, among which three stood out in terms of macronutrient contents, namely *Anacardium occidentale* L., *Bauhinia cheilantha* (Bong.) Steud., and *Eugenia pyriformis* Cambess. Many versatile species classified as threatened or in decline have not been the focus of nutritional studies, which signals the need for greater nutritional research efforts. It is also necessary to investigate whether food importance exerts any protective effect on these species, reducing timber use pressure (protection hypothesis).

**Keywords:** Biocultural conservation, Ethnobotany, Food use, Nutritional composition, Timber use, Use interaction.

## 1. Introduction

In various parts of the world, studies have underscored the importance of wild food plants for the food and nutrition security of local populations, particularly during periods of food shortage (do Nascimento et al., 2012, 2011; Medeiros Jacob et al., 2020; Medeiros et al., 2021; Shackleton et al., 2015; Shackleton and Shackleton, 2004). Wild plants can play an important role in a healthy diet as alternative sources of minerals, vitamins, and antioxidants (Bacchetta et al., 2016; Jacob et al., 2022; Rico et al., 2016), as well as macronutrients such as carbohydrates, proteins, and lipids (Medeiros Jacob et al., 2020). Consumption of wild food plants has been recommended as part of global strategies to manage malnutrition (Hunter et al., 2019) diversify the human diet (Baldermann et al., 2016), improve food systems, and generate income for small-scale farmers and extractivists (Delang, 2014).

The importance of wild plants extends well beyond socioeconomic and nutritional factors (Medeiros Jacob et al., 2020). From a conservation perspective, studies have argued that people who rely on utilitarian and/or economic returns from forests are less likely to carry out activities that generate changes in land use in forest areas. This concept became known as the "conservation by commercialization hypothesis" (Evans, 1993; Lowore, 2020). It is also noteworthy that the extraction of edible parts of plants is, in most cases, less harmful than timber extraction, being conducive to the application of sustainable management and use strategies. However, despite the great potential of wild food plants for sustainable management, many of these species have multiple applications, including timber extraction, which is a major cause of decline among plant populations (Bruschi et al., 2014; Ros-Tonen, 2000; Stanley et al., 2012). Timber uses include fuel, construction, and technological applications (Ramos et al. 2010).

Several plants found in forests and other natural ecosystems can be used both as food and timber. Such species need to be identified and their food–wood use interactions understood to guide the development of conservation actions. Populations of species with high potential to improve food and nutrition security may be threatened by more destructive uses than food extraction. This situation is particularly worrisome for woody species that combine multiple timber uses (versatile species), as they may be facing greater use pressure. In Brazil, several studies described woody species with nutritional potential (do Nascimento et al., 2012, 2011; Medeiros Jacob et al., 2020; Nunes et al., 2012). However, most studies have failed to analyze the intersection between nutritional potential and the extent to which plant populations are threatened by uses other than human consumption. Understanding the overlap of uses of woody plants is important because conservation strategies encompassing different uses of plant resources can greatly contribute to food and nutrition security.

Species extinction represents an irreversible loss of biodiversity and cultural heritage. To avoid this problem, it is essential to develop strategies from a biocultural conservation perspective, that is, seeking to combine environmental conservation actions with knowledge on the use of natural resources to reduce the loss of biological and cultural diversity (Gavin et al., 2015). Preserving the widespread use of wild food resources might be strategic because wild plants are found in many local communities that still face challenges related to hunger, food availability, diet diversification, and climatic events impacting crop production (do Nascimento et al., 2012, 2011; Medeiros Jacob et al., 2020).

On the one hand, timber extraction tends to be harmful to plant populations, which explains its use as a threat indicator. On the other hand, it is important to emphasize that (i) timber extraction can be carried out sustainably, as has been proposed in different socioecological contexts (Bahru et al., 2021; Cavalcanti et al., 2015; Lucena et al., 2007; Tabuti et al., 2011), and (ii), in some cases, food extraction can be more damaging to plant communities than timber extraction, depending on forest management intensity. A prominent example is açaí (*Euterpe oleracea* Mart.), whose management has led to the simplification of estuarine communities in the Amazon Forest (Freitas et al., 2021). In this study, we approach the topic with awareness of possible contrasting effects. Nevertheless, it is understood that woody species with multiple timber uses may be exposed to greater use pressure and, consequently, higher management intensity.

In this systematic review, we aimed to identify priority species for biocultural conservation that are, at the same time, strategic for the maintenance of food and nutrition security (in terms of micro- and macronutrient composition) and potentially threatened by multiple timber uses. For this, we identified woody species native to Brazil that are used by local populations for food and timber purposes and compiled nutritional information available in the scientific literature to answer the following questions: (i) Which woody food species have high versatility as timber? and (ii) Which food and timber species have high potential to contribute to food and nutrition security?

This study presents the results of two systematic reviews. The first, of an ethnobiological nature, summarizes information on wild plants with overlapping applications as food and timber, and the second, of a nutritional nature, compiles information on the chemical composition of these species.

## 2. Methods

### *2.1. Ethnobiological systematic review*

This systematic review was conducted based on the PRISMA guidelines (see Additional File 1). Figure 1 shows a flowchart of the research steps.

#### *2.1.2. Eligibility criteria*

Studies were selected according to the following eligibility criteria: (i) articles of an ethnobotanical nature, (ii) original studies, and (iii) studies assessing food and/or timber plants native to Brazil. Duplicates, articles focused on herbaceous plants only, studies not indexed in major databases, and review studies were excluded. Priority was given to studies with complete floras. Studies assessing plants from only one botanical family or only a few species (<5) were excluded.

*2.1.3. Information sources*

Searches were carried out between January and February 2022 in three databases: Web of Science, Scopus, and SciELO. The first two databases were chosen because they contain the largest number of articles published in international journals and achieved excellent performance in systematic reviews (Bramer et al., 2017). SciELO was included to reach a greater number of studies published in Brazilian journals. Additional articles were identified by screening the reference list of articles identified from database searches.

*2.1.4. Search strategy*

Database searches were performed on two occasions, hereafter referred to as B1 and B2. An additional search was performed via other sources (B3). After the initial search (B1), a second search (B2) was performed to expand the retrieval of articles not identified through the initial keywords. The reference list of all articles selected in B1 was screened for potentially relevant titles, and these newly identified articles were examined. We recorded and identified the most frequent keywords used in these articles, including keywords that had not been used in B1, in order to conduct a new cycle of searches (B2) in the three databases. A third search (B3) was performed through other sources, in which articles retrieved in B2 were consulted to identify new keywords and then submitted to the selection processes described in the next section.

The same search terms were used for the three databases, with the inclusion of Portuguese keywords for searches in the SciELO database. Search efforts were directed to article titles, abstracts, and keywords by using the different fields available in each database, as follows: topic (Web of Science); title, abstract, and keywords (Scopus); and all indexes (SciELO). The search strategies used in each database are available in Additional File 2.

*2.1.5. Study selection*

Search records were saved in RIS format and imported into the Mendeley reference manager, which automatically identifies and deletes duplicates. After that, references were exported to an Excel spreadsheet. In Excel, we were able to identify and manually delete some duplicates that had not been identified by Mendeley's automatic check, possibly because of errors in the references or titles written in different languages.

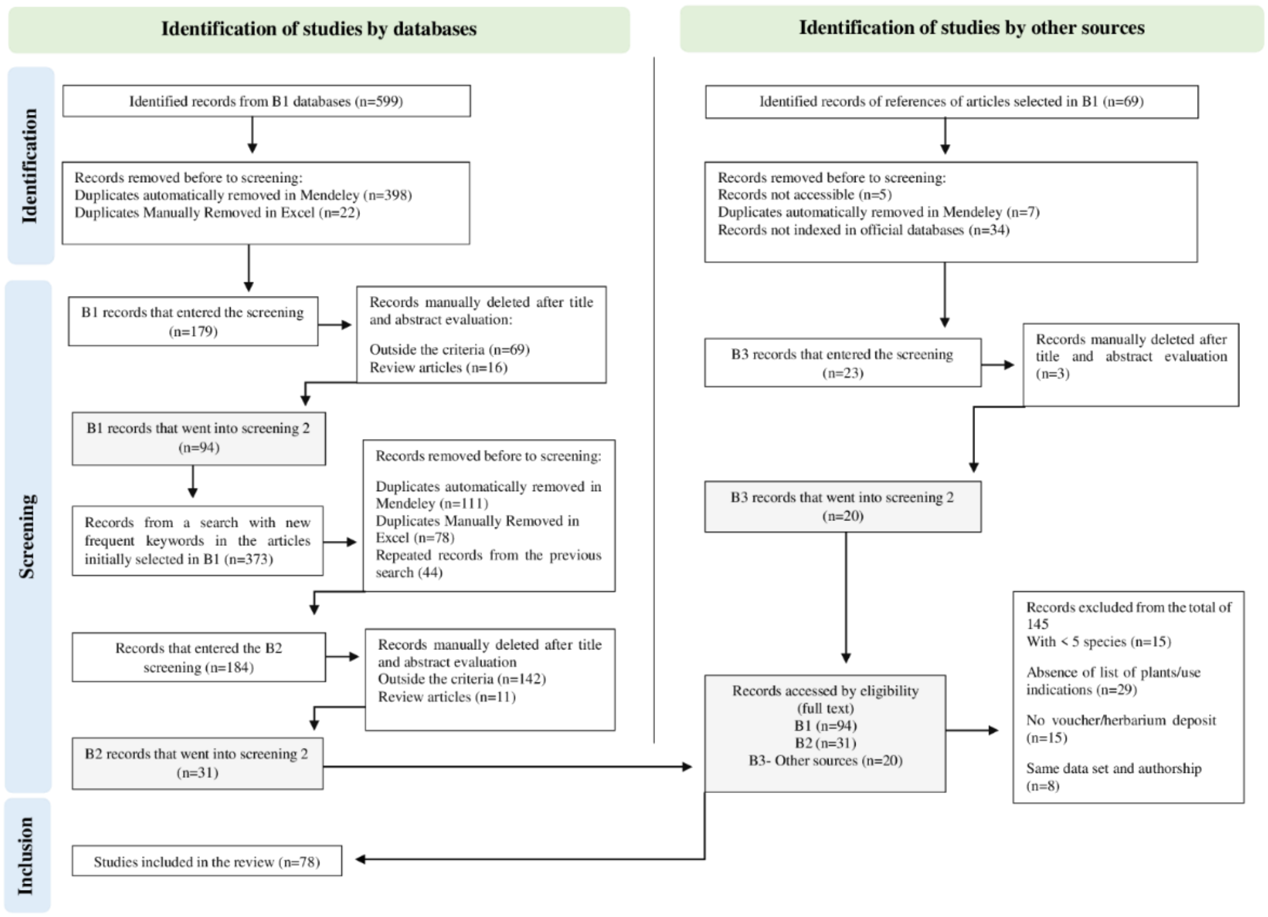



**Figure 1**. Flowchart with systematic review search and screening steps

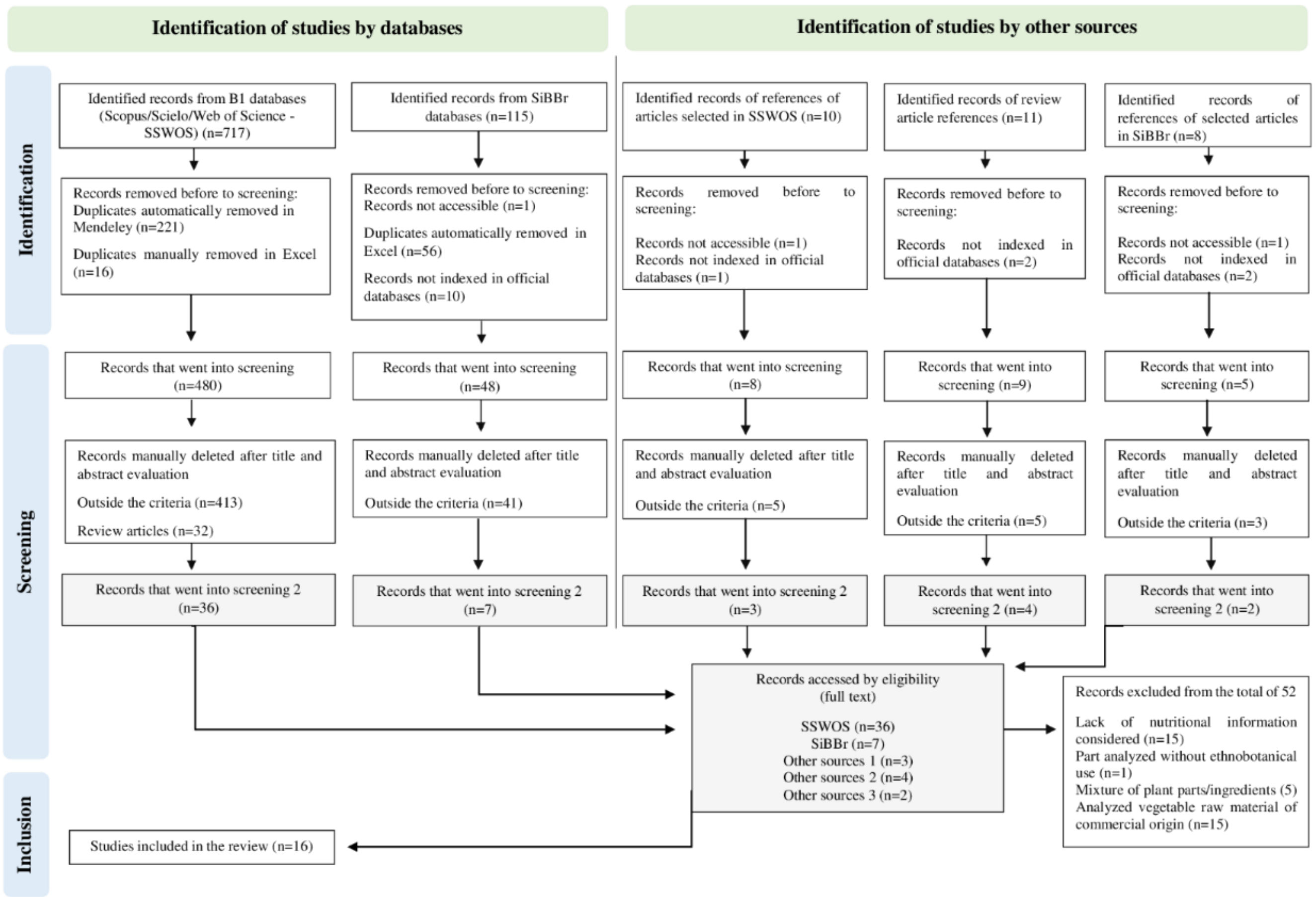
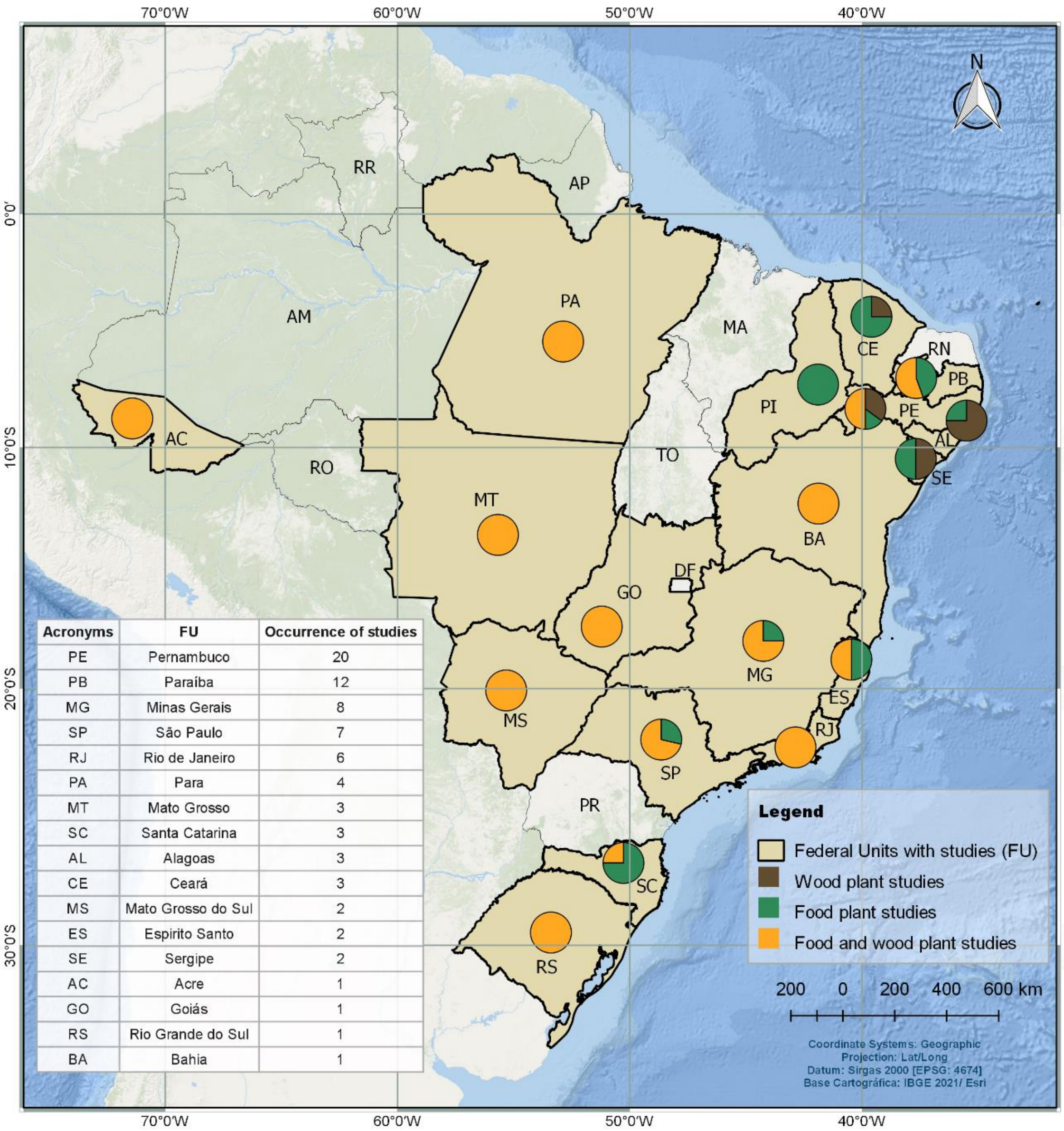



**Figure 2.** Flowchart with search and screening stages of the systematic review on nutritional aspects




| Acronyms | FU | Occurrence of studies |
|---|---|---|
| PE | Pernambuco | 20 |
| PB | Paraíba | 12 |
| MG | Minas Gerais | 8 |
| SP | São Paulo | 7 |
| RJ | Rio de Janeiro | 6 |
| PA | Para | 4 |
| MT | Mato Grosso | 3 |
| SC | Santa Catarina | 3 |
| AL | Alagoas | 3 |
| CE | Ceará | 3 |
| MS | Mato Grosso do Sul | 2 |
| ES | Espirito Santo | 2 |
| SE | Sergipe | 2 |
| AC | Acre | 1 |
| GO | Goiás | 1 |
| RS | Rio Grande do Sul | 1 |
| BA | Bahia | 1 |

**Figure 3**. Distribution of studies on food and/or timber plants extracted in this systematic review. Note that 80 studies distributed throughout Brazil are expressed (two more than the number mentioned in the text - 78). This occurred because two studies were carried out in areas of two different states (Pernambuco and Paraíba). Elaborated by Klebson da Silva.

The first author (RAC) selected articles individually according to previously mentioned eligibility criteria. First, titles and abstracts were screened, and those that did not meet the eligibility criteria or had already been retrieved in previous searches (B1 or B2) were excluded. In case of uncertainty regarding eligibility, another author was consulted (PMM). In the next step, potentially eligible texts were read in full, and once again analyzed according to eligibility criteria, that is, whether they presented a list of plants with indications of timber and/or food uses, analyzed more than 5 species, and did not have authors in common analyzing the same dataset. For B3 articles, as an additional quality filter before these procedures, we checked if the journals were indexed in official databases (SciELO or Scopus).

*2.1.6. Data extraction*

Data were extracted from selected articles to an Excel spreadsheet. The first author (RAC) was responsible for this procedure. The following information was collected: (a) article data (authors, year of publication, and journal), (b) plant species (without authority), (c) timber and/or food uses, and (d) use categories (food, fuel, construction, and technology).

Study quality was assessed based on the identification of botanical materials, including only articles that reported having deposited a voucher specimen in herbaria and/or indicated the voucher number in tables. This procedure was undertaken because poor identification or absence of records in herbaria could lead to the inclusion of information mistakenly linked to certain species (Medeiros et al., 2014). Although other ethnobiological studies used interviewees' samples as a criterion for risk of bias (De Medeiros et al., 2013), we chose to not apply this method, given that, for our approach, the fact that a study did not use a representative sample does not make it unfeasible to compile information on useful plants. Our approach, therefore, integrated different findings and was not aimed at comparing different studies.

*2.1.7. Synthesis of results*

Only angiosperms classified as food and/or timber were included in the species survey. Scientific nomenclature, habits, origin, botanical families, and identifiers were obtained using the flora package of R software, which is based on information from the Flora and Funga do Brasil website (Jardim Botânico do Rio de Janeiro, 2022). All taxa were updated to currently accepted nomenclature at the species level. Taxa identified only at the genus or family level were excluded, and taxa with subspecies or variety information are presented only at the species level.

For cases in which the flora package returned no result for the species, we manually consulted Flora and Funga do Brasil and World Flora Online (WFO, 2022). This review included only plants classified as native and woody (i.e., plants classified as "shrub" and/or "arboreal" in the "life form" field). Thus, our research does not cover the entire universe of wild food plants, being limited to native woody plants, which are the species of interest for conservation strategies at the food–wood interface.

Timber uses were classified according to a previous study (Ramos et al. 2010). When studies categorized or specified the uses of timber species, but such a classification merged fuel, construction, or technological applications under a different denomination (e.g., handcraft), we reclassified the use category in the spreadsheet under a new column labeled "Updated category." Species grouped together in the manufacture/handicraft categories that did not contain these specifications were excluded. This procedure did not lead to the exclusion of entire studies.

*2.1.8. Species of high importance for biocultural conservation*

Food species included in the four timber use categories (food, technology, construction, and fuel), referred to herein as versatile species, were considered of high importance from a biocultural conservation perspective.

*2.2. Nutritional systematic review*

The nutritional systematic review also followed PRISMA guidelines (see Additional File 3). It included only species considered versatile in the ethnobiological systematic review. A flowchart illustrating the steps in the nutritional systematic review is presented in Figure 2.

*2.2.1. Eligibility criteria*

Original articles focused on human food plants and assessing the nutritional composition of the selected plant species were screened by reading the title and abstract.

*2.2.2. Information sources*

A review of the scientific literature was conducted in the same three databases used in the previous review (Web of Science, Scopus, and SciELO) in addition to a specific database for nutritional composition information (Brazilian Biodiversity Information System, SiBBr) (SiBBr, 2022).

*2.2.3. Search strategy*

Search strings were constructed by combining the currently accepted scientific name of each species (without the authority) + nutritional. For species whose scientific names were recently modified or whose alternative nomenclatures, despite not being currently accepted, were or still are widely used in studies, alternative terms were included in the search (see Additional File 4).

The word "nutricional" was used in the SciELO database to search for articles written in Portuguese. In the SiBBr database, we used only the scientific name of species. All database searches were carried out between August and September 2022.

All procedures performed in Mendeley and Excel for the ethnobiological systematic review were also used in the nutritional systematic review. To identify additional studies from other sources, we screened the reference list of review articles directly related to the nutritional composition of the species of interest. We checked, moreover, the reference list of articles retrieved from the four databases and screened the keywords of these studies to enrich our search strategy. However, the most frequent keywords were very similar to those already in use, precluding the need for new searches.

### *2.2.4. Study selection*

Duplicates, articles not indexed in official databases, and review papers were excluded. Articles analyzing mixtures of ingredients, enriched products, or quality parameters during food storage and processing were also excluded.

### *2.2.5. Data extraction*

The following information was extracted from selected studies: (a) article data (authors, year of publication, and journal), (b) species names (without the authority), (c) part of the plant analyzed, (d) type of preparation, (e) ecosystem, (f) place of collection, (g) macronutrient composition (proteins, carbohydrates, and lipids), and (h) micronutrient composition (minerals and vitamins). At first, we chose to include the following micronutrients: calcium (Ca), potassium (K), phosphorus (P), magnesium (Mg), sodium (Na), iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), molybdenum (Mo), chromium (Cr), selenium (Se), sulfur (S), cobalt (Co), and boron (B). However, the nutritional tables presented in the results include only the following data: available macronutrients (proteins, carbohydrates, and lipids), total energy value, and mineral contents reported in at least two articles. Thus, the tables include information on the macrominerals Ca, K, P, Mg, and Na and the microminerals Fe, Zn, Cu, and Mn. Macrominerals are defined as minerals for which the recommended daily intake is greater than 100 mg. For microminerals, the recommended daily intake is less than 100 mg (Almeida et al., 2009). Information on carbohydrates was extracted from selected articles by searching for the term "carbohydrate," including different denominations, such as "total carbohydrates," "available carbohydrates," and "calculated carbohydrates."

Given the diversity of information found in some articles, we adopted criteria for the recording of nutritional information. For example, a study on uvaia (*Eugenia pyriformis* Cambess.) analyzed several accessions of the species. We opted to include data on the most common accession, as it is the most widely known. Another situation occurred when extracting data from a study on juá (*Ziziphus joazeiro* Mart.), which analyzed specimens collected in different regions of the country. In this case, we recorded information on the sample that had the highest values in all nutrient categories.

For the generation of nutritional tables, when more than one study analyzed the same plant species, food part, and type of preparation, we selected only one study for data extraction, whereas when studies analyzed the same species but different food parts or types of preparations, we included data from all studies. When there was an overlap between nutritional information, whether of macro- or micronutrients, plant species, or parts, we prioritized studies analyzing raw materials collected in Brazil. In case of information overlap between Brazilian studies, we selected the most recent publication.

The first author (RAC) participated in all stages of the nutritional systematic review, together with two collaborators (RZP) and (AJRCS), under the supervision of PMM.

## 3. Results

### *3.1. Ethnobiological systematic review: General aspects*

A total of 145 full papers were assessed for eligibility. Of this total, 78 were included in the ethnobiological systematic review (see Figure 1) after the exclusion of (i) publications analyzing less than five species, (ii) articles without indication of timber/food uses, (iii) articles that did not mention the inclusion of voucher specimens in herbaria, and (iv) studies that used the same dataset and had at least one author in common.

Most studies included in the review are of a descriptive nature and can be classified into three groups: studies on food plants (*n* =18), studies on timber plants (*n* = 15), and studies on plants with multiple uses (*n* = 45). The selected studies were conducted between 1992 and 2021 in all regions of the country, especially in the Northeast and Southeast. A map of Brazil showing the occurrence frequency of studies on plant groups included in this review is presented in Figure 3.

Most studies are concentrated in the Caatinga (*n* = 27) and Atlantic Forest (*n* = 27) biomes. The ecosystems with the lowest number of studies were Cerrado (4) and Pantanal (2). Additional information is presented in Table 1.

**Table 1**. Regions and ecosystems in Brazil where the studies were carried out

| **Brazilian regions** | **Number of studies** |
|---|---|
| Northeast | 40 |
| Southeast | 22 |
| Midwest | 6 |
| North | 5 |
| South | 4 |
| South/Southeast | 1 |
| **Ecosystems** | **Number of studies** |
| Caatinga | 27 |
| Atlantic forest | 27 |
| Cerrado | 4 |
| Pantanal | 2 |
| Amazon | 5 |
| Atlantic Forest and Cerrado | 2 |
| Pantanal and Cerrado | 1 |
| Various[a] | 3 |
| Missing information | 7 |

[a] When there are more than two informed ecosystems

*3.1.2. Versatile woody food species used as timber*

A total of 635 native woody angiosperms were recorded, of which 167 are used exclusively for food, 328 exclusively as timber, and 140 for both purposes. Of the woody food species used in all timber applications (fuel, construction, and technology), 42 are native to Brazil. However, given that many studies did not indicate the specific type of timber application, it is possible that the number of versatile species is much higher.

We observed that half of the versatile species occur in the Caatinga, supported by the fact that most studies specifying the type of timber use were carried out in this biome. The most represented botanical families in number of species were Anacardiaceae (*n* = 7), Fabaceae (*n* = 6), and Myrtaceae (*n* = 4). Other six families were represented by two species each, namely Lauraceae, Euphorbiaceae, Capparaceae, Celastraceae, Burseraceae, and Bignoniaceae. The major genera, represented by two species each, were *Spondias*, *Handroanthus*, *Monteverdia*, *Ocotea*, and *Eugenia* (Table 2).

**Table 2**. Woody food plants considered versatile because they are used in the three categories of wood uses (fuel, construction and technology). Data from the systematic review of Brazilian ethnobiological studies

| Family | Scientific name |
|---|---|
| Anacardiaceae | *Anacardium occidentale* L. |
| | *Astronium urundeuva* (M.Allemão) Engl. |
| | *Schinus terebinthifolia* Raddi |
| | *Spondias mombin* L. |
| | *Spondias tuberosa* Arruda |
| | *Tapirira guianensis* Aubl. |
| | *Thyrsodium spruceanum* Benth. |
| Araliaceae | *Didymopanax morototoni* (Aubl.) Decne. & Planch. |
| Bignoniaceae | *Handroanthus impetiginosus* (Mart. ex DC.) Mattos |
| | *Handroanthus serratifolius* (Vahl) S.Grose |
| Burseraceae | *Commiphora leptophloeos* (Mart.) J.B.Gillett |
| | *Protium heptaphyllum* (Aubl.) Marchand |
| Cactaceae | *Pilosocereus pachycladus* F.Ritter |
| Capparaceae | *Cynophalla flexuosa* (L.) J.Presl |
| | *Neocalyptrocalyx longifolium* (Mart.) Cornejo & Iltis |

| | |
|---|---|
| Celastraceae | *Monteverdia obtusifolia* (Mart.) Biral |
| | *Monteverdia rigida* (Mart.) Biral |
| Combretaceae | *Combretum leprosum* Mart. |
| Euphorbiaceae | *Croton heliotropiifolius* Kunth |
| | *Manihot dichotoma* Ule |
| Fabaceae | *Amburana cearensis* (Allemão) A.C.Sm. |
| | *Anadenanthera colubrina* (Vell.) Brenan |
| | *Bauhinia cheilantha* (Bong.) Steud. |
| | *Copaifera langsdorffii* Desf. |
| | *Inga thibaudiana* DC. |
| | *Libidibia ferrea* (Mart. ex Tul.) L.P.Queiroz |
| Lauraceae | *Ocotea glomerata* (Nees) Mez |
| | *Ocotea odorifera* (Vell.) Rohwer |
| Lecythidaceae | *Eschweilera ovata* (Cambess.) Mart. ex Miers |
| Malpighiaceae | *Byrsonima sericea* DC. |
| Moraceae | *Brosimum guianense* (Aubl.) Huber |
| Myrtaceae | *Eugenia pyriformis* Cambess. |
| | *Eugenia uniflora* L. |
| | *Myrcia splendens* (Sw.) DC. |
| | *Psidium guineense* Sw. |
| Rhamnaceae | *Ziziphus joazeiro* (Mart.) |
| Rubiaceae | *Genipa americana* L. |
| Sapindaceae | *Talisia esculenta* (Cambess.) Radlk. |
| Sapotaceae | *Sideroxylon obtusifolium* (Roem. & Schult.) T.D.Penn. |
| Simaroubaceae | *Simarouba amara* Aubl. |
| Urticaceae | *Cecropia pachystachya* Trécul |
| Ximeniaceae | *Ximenia americana* L. |

The plant parts most frequently mentioned were fruits (*n* = 26), flowers (*n* = 4), and seeds (*n* = 4). Leaf, root, and pseudofruit/floral peduncle were cited twice each, and exudate and resin were cited once. The parts of interest of six species were not specified in any study.

### *3.2.1. Nutritional systematic review: General aspects*

After the first stage of screening, 52 articles were retained and read in full (see Figure 2). Of these, 36 articles were excluded for the following reasons: (i) raw material of commercial origin (in these studies, pulps/fruits were obtained commercially and information on place of origin or possible mixtures with other materials or parts, such as nectar, peel + pulp, or mesocarp + exocarp, pericarp, was not provided), (ii) absence of nutritional information (e.g., studies on bioactive compounds), (iii) plant parts with no ethnobotanical uses identified in our previous review, and (iv) plant parts and ingredients mixed and/or analyzed in combination (e.g., pulp and peel, sweetened nectar). Therefore, 16 articles were included for compilation of nutritional data. These studies were published between 1986 and 2020.

Of the 16 studies included in this review, only 4 concerned plant material collected in countries other than Brazil (Nigeria and India). The plant species with the most nutritional studies were *Anacardium occidentale* L. (*n* = 5), *Spondias mombin* L. (*n* = 4), and *Pilosocereus pachycladus* F.Ritter (*n* = 2). Five species were addressed in a single study, namely *Genipa americana* L., *Bauhinia cheilantha* (Bong.) Steud., *E. pyriformis* Cambess., *Manihot dichotoma* Ule, and *Z. joazeiro* (Mart.).

After application of eligibility criteria, 11 articles were selected to generate the nutritional tables, 10 of which concerned material collected in Brazil. Four of these studies provided information on both macro- and micronutrients. The nutrients analyzed in nutritional tables and the number of species investigated are described in Table 3.

**Table 3**. Nutrients and number of species contain them

| Nutrient type | Number of plant species |
|---|---|
| Carbohydrates | 6 |
| Lipids | 7 |
| Proteins | 8 |

| | |
|---|---|
| Calcium | 4 |
| Iron | 4 |
| Zinc | 2 |
| Potassium | 3 |
| Phosphorus | 4 |
| Sodium | 2 |
| Copper | 2 |
| Magnesium | 3 |
| Manganese | 2 |

The nutritional tables (Tables 4 and 5) contain information on eight plant species. Two studies analyzed different plant parts of *A. occidentale* (nut and pseudofruit) and *P. pachycladus* (cladode and fruit). The main plant tissue analyzed was the fruit (*n* = 5). Other parts included cladode, root, seed, nut, and fruit/pseudofruit (floral peduncle of cashew).

*3.2.2. Macro- and micronutrient contents in versatile wild food plants used as timber*

*3.2.3. A. occidentale*

The nut and fruit/pseudofruit of the species were analyzed, with more than one type of preparation reported. The analyzed studies provided information on the macronutrient composition of the plant. The highest macronutrient content was found in cashew nut. The major macronutrients were lipids in both roasted (47.79 g) and raw (47.4 g) cashew nuts. These values are similar to the lipid content of peanut (*Arachis hypogaea* L.), as reported by (Ayoola, P. B, Adeyeye, 2010). The lipid content of roasted cashew nut is higher than that of roasted peanut (40.60 g).

*A. occidentale* nut also had the highest micromineral contents, including K (roasted, 556.16 mg; raw, 540 mg), P (roasted, 1101.04 mg; raw, 470 mg), and Mg (roasted, 277.09 mg; raw, 240 mg). Regarding microminerals, the species is rich in Zn (roasted, 4.98 mg; raw, 5.0 mg). The micronutrient contents of cashew nut are higher than those of peanut (Ayoola, P. B, Adeyeye, 2010).

*3.2.4. B. cheilantha*

The macronutrient content of different preparations of *B. cheilantha* seed flour was assessed. Protein was the major macronutrient (soaked flour, 36.0 g; raw seed flour, 35.9 g; heated seed flour, 31.5 g). The protein content of the seed flour is similar to that of peeled soybean (*Glycine max* (L.) Merr.) seed (37.8 g) (TBCA, 2022). In our review of the literature, no data were found on the micronutrient content of *B. cheilantha*.

*3.2.5. E. pyriformis*

The fruit pulp of the species is rich in carbohydrates (53.651 g), having a higher content than the fruit pulp of *Mangifera indica* L. (16.0 g), according to the Brazilian Food Composition Table (TBCA, 2022). The carbohydrate content of *E. pyriformis* fruit pulp is also higher than that of a well-known banana variety (*Musa acuminata* Colla × *Musa balbisiana* Colla), which, raw, contains 32.1 g of carbohydrates (TBCA, 2022).

*E. pyriformis* had the highest Ca content (341.33 mg) among all evaluated species. This micronutrient content is higher than that of raw orange (*Citrus sinensis* (L.) Osbenk., 34.6 mg) (TACO, 2011). *E. pyriformis* ranked second in P (134.00 mg) and Mg (41.00 mg) contents and third in K content (134.00 mg). Compared with *C. sinensis*, the micronutrient contents of *E. pyriformis* are high, except that of K, which is higher in orange (170 mg) (TACO, 2011).

The major microminerals in *E. pyriformis* are Fe (5.37 mg), Cu (0.58 mg), and Mg (3.05 mg). The Fe content of the species is higher than that of conventional fruits, such as plantain, orange, strawberry (*Fragaria* × *ananassa*), and Hass avocado (*Persea americana* L.) (Motalab et al., 2022; Rozan et al., 2021; TACO, 2011). Furthermore, the Mn content of *E. pyriformis* is higher than that of avocado pulp (0.30 mg) (Motalab et al., 2022).

*3.2.6. M. dichotoma*

*M. dichotoma* root flour has high carbohydrate content (24.2 g), although lower than that of the more common species of the same genus *Manihot esculenta* Crantz (87.9 g) (TACO, 2011). However, it is similar to raw yam (*Colocasia esculenta* L.) in terms of carbohydrate content (23.2 g) (TACO, 2011).

Although it is widely used as both fodder and human food, especially in periods of scarcity, *M. esculenta* is reported to have toxic properties (do Nascimento et al., 2012; Nunes et al., 2018). Adequate preparation is necessary before consumption to avoid poisoning, which has been reported by local peoples over the years. In our review, no data on micronutrients were found for this species.

### *3.2.7. S. mombin*

The fruit does not have an expressive macronutrient content; nevertheless, it has gained relevance for its micronutrient content. The major macromineral was Na (5.551 mg), with the highest value among the analyzed species. *S. mombin* ranked second in K content (288.276 mg) and third in P (32.849 mg) and Mg (15.095 mg) contents. Compared with avocado, a reference fruit in terms of these macronutrients (K, 514.6 mg; P, 60.5 mg; Mg, 27.7 mg), *S. mombin* fruit has low contents (Rozan et al., 2021). However, these values are higher than those of raw *C. sinensis* fruit (TACO, 2011).

*S. mombin* fruit had the second-highest Cu (0.118 mg) and Mn (0.025 mg) contents, behind only *E. pyriformis*. Its Cu content is higher than that of *C. sinensis* (0.04 mg) (TACO, 2011).

### *3.2.8. G. americana*

Genipap pulp ranked third in the macromineral Ca (45.82 mg) and micromineral Fe (0.80 mg). Genipap has a higher Fe content than strawberry (*Fragaria* × *ananassa*), reported as 0.41 mg by (Motalab et al., 2022), and a higher Ca content than Hass avocado pulp (*P. americana*), reported as 13.4 mg (Rozan et al., 2021).

The macro- and micronutrient contents are listed in Tables 4 and 5.

### *3.3. Woody species with the potential to promote food and nutrition security*

Of the species for which macro- and micronutrient data were available, six stood out for their nutritional value, namely *A. occidentale* (roasted and raw cashew nuts), *E. pyriformis* (fruit pulp), *S. mombin* (fruit pulp), *M. dichotoma* (root flour), *G. Americana* (fruit pulp), and *B. cheilantha* (seed flour). Although all eight versatile species have some nutritional value and are versatile in terms of timber applications, demonstrating their importance for further conservation and nutritional studies, we consider these six species as priorities for future studies. A summary of the results on woody food species used as timber identified in this systematic review is presented in Figure 4.

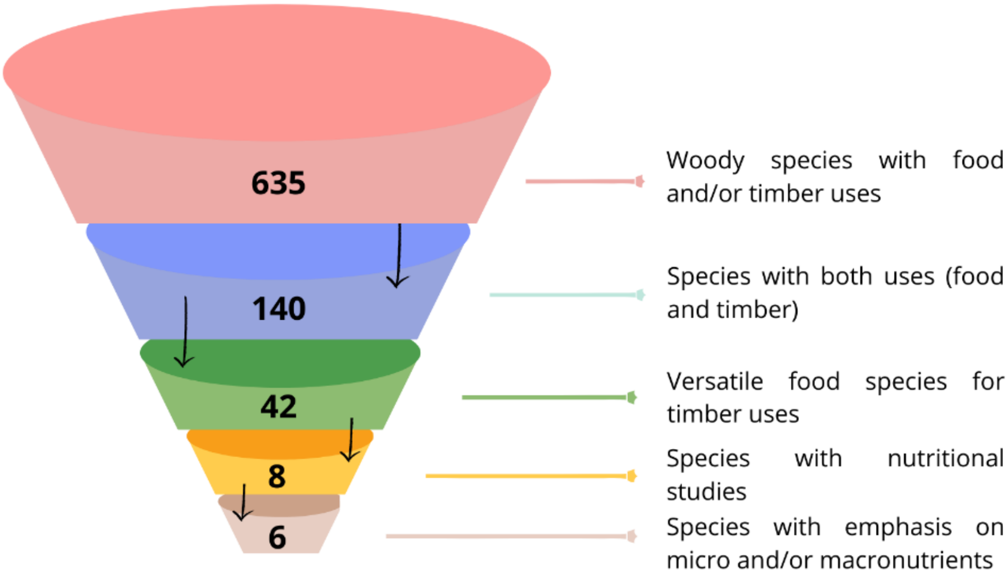



**Figure 4**. Number of woody food and/or timber species found during the stages of the ethnobiological and nutritional reviews. Edited in Canva (free version).

**Table 4**. Macronutrient composition of parts of versatile food woody plants for wood uses. Data from the systematic review of nutritional studies

| Species name | Analyzed part | Preparation type | Protein | Carbohydrates | Lipids | Sources |
|---|---|---|---|---|---|---|
| *Anacardium occidentale* L. | Pseudofruit (peduncle) | Pulp | 1.130* | - | 0.666* | Singh et al. (2019) |
| | Cashew nut | Ground (roasted) | 22.67 | 19.86 | 47.79 | Oliveira Sousa et al. (2011) |
| | Cashew nut | Fresh (Raw) | 20.2 | 20.9 | 47.40 | Rico et al. (2015) |
| *Bauhinia cheilantha* (Bong.) Steud. | Seed | Raw flour | 35.9 | 6.2 | 8.7 | Teixeira et al. (2013) |
| | | Soaked flour | 36.0* | 7.0* | 8.6* | |
| | | Heated flour | 31.5 | 12.8 | 8.6 | |
| *Eugenia pyriformis* Cambess. | Fruit | Pulp | 2.617 | 53.651 | 0.924 | Silva et al. (2019) |
| *Genipa americana* L. | Fruit | Pulp | 0.68* | - | 0.35* | Figueiredo et al. (1986) |
| *Manihot dichotoma* Ule | Root | Flour | 0.1* | 24.2* | 0.4* | Nascimento et al. (2012) |
| *Pilosocereus pachycladus* F.Ritter | Cladode | Crushed | 0.25 | 4.75 | 0.53 | Nascimento et al. (2011) |
| | Fruit | Pulp | 1.15* | - | - | Souza et al. (2015) |
| *Spondias mombin* L. | Fruit | Pulp | 1.06 | 13.9 | 0.62 | Tiburski et al. (2011) |
| *Ziziphus joazeiro* (Mart.) | Fruit | Pulp | 1.68 | - | 0.17 | Oliveira et al. (2020) |

**Nutritional values in which the unit of macronutrient composition is percentage.*

**Table 5.** Composition of mineral content (mg/100g) in parts of versatile food woody plants for wood uses. Data from the systematic review of nutritional studies

| **Species name** | **Analyzed part** | **Preparation type** | **Ca** | **Fe** | **Zn** | **K** | **P** | **Mg** | **Cu** | **Mn** | **Na** | **Sources** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Anacardium occidentale* L. | Cashew nut | Ground (roasted) | 64.05* | 3.89* | 4.98* | 556.16* | 1101.04* | 277.09* | | | 3.08* | Oliveira Sousa et al. (2011) |
| | | Fresh (Raw) | 28.0 | 5.1 | 5.0 | 540.0 | 470.0 | 240.0 | - | - | - | Rico et al. (2015) |
| *Eugenia pyriformis* Cambess. | Fruit | Pulp | 341.33* | 5.37* | 1.03* | 134.00* | 134.00* | 41.00* | 0.58* | 3.05* | - | Silva et al. (2019) |
| *Genipa americana* L. | Fruit | Pulp | 45.82* | 0.80* | - | - | 33.50* | - | - | - | - | Figueiredo et al. (1986) |
| *Spondias mombin* L. | Fruit | Pulp | 11.038* | 0.327* | - | 288.276* | 32.849* | 15.095* | 0.118* | 0.025* | 5.551* | Tiburski et al. (2011) |

*Medium values.

## 4. Discussion

*4.1. Versatile woody food species used for fuel, construction, and technological applications*

In this systematic review, we identified a significant number of native species that may be suffering from intensive use (*n* = 42), because they are traditionally used as food and also for timber purposes (fuel, construction, and technology) (see Table 2). These numbers might be underestimated, given that many studies did not detail the categories of timber use, hampering analysis of versatility. Studies on the harvesting patterns of timber resources have shown that there are differences in replacement time, parts of plants used, harvest volume, and the state in which the plant material is preferentially harvested (alive or dead) according to timber use (De Medeiros et al., 2012). However, it is not yet possible to identify which usage is more harmful to plant populations. Various studies indicated the potential effect of chronic anthropogenic disturbances on gradual extinction of local species and alteration of vegetation structure (Ribeiro et al., 2019, 2015). Therefore, the greater the timber versatility of a given species, the greater the chances that it is somehow affected by unsustainable management strategies.

Of the identified versatile species, at least five are characterized as preferential fuel wood in the Brazilian semiarid because of their physical properties, namely *Anadenanthera colubrina*, *B. cheilantha*, *Astronium urundeuva*, *A. occidentale*, *Z. joazeiro*, *M. dichotoma*, and *Eugenia* sp. (Ramos et al., 2008). It is possible that these species are suffering high use pressure from local populations, given their good timber qualities.

A total of 31 of the 42 identified species are classified as least concern in the Red List of the International Union for Conservation of Nature (IUCN, 2022). Moreover, eight are not on this list, and three are considered important from a conservation point of view. *Amburana cearensis* and *Handroanthus serratifolius* are classified as endangered, with a declining population trend. *Handroanthus impetiginosus* is classified as near threatened, with a declining population. Other species, despite being classified as least concern, have records of decreasing population trends in some areas. This is the case of *A. colubrina*, *Protium heptaphyllum*, and *P. pachycladus*. *A. urundeuva* is overexploited as timber and is classified as data deficient. This category indicates that more information is needed for possible reclassification of the species and that potential threats are not excluded.

Although there was no information on the nutritional characteristics of these species, except for *P. pachycladus*, we believe that they must be included in conservation strategies. It is also necessary to quickly identify whether any of these species have strategic importance for food security, as this factor would be an additional argument for the creation of public conservation policies.

*4.2. Strategic species for food and nutrition security and biocultural conservation*

Of the eight species with available nutritional data, six stood out in terms of macronutrient (proteins, lipids, and carbohydrates) and/or mineral contents: *A. occidentale*, *E. pyriformis*, *S. mombin*, *M. dichotoma*, *G. americana*, and *B. cheilantha*. Some of these are well-known for their food applications, such as *A. occidentale*, *S. mombin*, and *G. americana*, whose pulps are sold in various regions of Brazil. Figure 5 shows photographs of fruit pulps marketed by a company in Alagoas State. In addition to occurring naturally in Brazilian ecosystems, these three species are also domestically grown and cultivated on a small/medium scale (Araújo et al., 2010; Mattietto and Matta, 2011; Rocha et al., 2015), contributing to the reduction of conservation pressures.


**Figure 5.** Commercial fruit pulps of the species (A) *S. mombin*, (B) *A. occidentale* and (C) *G. americana*. Edited in Canva (free version)

Species with high nutritional potential but little used as food (*E. pyriformis*, *M. dichotoma*, and *B. cheilantha*) deserve special attention in conservation strategies, because they are obtained almost entirely by extraction practices; there are few reports of their cultivation in agroforestry systems (Florentino et al., 2007; Freitas et al. 2016). For species with low food popularity, biocultural conservation strategies could include dissemination of their food potential, which could contribute to income generation and reduction of timber extraction. In fact, a study conducted in the Brazilian semiarid demonstrated that species with high medicinal potential were less used for timber purposes than would be expected considering their availability and wood quality (Silva et al., 2021). It is necessary, however, to test the hypothesis of protective effects from food use in other socioenvironmental contexts.

Additional strategies that involve the entire plant community and not only species of food interest are required, given that, if one species is protected from extraction, other timber species may be targeted compensatorily, intensifying anthropogenic pressures on the latter. Because low income in the countryside in certain regions of Brazil has been one of the greatest intensifiers of logging for domestic purposes (De Medeiros et al., 2012; Specht et al., 2015), strategies that generate income from the marketing of wild food plants could have a secondary effect on timber use.

Sustainable extraction of species with nutritional importance can be achieved by their inclusion in agroforestry systems, enhancing the supply of these products, increasing the chances of successful food–timber management, and linking agriculture and extractivism. In some regions of the country, however, small farmers are reluctant to make the transition from conventional cropping to agroforestry, especially because of uncertainties regarding the success of such systems, a possible decrease in the yield of the main crop, lack of successful models, and limited knowledge on the subject (Sagastuy and Krause, 2019). Some of the difficulties encountered by agroforestry farmers include the marketing of agroforestry products and absence of public policies (Shennan-Farpón et al., 2022). Thus, a public approach toward agroforestry production is essential to increase the cases of success and the number of small producers and extractivists involved in the practice.

The biocultural conservation strategies discussed herein should be aimed not only at the few versatile species with available nutritional studies but at all species with overlapping timber and food potentials. Four of the five versatile food species with timber applications that did not have nutritional information in the literature are classified as least concern in the IUCN Red List (IUCN, 2022), namely *Byrsonima sericea*, *Combretum leprosum*, *Monteverdia rigida*, and *Ocotea glomerata*. Although these species are currently classified in this category, our first systematic review identified that these species are used as food and timber. In other words, these species may be suffering from anthropogenic pressure with regard to timber extraction in local and regional contexts, which could compromise their populations over time, hampering their use in food systems.

Even for species with available data, it is necessary to carry out local diagnostics to identify the real use pressure on these resources, the feasibility of incorporating them into regional agroforestry systems, and the potential for expanding associated demand and production chains. Studies focused on consumer behavior can be strategic for identifying potential demands (Barbosa et al., 2021).

### *4.3. Recommendations for future ethnobiological studies*

It is important to fill the knowledge gap on the sustainability of timber extraction of species at the food–wood interface. In addition to biological conservation, the cultural importance of these species must be investigated and preserved, given that these aspects are inseparable (Gavin et al., 2015).

Many ethnobiological studies on food plants do not identify the edible parts that are consumed or used in traditional preparations. This makes it difficult to carry out nutritional analyses focused on specific parts of the plant that are appreciated or of commercial value to local communities. This lack of information is also observed in timber research, as various studies do not indicate the type of application of timber species. Considering the heterogeneity of use dynamics among different timber categories (Walters, 2005) and the need to understand the versatility of timber species, we recommend that further studies provide more details on the timber uses of target species.

### *4.4. Study limitations*

Given that this is a systematic review, it is important to highlight that species not contemplated here may also be versatile and, therefore, could be included in the group of keystone species. The key species identified might be biased by the research effort, which was greater in certain ecosystems of the country, such as the Caatinga. This is due to the fact that there is a higher proportion of ethnobiological studies in the Caatinga biome and that these studies provided more information on timber uses. It is possible that there are many other priority species for conservation in other ecosystems but that have not been as widely studied as Caatinga species. The current study can be seen as a preliminary effort, which will need to be augmented with new species through further investigations.

## 5. Conclusion

We identified a representative number of native woody plants that have overlapping uses as food and timber. Such results underscore the need to assess sustainability and propose conservation strategies for these species to ensure the continued existence of potential resources for food and nutrition security. On the basis of ethnobiological and nutritional data available in the literature, as well as ecological profiles, we recommend that *E. pyriformis* and *B. cheilantha* be the target of ecological studies and popularization strategies because they are versatile in terms of timber uses and have high nutritional relevance.

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**Conflicts of interest**

The authors have no relevant financial or non-financial interests to disclose and have no conflicts of interest to declare that are relevant to the content of this article.

**Ethical approval and consent to participate**

Not applicable for this research.

**Consensus for publication**

Not applicable for this research.

**Other information**

We declare that this review has not been registered.

**Supplementary information**

Additional File 1: PRISMA Protocol Checklist – Ethnobiology review

Additional File 2: Search strategies – Ethnobiology review

Additional File 3: PRISMA Protocol Checklist – Nutritional review

Additional File 4: Search strategies – Nutritional review

**Availability of data and materials**

Datasets that support the conclusions of this article are included in the article (and its appendices). Other data referring to the list of articles of systematic reviews can be made available on request.

**Author statement**

RAC – Conceptualization; Investigation; Methodology, Data curation, Writing - original draft. EMCS – Organization and creation of figures; Writing - revision and editing. RRVS e ARC – Supervision; Writing - revision and editing. PMM – Conceptualization; Methodology; Writing - revision and editing. RZP – Methodology; Data curation, Writing - revision and editing.

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**CAPÍTULO 2**

# 4. CONSERVATION OF WILD FOOD PLANTS FROM WOOD EXPLOITATION: EVIDENCE SUPPORTING THE PROTECTION HYPOTHESIS IN NORTHEASTERN BRAZIL

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**Abstract**

**Background:** The interplay between different uses of woody plants remains underexplored, obscuring our understanding of how a plant's value for one purpose might shield it from other, more harmful uses. This study examines the protection hypothesis by determining if food uses can protect woody plants from wood exploitation. We approached the hypothesis from two distinct perspectives: 1) the protective effect is proportional to the intensity of a species' use for food purposes, and 2) the protective effect only targets key species for food purposes.

**Methods:** The research was conducted in a rural community within *Restinga* vegetation in Northeast Brazil. During a participatory workshop, we pinpointed three food species vital for both consumption and income (key species), along with their natural occurrence and collection areas. A floristic survey in three distinct areas identified additional species coexisting with the key species. Using a field herbarium and species photographs as visual stimuli, participants assessed the species for wood quality, perceived availability, and usage. We employed Cumulative Link Mixed Models (CLMMs) to evaluate the hypotheses "the food uses (specialized) protect plants from wood exploitation (generalist)" from two different perspectives (generalized protection and protection targeted at key species).

**Results:** Findings suggest there is no proportional protective effect from food uses across species. However, domestic food use of key species exhibited a marked protective effect. Perceived availability and utility emerged as notable predictors for wood exploitation.

**Conclusion:** We advocate for biocultural conservation strategies that enhance the food value of plants for their safeguarding, coupled with measures for non-edible woody species under higher use-pressure.

**Keywords:** Conservation through use. Ethnobiology. Traditional management. Wild Edible plants. Wood uses.

## Background

A growing body of research points to the potential effects of chronic anthropogenic disturbances leading to the gradual extinction of local species and alterations in vegetation structure(1,2). Among these disturbances, the impact of forest product utilization has been highlighted, demonstrating that while wood use is crucial for local communities, especially in developing countries, it often results in more pronounced impacts on plant populations ((3,4).

While wood exploitation exerts considerable pressure on plant resources, the sustainability of non-timber forest product (NTFP) collection is also not always assured (5). Nevertheless, the extraction of NTFPs, particularly the harvesting of wild fruits, generally has a lesser impact on forest structure and ecosystem functions than other uses (6). Moreover, the consumption of NTFPs fulfills multiple roles, frequently underpinning rural livelihoods and local economies, aiding food security, fostering trade, and preserving cultural traditions and knowledge (7).

Hence, some researchers argue that discouraging the commercialization of wild food plants may adversely affect the income of local populations, potentially leading to greater reliance on other forest resources with more harmful consequences than food collection itself (8). Conversely, the commercial value of NTFPs, coupled with the opportunity for income generation, may incentivize conservation efforts among local communities for the forests that supply these resources (9).

Since the 1990s, investigations into the sustainability of food plant use have sought to determine the impact on species populations without conclusively addressing whether such use confers protective benefits. In contrast, research on plant domestication supports the notion that significant food value may lead to conservation practices, such as tolerance, protection, and promotion (10). Plants with desirable traits may be maintained during deforestation or other disturbances, promoted through distribution and dispersal, and specifically safeguarded against competitors and herbivory (10).

However, the extent to which a plant's significance for one use can shield it from more destructive applications, namely the interaction effects among different utilization types, remains underexamined. This gap hinders our comprehension of protective dynamics in socio-ecological systems and their economic benefits for humans. Such insights are vital for shaping biocultural conservation frameworks that recognize the multifaceted advantages of maintaining cultural practices intertwined with biodiversity.

It is conceivable that certain NTFP uses, including for food, may exert a protective effect against more damaging activities such as wood exploitation. Although overharvesting of fruits has been shown to affect the regeneration of wild fruit trees adversely (11,12), food use is typically seen as specialized, with minimal impact on plant populations, whereas wood exploitation is often deemed generalist, posing broader threats (3).

The classification of plant uses as specialized or generalist may vary depending on the social-ecological context. In the context of several South American communities, specialized uses are defined by a narrower range of suitable plants meeting specific requirements, with the specialization premise reinforced by observations that plant availability exerts little to no influence on such uses (13,14). In contrast, generalist uses accommodate a broader spectrum of species, with the most utilized often being the most accessible, as with many wood exploitation practices (15).

Although quality may also be an important predictor of plant importance for generalist uses (16), the generalist nature of wood use is supported by studies investigating the apparency (availability) hypothesis, which posits a correlation between environmental availability and species utilization (15,17,18). Therefore, for generalist applications, alternatives may spare certain species for specialized uses, such as food, where fewer species can act as substitutes.

The protection hypothesis, initially proposed by Silva et al. ((19)), analyzed Caatinga woody plants utilized domestically for medicinal and fuel purposes to assess whether medicinal significance (specialized use) impacts wood exploitation (generalist use). Their findings revealed a modest yet significant medicinal use effect on wood exploitation, providing supportive evidence for the hypothesis as plants of greater medicinal value saw less wood utilization. Moreover, Silva et al. (19) suggested that the protective effect could be more pronounced in species with high medicinal importance.

The use of plants for food is also considered a likely candidate for conferring protective effects against wood exploitation. Wild food plants are often crucial for providing essential nutrients or for supplementing diets, playing a vital role in ensuring food security and offering economic benefits through the trade of these resources. Given food use's specialized nature, dietary importance, and economic potential, there is a presumption that communities may prefer to preserve these plants from irreversible harm, such as wood exploitation. For the latter, alternative species are available due to the generalist nature of wood use.

In this context, we investigate the protection hypothesis from two distinct perspectives. We hypothesize that food uses (specialized) protect plants from wood exploitation (generalist). We examined: 1) whether the protective effect is proportional to the intensity of a species' use for food purposes, and 2) if a protective effect only targets key species for food purposes. Here, 'key species' denotes wild food plants of high regional importance for consumption and income.

This study is the inaugural inquiry into the protection hypothesis concerning the protective effect stemming from food use. Moreover, unlike Silva et al. (19), our study incorporates the commercial relevance of woody plants, providing income for the local population. Methodologically, we refine hypothesis testing by employing the checklist-interview technique (20) to boost respondent recall, ensuring all associated uses (food and wood) are considered.

## Materials and methods

### Study area and socioeconomic characterization

The research was carried out in a rural community within the coastal *Restinga* vegetation of Piaçabuçu, situated on the southern coast of Alagoas state. Piaçabuçu spans an area of 243.686 km², housing a population of 15,908 individuals (21). It features a tropical 'As' climate in the Köppen and Geiger classification, with an average annual temperature of 25.3ºC and an annual rainfall average of 1283 mm (22). Notably, the municipality is designated with two

Environmental Protection Areas (APAs): the federally instituted APA Piaçabuçu, established in 1983, and the state-sanctioned APA Marituba do Peixe, created in 1988, both of which are classified as sustainable use Conservation Units.

The APA Marituba do Peixe spans 18,556 hectares and extends over portions of the Alagoan municipalities of Piaçabuçu (45%), Feliz Deserto (43%), and Penedo (6%) (23). This area boasts diverse vegetation, including native *Restinga*, *Várzea*, and other forest formations (23). Within the Indirect Influence Area of APA Marituba do Peixe lies the village of Retiro (depicted in Figure 1), which was the focal point for the ethnobiological segment of this study.

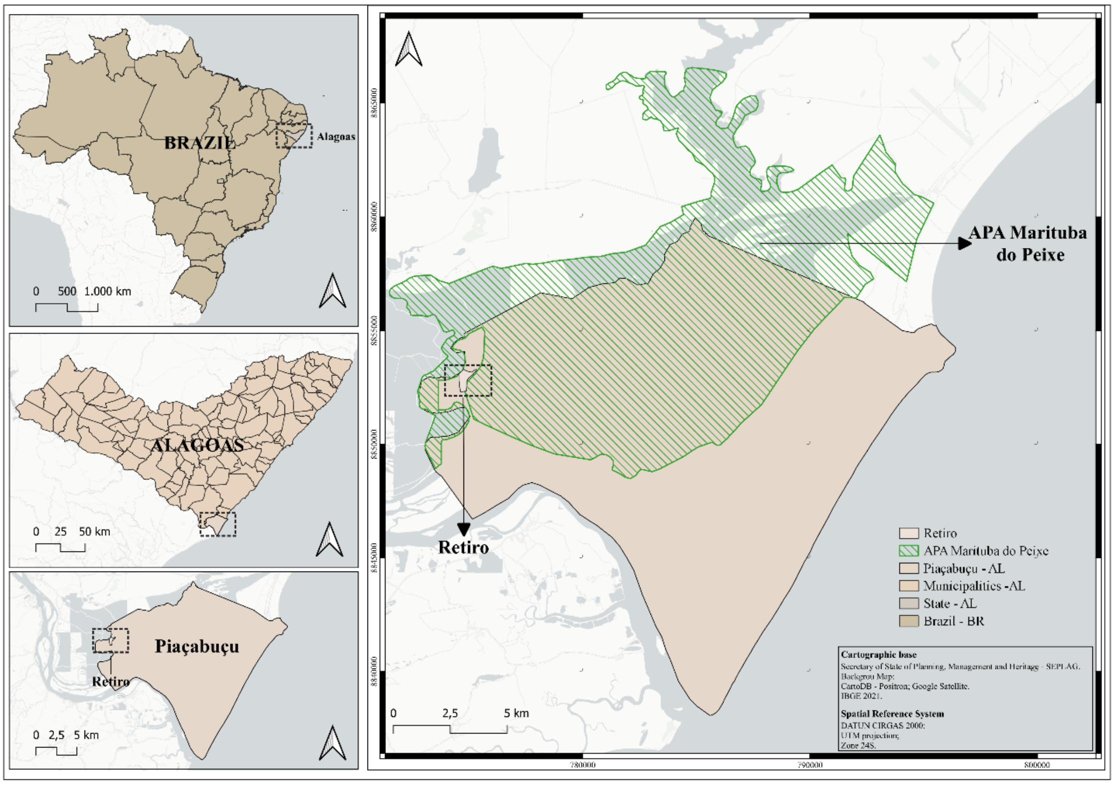


**Fig. 1** Geographic Location of the Retiro Community in the Municipality of Piaçabuçu-Alagoas, Brazil.

The Retiro community is structured with a residents' association and a family farmers' association. It is equipped with a primary healthcare unit and a municipal elementary school.

The predominant faith among residents is Christianity, represented by two Catholic and two evangelical churches. Currently, the community comprises approximately 288 families, a decrease of 81 families since before the pandemic, as reported by Gomes et al.(24). This discrepancy may be partly due to some families not being documented, a requirement for health unit registration.

Retiro was selected for this study due to the local reliance on plant resources for both food and wood. The community's economy is significantly driven by the extraction and commercialization of wild food plant fruits (24), along with shrimp and fish (25). Wood resource extraction for personal use and commerce, particularly firewood, charcoal, and materials for fencing, is also prevalent. These resources are marketed through open markets or direct orders in Piaçabuçu and Penedo, whereas wood products are solely distributed by order.

Firewood is the primary cooking fuel in the community, though some households use both cooking gas and firewood. Meals are typically prepared on traditional clay or makeshift brick stoves. Firewood also serves in roasting shrimp and baking cakes from rice straw, a common bait for shrimp in local fishing gear known as *cóvu*.

Architecturally, many *taipa* houses (rammed earth) are present within the community, often serving as dwellings for individuals from other regions staying temporarily in the area.

The primary livelihoods include gathering, particularly collecting edible fruits, as well as retirement, fishing, and agriculture, with some engaging in multiple occupations. A variety of other professions are represented to a lesser extent. The demographic profile of interviewees spans ages 18 to 82. Most interviewees are literate (76.65%) are literate, of whom 73.91% have completed or partially completed basic education, and 1.74% have higher education qualifications. The number of people occupying the residences ranges from one to seven residents. However, the majority of houses are occupied by: two or three residents (29.57%), followed by one or four resident(s) (15.65%). Household incomes show substantial variation, as show the frame 1.

**Frame 1** Monthly household income and the corresponding percentage of interviewees who possess it.

| Monthly household income | % of household |
|---|---|
| Under one minimum wage | 28.70 |
| One minimum wage | 14.78 |
| One and a half to two minimum wages | 41.74 |
| Up to three minimum wages | 13.04 |
| More five minimum wages | 1.74 |

Ethical and legal aspects of the research

This research project received approval from the Research Ethics Committee by Federal University of Alagoas (UFAL), Nº 1998673, securing authorization for studies involving human participants as per the stipulations of National Health Council Resolution 466/2012. Additionally, scientific activities involving the collection and transport of botanical specimens within the Marituba do Peixe Environmental Protection Area were duly registered with Chico Mendes Institute for Biodiversity Conservation/Biodiversity Authorization and Information System (ICMBio/SISBIO), Nº 87112-1.

To ensure ethical compliance, all community members aged 18 and older who comprehended the objectives of the research and consented to participate were asked to provide a signature or thumbprint on the Informed Consent Form (ICF), as well as on the image use authorization form.

Data Collection

Data collection was carried out in three distinct phases: a participatory workshop, a forest inventory, and checklist-interviews, all of which are depicted in Figure 2.

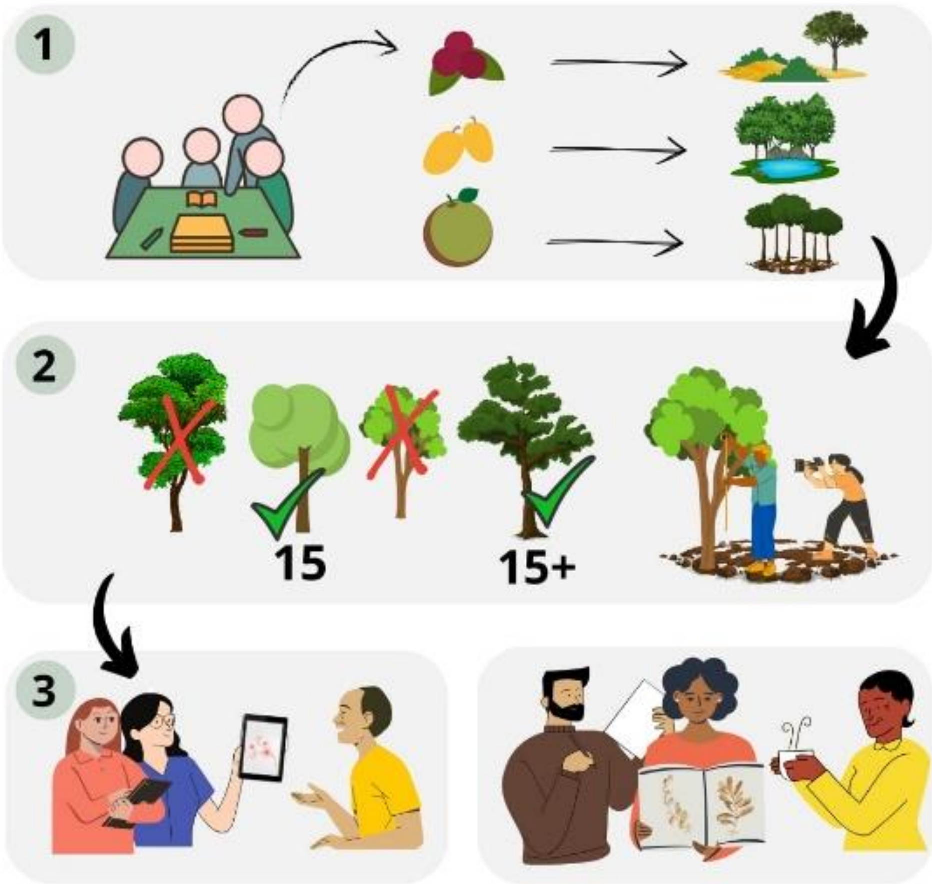


**Fig. 2** Stages of ecological and ethnobiological data collection: (1) Participatory workshop for identifying key species and collection areas; (2) Forest inventory to detect species co-occurring with key species, accompanied by botanical collection and plant photography; (3) Checklist-interview utilizing visual stimuli, including photos and exsiccates (field herbarium). Image edited using Canva (free version).

1st Data Collection Stage: Participatory Workshops

Participatory workshops with the residents of the Retiro community aimed to identify significant wild food plant species for consumption and commercial use, as well as their harvesting locations. These workshops were facilitated by local leaders and a researcher from the Laboratory of Biocultural Ecology, Conservation, and Evolution (LECEB), who had previously interviewed community members.

In the inaugural workshop, residents listed wild food plants harvested for sale or personal use. They documented the common names on cardboard, selecting eleven for further discussion. Participants then evaluated these plants for their economic significance within the community, ultimately ranking the top five in importance.

Additionally, the workshop served to note wood resources tied to food plants and their utilization for consumption and commerce within the community.

Thirteen women and three men, ranging in age from 31 to 82, contributed to this first workshop. While all were identified as gatherers, some also engaged in agriculture and fishing. A follow-up workshop sought to enrich this data with contributions from another set of gatherers (n=17), including eight newcomers. This session, comprising thirteen women and four men from the same age bracket, validated the initial findings regarding species and harvesting sites.

Participants utilized a detailed satellite image from Google Earth to denote areas frequented for food and wood collection. An overlay of transparent acetate allowed them to make corrections directly on the map.

Subsequent to pinpointing these areas, we selected those most frequented for the harvesting of both food plants and wood, prioritizing locations where the ranked key species were prevalent. Among the listed species - *Myrciaria floribunda* H. West ex Willd.) O. Berg, *Genipa americana* L., *Psidium guineense* Sw., *Spondias mombin* L., and *Tamarindus indica* L. - only the first three were deemed key for this study due to their abundance in native and less disturbed habitats.

Three sites were thus chosen for the forest inventory: two with a natural predominance of key species and one characterized by a more generalized distribution of various plant species, including those bearing edible fruits.

In addition to these participatory workshops, our study relied on complementary previous information reinforcing the high economic and consumption importance of these three plant species in the Retiro community. This information was obtained from: 1) direct observations of residents' routines and 2) a previous doctoral research study (24).

The research design we adopted gave precedence to examining species that occurred alongside the key species; consequently, not all food and wood plants were included in our scope. Notably, *Schinus terebinthifolia* Raddi, while not a key species within Retiro, is a significant commercial species in the community and the most important commercial plant in neighboring areas, such as the Fazenda Paraíso settlement (24).

2nd Data Collection Stage: Forest Inventory and Field Herbarium

The research included a forest inventory as part of a larger investigation of our research group into plant resource utilization within the region. For the purposes of this study, the forest inventory was only used to identify species that co-occur with the key species. The sites selected for the inventory were privately owned yet accessible to local gatherers. Two of these sites fell within the Marituba do Peixe APA boundaries in Piaçabuçu, while the third was in the municipality of Penedo, outside the APA but still proximal to the community.

We established five permanent plots, each measuring 50 x 20 meters, and further divided these into 50 smaller subplots of 10 x 10 meters situated within the primary native vegetation gathering sites designated during the workshops. This amounted to 0.5 hectares per area, with a total of 1.5 hectares surveyed across all areas.

During the inventory, we collected at least three reproductive samples of each plant species within the plots for identification and to assemble a field herbarium for use in subsequent interviews. Certain species, commonly referred to as *Ingá* and *Pau d'arco*, lacked fertile material at the time of collection, leading us to categorize them as ethnospecies for the purposes of this study. Consequently, in our identification records, we referred to these simply as *Ingá* and *Pau d'arco*, acknowledging that these common names might represent multiple botanical species. Furthermore, the ethnospecies *Cambuí*, although biologically uniform – belonging to the species *Myrciaria floribunda* (H. West ex Willd.) O. Berg – was recognized by some residents as having different ethnovarieties – a distinction not universally acknowledged. In our analysis, we accounted for each mention of *Cambuí* by participants, even though the general data summary did not differentiate between ethnovarieties. For instance, if Interviewee A identified two types of *Cambuí* (Yellow and Red) and Interviewee B referred to one (a general *Cambuí*), we recorded two entries for A and one for B in our database.

For the field herbarium, we mounted exsiccates from species with more than 15 individuals in the surveyed areas onto duplex paper of dimensions 42 x 29.7 cm and stored them in folders of matching size. The herbarium included 24 species in total and 2 taxa that were treated as ethnospecies.

Photography of each species was conducted *in situ*, capturing images that emphasized the plants' distinguishing features: overall appearance, flowers and/or fruits, branches, and stems. These photographs were compiled into folders on a tablet, which was employed to display the images during interviews. Both the exsiccates and the photo folders were numerically coded to correspond with the identifiers on the interview forms, ensuring that interviewees were unaware of the plant names and assisting the interviewer.

The botanical collection phase commenced in November 2021 and concluded in April 2023, an extended period due to intermittent interruptions from COVID-19 peaks and flooding that hindered fieldwork.

A local guide with extensive knowledge of the vegetation provided assistance for all fieldwork involving local vegetation access. We adhered to standard botanical collection protocols, and the exsiccate samples were deposited at the IPA Herbarium (Instituto Agronômico de Pernambuco) - Dárdano de Andrade Lima.

### 3rd Data Collection Stage: Checklist Interview

Before commencing the interviews (third stage), we mapped all Retiro households in May 2023. This mapping was imperative for sample size calculation due to the absence of a census record; the health unit's data was limited to registered families. We determined that household heads (one per household) aged 18 or older present during our visit would be interviewed. Considering that some individuals reside in the community only for short periods, we established an inclusion criterion that only families living in the area for more than one year would be eligible for the study.

We ascertained the number of residences, including both occupied and vacant, to be 361, initially yielding a sample size of 187 residences based on a 95% confidence level and a 5% margin of error. Subsequently, we conducted a simple random selection.

As every house in the community was recorded, including unoccupied ones, some selected residences were vacant. Additionally, given the research's focus on potentially harmful wood resource use within the APA, some families were reluctant to participate. Therefore, from the 187 chosen residences, we could only conduct interviews in 81 interviews of them. To overcome refusals, flood-affected houses, and temporary residents, additional draws were made.

After all draws, we excluded unoccupied houses (n=82), residences on flood-impacted streets (n=12), households temporary inhabitants (n=18) and refusals or unavailability (n=74) from the sample. After three unsuccessful attempts to locate a household head, we inferred their non-participation.

A notable number of individuals opted out of the study, a figure aligned with expectations for wood use research in protected areas, mirroring findings from Medeiros et al. (3). The considerable number of unoccupied houses in the community can be primarily attributed to their use as summer residences by individuals from nearby municipalities, taking advantage of the community's closeness to the beach. Additionally, a number of these houses are situated in areas susceptible to flooding during the rainy season, which also contributes to their vacancy.

The final sample consisted of 115 individuals—81 women and 34 men. Interviews were conducted from May to July 2023. During interviews, we applied the checklist-interview technique (20) to ensure uniform visual stimuli across all informants, enhancing recall of all plant-associated uses.

Interviewees were shown photos of each species and queried on whether they recognized the species. Affirmative responses led to further questions on the plant's name, its uses (food and wood), whether the interviewee actually used the species, parts utilized, commercial harvesting, and collection and sale sites. For recognized plants, a Likert scale rated: perceived availability (only for those interviewees that often frequent vegetation areas), wood quality by use category (fuel, construction, technology), domestic use for wood and food, and commercial use. The ratings and responses are presented in Figure 3.

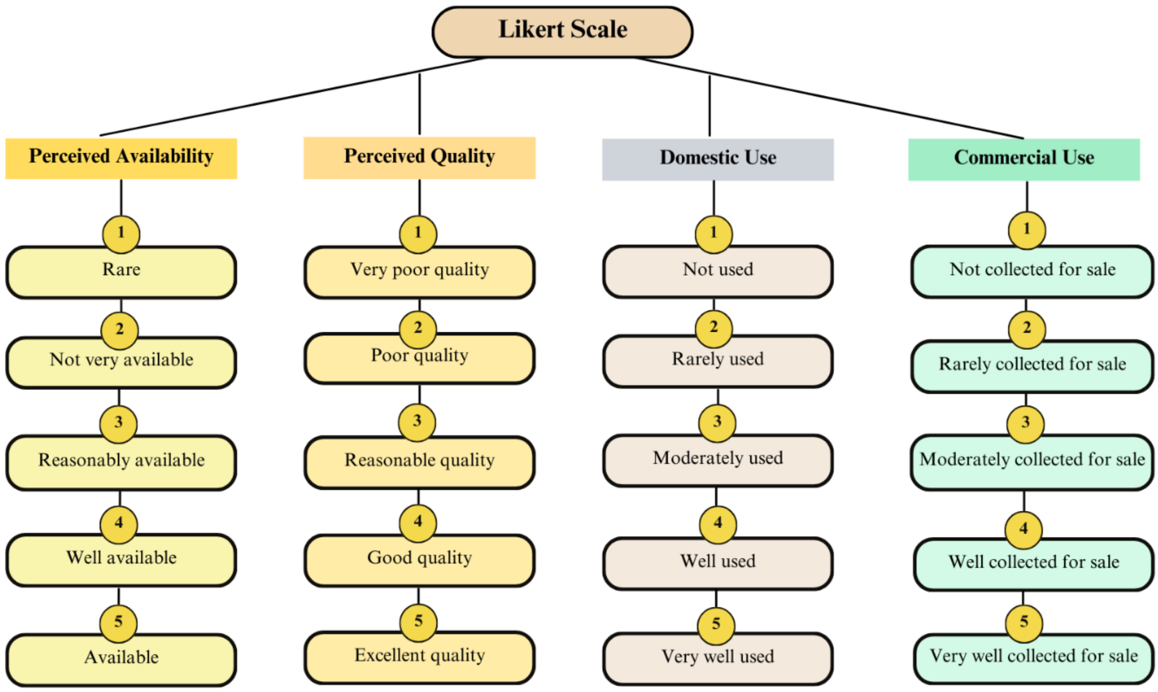


**Fig. 3** Information collected using a Likert scale on the variables considered in this study.

During interviews, we outlined the three primary categories of wood use considered in our study: fuelwood, construction, and technology. This classification facilitated the synthesis of scoring for perceived wood quality, allowing individuals to assign ratings by category rather than for each specific use. If a participant identified a plant as useful for wood but did not personally use it, we probed for the reasons behind this choice. We also asked if there were any of the mentioned plants that, despite being good for wood uses, the interviewee did not collect. These questions were posed to obtain qualitative responses about the protection of food plants from wood uses. Additionally, we gathered socio-economic data from all informants through structured interviews, including gender, age, occupation, income, place of origin, education, and length of residence.

Only for the ethnospecies *Ingá* and *Pau d'arco*, instead of showing the photos and exsiccate, we asked directly if the person knew them for food or wood uses. In case of a positive answer, we asked the same cycle of questions conducted for the other species. This was done because we did not obtain sufficient fertile material for the taxonomic identification of all species of *Ingá* and *Pau d'arco* during the various collection events.

Data Analysis

For statistical analyses, we removed from the database any instances where species were identified for food purposes but not for wood purposes, as the focus of the research was on criteria for selecting wood plants. Consequently, non-wood plants were disregarded. Similarly, we excluded data from individuals who did not frequent forest environments to ensure that our information on species availability came from realistic assessments.

Our response variable, domestic wood use, was ordinal, as depicted in Figure 4. Therefore, we utilized Cumulative Link Mixed Models (CLMMs), incorporating the interviewee as a random effect to account for the non-independence of information from the same individual. The CLMMs were executed using the *clmm* function from the R package *ordinal*.

To evaluate the stability of our models and check for multicollinearity, we used the *omcdiag* function from the *mctest* package in R. We determined an absence of multicollinearity if none or at most one of the six indicators were positive. To circumvent multicollinearity, we constructed two models. The first model, termed the widespread protection model, assigned domestic and commercial food use values on a 5-point Likert scale based on reported usage intensity. For the key species-based protection model, food use was a binary variable: it took the value of 1 if the mention included the use of a key species, and 0 if the mention involved a key species only known but not used, or non-key species, regardless of usage.

Model selection was based on the most parsimonious option, as indicated by the lowest Akaike Information Criterion corrected for small sample sizes (AICc). We interpreted a ΔAICc (difference from the lowest AICc) of less than 2 as substantial support for the model's inclusion among the best set of models, following Burnham and Anderson (26). Following model selection, we computed a model average, which considered the average beta of all variables within the parsimonious models. Since the variables were standardized via z-standardization, we compared the relative effect sizes of all variables.

The variable 'commercial wood use' was not included in the models due to its limited mentions (n=5) within the community and only six citations of species that are commercially traded for wood, exclusive of domestic use.

In addition to the explanatory variables related to food use, both models incorporated control variables for availability and quality, as previously identified in the literature as predictors of wood use (16–18). Our quality indicator was the maximum perceived quality. It was determined by the highest Likert scale quality rating given by an interviewee for a species across the three categories of wood use. For example, if, for a given species, values of 3, 4, and 5 were assigned by an interviewee to the categories of construction, technology, and fuelwood, respectively, the maximum perceived quality would be recorded as 5.

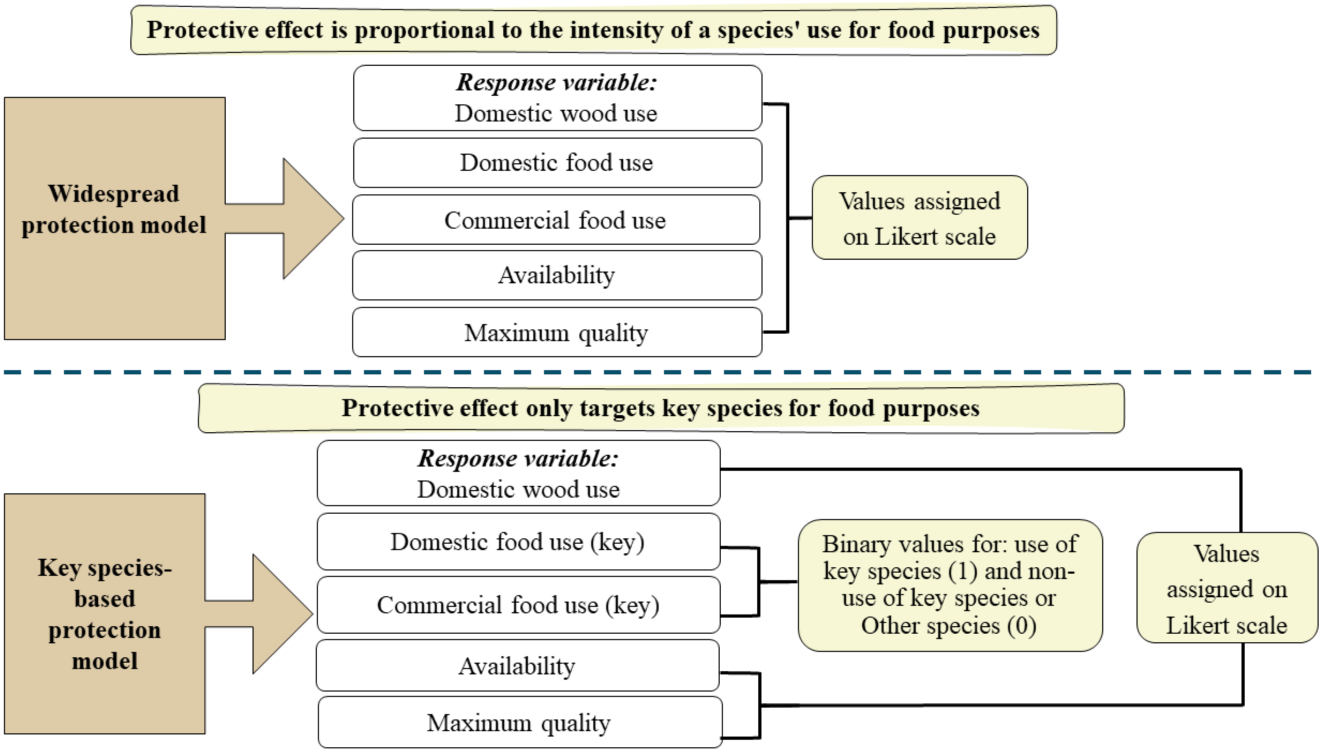


**Fig. 4** Widespread species model and key species-based model with their variables and respective measures.

## Results

### Wood and food uses: general aspects

All plants were recognized to varying extents by the interviewees. The most recognized species/ethnospecies were: *Genipa americana* L. (Jenipapo), *Inga* spp. (Ingá), *Myrciaria floribunda* (H. West ex Willd.) O. Berg (Cambuí), *Manilkara salzmannii* (A.DC.) H.J.Lam (Massaranduba), *Psidium guineense* Sw. (Araçá), *Mouriri* sp. (Cruirí), and Bignoniaceae spp. (Pau d'arco), with recognition rates of 56.5% or higher during interviews. The first five species achieved high recognition levels, exceeding 80%. Notably, *G. americana*, *M. floribunda*, and *P. guineeense* were identified as key species during the workshops. A comprehensive list of all species included in the checklist, along with their recognition and citation frequencies, is presented in Table 1.

Over half of the species on the checklist (58.33%) were recognized for both food and wood uses. Within the three categories of wood use addressed in this study, fuelwood (37.89%) and construction (36.93%) had the highest citation percentages. Technology accounted for only 25.18% of wood citations. Within the fuelwood category, firewood led with the highest percentage (62.82%) of citations relative to the total uses in the category, followed by charcoal (37.18%). The construction category comprised 25 wood uses, with over half (50.55%) the citations pertaining to fences, and the remainder divided among uses such as line (11.98%) and rafter (10.74%). The technology category included 67 wood uses, featuring lower usage percentages compared to the other categories. Uses such as hoe handle (11.92%) and hoe shaft (10.30%) were the only applications exceeding 10% of citations in relation to the total uses within this category. All wood uses attributed to the species are detailed in Table 2.

**Please, put the table 1 and 2 here.**

Widespread protection model

In the widespread protection model, domestic and commercial food use did not significantly influence domestic wood use when controlling for availability and quality variables (Figure 4). Quality and availability were significant predictors of domestic wood use in the model. This suggests that, within the local context, there is a tendency to use woody plants for wood purposes based on their higher quality and greater availability.

Key species-based protection model

We observed a pronounced protective effect on key species, where the domestic use variable was more influential than both perceived availability and wood quality (see Figure 5). However, the variable indicating commercial use did not significantly affect the use of wood for domestic purposes.

Within the model focusing on key species, both availability and wood quality (considered as control variables) had a significant impact on wood use. Consequently, our findings imply the existence of a threshold level of importance for the protective effect of food use on wood uses. This indicates that only those plants with substantial domestic food importance are shielded from being utilized for wood by the local population. The complete statistical results are available in the Additional file 1.

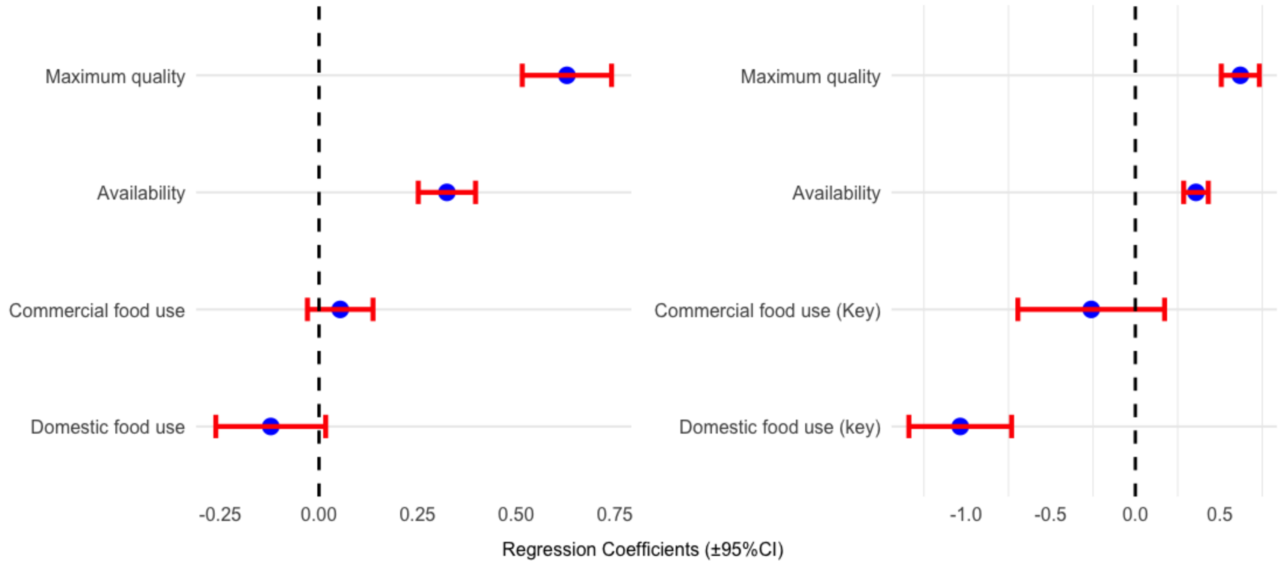


**Fig. 5** Impact of Predictor Parameters (quality, availability, domestic food use, commercial food use, domestic use of key species, and commercial use of key species) on domestic wood utilization of wild edible plants. Left: widespread protection model. Right: key species-based protection model. The central circles indicate the median coefficient estimates of the associations, and the horizontal lines delineate the 95% credibility intervals. The parameter coefficient estimates are plotted along the x-axis, while the predictor levels are represented on the y-axis. The vertical line intersecting the zero point on the x-axis (indicating no effect) facilitates comparison of the sizes of positive, negative, and null effect coefficients. In the parameter level grouping, non-overlapping horizontal bars denote significant differences. Horizontal bars intersecting the zero line on the x-axis signify a non-significant effect.

Evidence of protection based on qualitative data

When inquiring whether individuals refrained from harvesting any of the recognized plants for wood purposes, despite acknowledging their suitability for such use, we gathered responses that support a tendency to protect certain species with dual edible and wood functions. The key species identified during the participatory workshop as significant to the local community, and which garnered substantial recognition in the checklist, were notably prominent in this context.

Out of the 60 respondents to this question, 37 reported no restraint in harvesting plants suitable for wood purposes. Among the 23 participants that chose not to collect certain plants, 12 indicated not collecting species had both edible and wood uses.

Of all mentions of plants with both edible and wood applications, seven pertained to key species (as shown in Frame 2). The primary rationale for sparing these species from wood harvesting, or only using their dry branches, is their provision of edible fruits valued within the community. This rationale is illustrated by the testimonies concerning *P. guineense*, *G. americana*, and *M. floribunda*.

**Frame 2** Responses from interviewees indicating the protection of key species regarding wood uses.

| Key species | Explanations |
|---|---|
| *Psidium guineense* Sw. | *"Because if you take the wood, it will dry, and the plant will stop bearing fruits".* |
| | *"They are good (as wood), but they are also fruits."* |
| *Genipa americana* L. | *"Because the fruit is good and sought after by the people, if it's green, I don't take it, only if it's dead and dry."* |
| | *"I don't take the female one because it bears fruit."* |
| *Myrciaria floribunda* H. West ex Wild. | *"Because I really like the fruit, and I find it very beautiful."* |
| | *"Because it's a nostalgic, good fruit."* |
| | *"I avoid taking them because they are fruits. I only collect the dry branches."* |

*Manilkara salzmannii* though having a limited role in commerce, garners mixed views on its suitability for consumption within the community. Nonetheless, six interviewees mentioned the species, with two specifically expressing their intent to conserve it from being used for wood purposes: 1) *"I don't take it, thinking about the fruits and the future. I don't like to take it (wood) while it's still green, I only pick up the dry branches that have fallen on the ground."* 2) *"Because it's a plant that bears fruit, and it doesn't sprout again if you cut it."*

Despite *M. salzmannii* not being designated as a key species during the participatory workshop, it nonetheless received noteworthy acknowledgment in the checklist-interview. This suggests that *M. salzmannii* may possess a certain degree of importance for food-related uses within the community.

**Discussion**

In our widespread protection model, neither commercial nor domestic food use significantly explains domestic wood use. By contrast, in the key species-based protection model, domestic use emerges as the primary explanatory variable. In both models, perceived availability and quality significantly explain wood use, with quality being more important than availability.

Consistent with our hypothesis, we identify a protective effect of food use on wood use. This effect is not directly proportionate to the food use of the species but is confined to plants with considerable domestic food importance. Research conducted in the Brazilian *Caatinga* region, which initially tested the protection hypothesis using medicinal (specialized) and wood (generalist) use, suggested this possibility (19). Although they observed a modest yet significant linear trend supporting the hypothesis, the authors graphically demonstrated that the protective effect intensified specifically among highly valued medicinal plants. This study furnishes statistical substantiation for what was previously inferred graphically.

Given that the protective effect is selective for key species, it indicates that merely having intermediate or low food importance is insufficient for wild food plants to evade wood use. Protection is afforded only to those species recognized as highly important. Indeed, key species not only receive high acknowledgment in the checklist (>80%) but are also extensively consumed and increasingly traded within the community, in forms such as fresh fruit, juice pulp, and in the manufacture of alcoholic beverages, ice pops, among other products. Literature highlights that elevating the value of non-timber forest products for local populations acts as an incentive for forest species conservation (9,27).

Our findings suggest that protection is predominantly correlated with domestic consumption. The domestic use of non-timber forest products can be a way for poorer local populations to save money (28), as is the case with edible fruits that can replace commercially purchased foods. Although wild food plants serve only as supplementary food resources within the community—with staple crops like rice and beans constituting the primary plant food intake—the cultural significance of key wild food plants likely motivates the observed protection behaviors.

The absence of protective behaviors reported in interviews could stem from various factors. Not all protective actions are necessarily conscious. Additionally, individuals may inadvertently omit mention of such behaviors in response to indirect inquiries like those posed in our study. Furthermore, protection may not be universally practiced within the community, and while the pressure to use wood from wild food plants may not be entirely eliminated, it could be reduced by fewer community members intensively exploiting key food plants for wood purposes.

Wood quality and species availability are significant determinants of wood use. It appears that, aside from key food species—whose utilization for wood is limited due to their value as food—other species are more likely to be used for wood purposes when they offer better trade-offs between availability and quality. Most studies that investigate the drivers of wood use tend to analyze quality or availability indicators separately, rather than in combination. These studies have found that either quality or availability can influence wood use (16–18).

Studies that consider multiple predictors of wood use have yielded divergent results. While availability seems to be a consistent predictor across different contexts, quality may or may not be a determinant of wood use (29,30).

In various social-ecological contexts, research has indicated that trade-offs between multiple variables act as drivers of plant resource use (29,31). However, these trade-offs are often considered within a single use-category (e.g., the trade-off between quality and availability to explain fuelwood use). Therefore, the evidence of protection underscores the necessity of considering interactions between use-categories when evaluating criteria for plant resource selection (Figure 6).

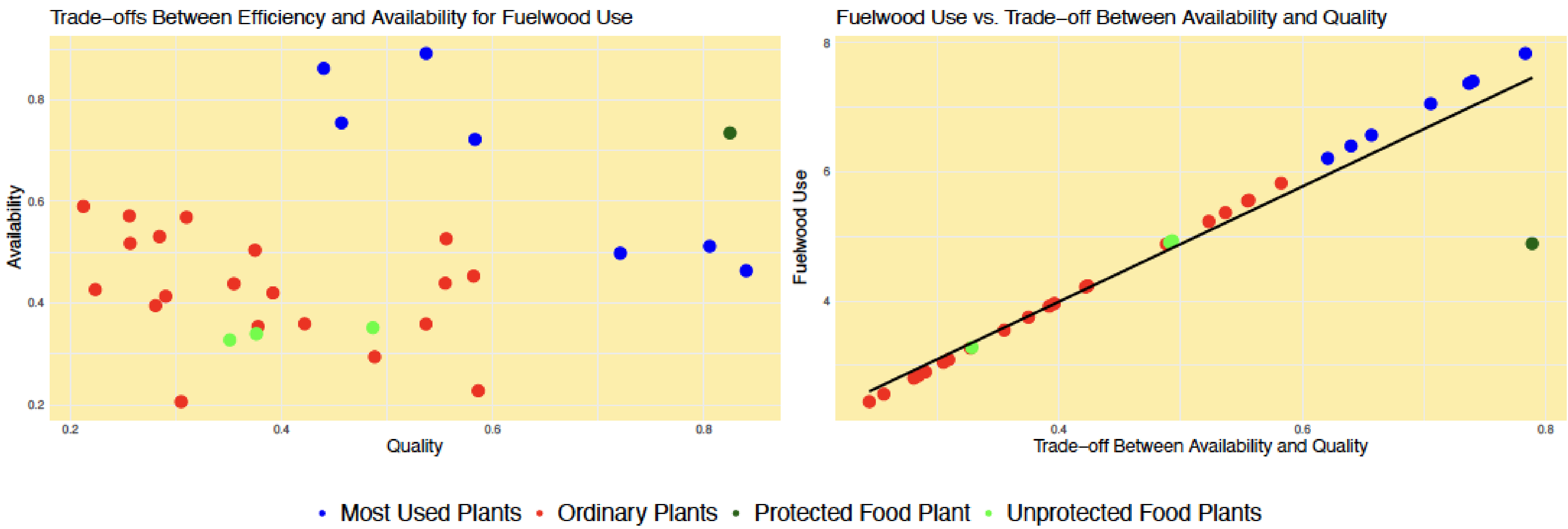


**Fig. 6** Hypothetical example of a trade-off between availability and quality explaining fuelwood use. In a simplified scenario where these are the only predictors of plant use within the fuelwood category, the most utilized species would be those exhibiting the highest trade-offs between availability and quality (represented by the blue dots in the right and left graphs). When considering the interaction with the food use-category under the key-species based protection model, the use of wood species with low to intermediate food importance would be proportional to the trade-off between quality and availability (graph on the right). However, for species that are considered key food plants (indicated by the dark green dot), their utilization for fuelwood would be less than what is predicted by their quality and availability alone.

Recommendations for conservation strategies for plant species

The practical implication of a protective effect that acts solely on species of high food importance is that species recognized as having intermediate or lower importance remain unprotected, as do wood species without any associated food use. Moreover, if only a few species are highly valued for food, they might experience intense pressure from their use as food or be protected at the expense of other species. Therefore, we recommend that conservation strategies be mindful of these dynamics.

For species with intermediate or lower food importance, popularization strategies could prove beneficial to enhance their perceived value. Programs aimed at popularizing such species are crucial, as they may significantly contribute to food and nutritional security, while their use as food might concurrently protect them from being exploited for wood. These programs should establish incentives that encourage community members to use these resources sustainably. However, the effectiveness of this approach should be continuously monitored, as if cultural significance is the primary factor driving protective behaviors, integrating other wild food plants into the set of key species may prove challenging.

Although the commercial importance of key species did not lead to protection in this study, the inclusion of certain species in local markets could also positively influence domestic use. Thus, popularization strategies could extend beyond local communities, emphasizing the importance of these plants for diet diversification and their potential nutritional value to generate demand for products sourced from local communities. One method to achieve this is through marketing campaigns that raise awareness about the significance of these plants in local markets and across social and conventional media platforms (32).

However, it is crucial to approach the popularization of highly important food species with caution to prevent the oversimplification of the plant community, as observed with açaí (*Euterpe oleracea* Mart.), where management practices have simplified estuarine communities in the Amazon Rainforest (33).

For wood species that lack an associated food use, conservation strategies must be implemented to mitigate the pressure on their exploitation. Considering that the primary wood uses in the community are for fuel (firewood) and construction (fencing), conservation efforts should be tailored to these applications. Firewood is the most commonly cited use in the Retiro community, and due to its characteristics regarding short replenishment time and large volume of wood used, it poses a significant threat to species conservation, depending on the collection method (green or dry). For people with greater social vulnerability, firewood is an important resource for cooking. To address this, we recommend the use of efficient wood stoves. These stoves, through their structural configuration, reduce cooking time and, consequently, the daily volume of wood used and deforestation compared to traditional stoves (34).

Although there is controversy in the literature regarding the long-term economic costs and benefits of improved stove use in developing countries (35) and their efficiency(36), several studies have shown significant reductions in firewood use with the adoption of this technology (34,37,38). For instance, a study based on an improved stove intervention in the Chalaco District, Northern Andes of Peru, recorded a 46% reduction in firewood consumption (approximately 650 kg of firewood per household throughout the rainy season) among households that properly used improved stoves during winter (38). Similarly, Bensch and Peters (37), who evaluated the impact of these stoves in rural Senegal through a randomized clinical trial, found a total 31% reduction in firewood consumption over one week. Additionally, the use of efficient stoves can contribute to a higher quality of life for users by reducing smoke from wood combustion, which can cause respiratory diseases (39). However, for successful implementation of efficient stoves, besides local community interest, factors influencing long-term adoption, such as maintenance costs, need to be considered.

An alternative to replacing firewood use is increased investment in public policies that ensure access to Liquefied Petroleum Gas (LPG). While families receiving the gas voucher through the federal government program (Bolsa Família) still use a mix of LPG and firewood in the community, education, health, and human well-being initiatives, combined with these public policies, may have a better response in the community during the transition from firewood to LPG use. This is especially important considering that the use of firewood, for the most part, spans generations. The same applies to the transition from traditional or makeshift brick stoves to efficient stoves.

To reduce the use of species employed in the construction of dead fences - where trunks and branches of woody plants are cut green for use - we recommend a gradual replacement with species used as living fences, which are kept alive. This strategy has been indicated as effective as it represents a gene bank of native species and contributes to the maintenance of these species (40). "Rompe gibão" (*Phyllanthus* sp.) and "Cruirí" (*Mouriri* sp.) were mentioned by some interviewees as species used for living fences, and "Peroba" *(Tabebuia elliptica* (DC.) Sandwith) was mentioned as having the ability for its stake to remain green in a humid environment. They are considered hard and resistant woods ("fixe") by the interviewees who recognized them on the checklist. These species could potentially be used for this purpose, but they need to be evaluated in terms of their characteristics and ecological status.

Finally, although our results admit that there is a protective effect on species with high food importance (key species) regarding wood uses, it is necessary to investigate the ecological status of these species to assess whether harvesting is being done sustainably and if overexploitation of these species is not occurring, as has been identified in other studies with non-timber forest products (5,11,12).

## Recommendations for future ethnobiological studies

Some challenges for testing the protection hypothesis in future studies include:

Studies should account for the interactions not only between two use-categories but also among all use-categories associated with the plant species. For instance, a plant might be protected from wood uses not solely due to its food or medicinal value, but because it serves multiple purposes. Thus, protection may only become apparent when evaluating the full spectrum of plant use dynamics.

Gender and age variables ought to be incorporated into the tests of the protection hypothesis, given that individuals of different ages or genders may protect plants for varied purposes.

Studies could delve into the affective aspects of protection, as these may inspire individuals to spare certain species from wood uses due to resources that evoke positive affective memories. For example, a fruit that was greatly cherished during one's childhood or that constituted the main sustenance for a person's family might be protected. While affective reasons are personal, common patterns may surface, especially among individuals with similar cultural or community backgrounds who may share collective memories.

It's necessary to further investigate the influence of social organization on the protective behaviour of local peoples towards wild food species. For instance, in contexts where there are associations of fruit gatherers or cooperatives, protective behaviour may increase compared to rural communities where social organization is poorly established or absent. Alternatively, protective behaviour may be directed on an individual basis.

Research designs should enhance the methodological approach concerning qualitative evidence for protection. The questioning should be crafted to elicit precise responses without leading the participant, yet still addressing the core issue effectively. Our study utilized indirect questions that may not have fully captured our main objective. We propose that future research adopting discourse analysis techniques (underpinned by multiple theoretical frameworks) would yield valuable insights.

## Limitations of this study

For two groups of plants treated in this study as ethnospecies (*Pau d'arco* and *Ingá*), we were unable to elucidate their taxonomies despite our efforts. Our results suggest that these ethnospecies are not under the protective effect of food use, and the lack of botanical identification complicates the targeting of conservation strategies, especially for future studies in this region. Although we don't know the quantity and specific species, we suspect they are at risk of threat due to logging, especially for *Pau d'arco* (Bignoniaceae spp.). At least two species of *Pau d'arco* are listed in the International Union for Conservation of Nature Red List with concerning ecological statuses: *Handroanthus impetiginosus* (Mart. ex DC.) Mattos (*Pau d'arco rosa*) listed as near-threatened and *Handroanthus serratifolius* (Vahl) S. Grose (*Pau d'arco amarelo*), listed as endangered (41). Both were assessed for the list in 2020. As respondents mentioned three types of *Pau d'arco* (*roxo*, *amarelo*, and *branco*), it's possible that species of this genus are included. Through botanical identification, we identified that a plant known in the community as *Peroba* is the species *Tabebuia elliptica* (DC.) Sandwith (White Pau d'arco), specified on the Red List with a status of least concern. This makes this area an interesting occurrence for this plant group. In light of this, we acknowledge this limitation in our study and invite other researchers specializing in these plant groups to direct research efforts in this region and clarify the taxonomy of these species.

Our data on the perceived quality of wood were collected from a single Likert-scale value considering all wood uses of the plant reported by the interviewee for each wood use category, instead of considering the quality for each reported wood use in each category. This optimized data collection. However, the heterogeneous nature of categories such as technology, where the wood quality of the plant can vary significantly among uses (e.g., tools, furniture, boat), can be challenging for the interviewee to assign a single rating considering various distinct uses. This may have biased our results with very generic perceptions of species quality. Given that wood use is diverse, future studies could consider a more meticulous design, such as focusing on the most relevant uses within each category in the local community and assessing their perceived quality independently.

The inclusion of species for the composition of the checklist interview was based on their availability in areas of co-occurrence with key species. Although greater availability of species is a potential indicator of higher use, it is not universal. There may be species in the sampled vegetation areas that are less available precisely because they are under greater use pressure or due to other environmental or intrinsic factors not considered in this study. Therefore, it is essential to also consider ecological approaches in research to have an overall assessment of the impact of such uses on the plant community structure, even if the focus of the research is on the most important plant species.

**Conclusion**

We have identified a protective effect of domestic food use against wood exploitation, specifically directed towards key species. Consequently, we encourage future studies to test the protection hypothesis within various socio-environmental contexts and we suggest considering two distinct perspectives: generalized protection and protection targeted at key species.

In light of our findings, we advise that species demonstrating an overlap between food and wood uses, yet possessing intermediate or lower food importance as detailed in Table 1, should be prioritized in popularization strategies to raise their significance. Moreover, species solely used for timber, which do not benefit from food-related protection, also require attention through biocultural conservation strategies. Given that the protective effect is limited to a select number of plant species, these species warrant further ecological investigation to determine their conservation status within their natural habitats, to identify whether they face increased pressure from their use as food, and to ascertain if their prominence is leading to a reduction in plant diversity.

**Abbreviations**

| | |
|---|---|
| CLMMs | Cumulative Link Mixed Models |
| NTFPs | Non-Timber Forest Products |
| APAs | Environmental Protection Areas |
| UFAL | Universidade Federal de Alagoas (Federal University of Alagoas) |
| SISBIO | Sistema de Autorização e Informação em Biodiversidade (Biodiversity Authorization and Information System) |

| | |
|---|---|
| ICMBio | Instituto Chico Mendes de Conservação da Biodiversidade (Chico Mendes Institute for Biodiversity Conservation) |
| ICF | Informed Consent Form |
| LECEB | Laboratory of Biocultural Ecology, Conservation, and Evolution |
| AICc | Akaike Information Criterion |
| LPG | Liquefied Petroleum Gas |

**Supplementary Information**

**Additional file 1 -** Multicollinearity diagnosis and model average for the widespread protection model and the key species-based protection model.

**Declarations**

**Ethics approval and consent to participate:**

This study was approved by the Ethics Committee in research by Federal University of Alagoas (UFAL), Nº 1998673. Furthermore, all participants previously signed the Informed Consent Form (ICF).

**Consent for publication**

Not applicable

**Data Availability**

Data is provided within the manuscript or supplementary information files.

**Competing interests**

I declare that the authors have no competing interests as defined by BMC, or other interests that might be perceived to influence the results and/or discussion reported in this paper.

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**Authors' contributions**

RAC - Conceptualization; Investigation; Methodology; Writing - original draft and final. ELGS - Writing - revision and editing. LFCN - Writing - revision and editing; Data compilation; RRVS and ARC - Supervision; Writing - revision and editing. PMM - Conceptualization; Methodology; Writing – final version and editing. All authors read and approved the final version.

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**Table 1** Plants that were part of the checklist interview, their citation percentages (general and by use), and occurrence areas.

| Popular name | Family | Scientific name | Areas[1] | Voucher | Nº of citations | % general | % Food use | % Wood use |
|---|---|---|---|---|---|---|---|---|
| Jenipapo | Rubiaceae | *Genipa americana* L. | C | 94826 | 114 | 99.1 | 99.1 | 57.4 |
| Ingá* | Leg. Mim. | *Inga* spp. | A, B and C | - | 112 | 97.4 | 97.4 | 67.8 |
| Cambuí | Myrtaceae | *Myrciaria floribunda* (H. West ex Wild.) O. Berg | A and B | 94056 | 103 | 89.6 | 89.6 | 41.7 |
| Massaranduba | Sapotaceae | *Manilkara salzmannii* (A.DC.) H.J.Lam | A and B | 93971 | 96 | 83.5 | 82.6 | 77.4 |
| Araçá | Myrtaceae | *Psidium guineense* Sw. | C | 94807 | 93 | 80.9 | 80.9 | 30.4 |
| Cruiri | Melastomataceae | *Mouriri* sp. | C | 94822 | 75 | 65.2 | 64.3 | 51.3 |
| Pau d'arco* | Bignoniaceae | *Bignoniaceae* spp. | A and B | - | 66 | 57.4 | 0 | 57.4 |
| Carrapatinho | Rutaceae | *Esenbeckia grandiflora* Mart. | A and B | 93988 | 27 | 23.5 | 0 | 23.5 |
| Banana de papagaio | Clusiaceae | *Kielmeyera rugosa* Choisy | A and B | 93982 | 26 | 22.6 | 0 | 22.6 |
| Murici comum | Malpighiaceae | *Byrsonima sericea* DC. | A, B and C | 94066 | 22 | 19.1 | 13.9 | 18.3 |
| Murta roxa | Myrtaceae | *Neomitranthes obtusa* Sobral & Zambom | A and B | 94767 | 18 | 15.7 | 10.4 | 15.7 |
| Peroba | Bignoniaceae | *Tabebuia elliptica* (DC.) Sandwith | A and B | 94765 | 18 | 15.7 | 0 | 15.7 |
| Orelha d'onça | Polygonaceae | *Coccoloba laevis* Casar. | A | 94000 | 18 | 15.7 | 7.8 | 15.7 |
| Louro | Lauraceae | *Ocotea notata* (Nees & Mart.) Mez | A and B | 94064 | 16 | 13.9 | 0.9 | 13.9 |
| Sicupira | Leg. Caes. | *Diptychandra aurantiaca* Tul. | A | 93999 | 14 | 12.2 | 0 | 12.2 |
| Espinho branco | Rubiaceae | *Machaonia acuminata* Bonpl. | C | 94813 | 12 | 10.4 | 0 | 10.4 |
| Meiru | Annonaceae | *Xylopia laevigata* (Mart.) R.E.Fr. | A and B | 94067 | 9 | 7.8 | 0 | 7.8 |
| Murici de vaqueiro | Malpighiaceae | *Byrsonima bahiana* W.R.Anderson | A | 93989 | 9 | 7.8 | 7.8 | 6.1 |
| Pirunga | Myrtaceae | *Myrcia arenaria* L.L.Santos et al. | A and B | 93995 | 9 | 7.8 | 7.0 | 6.1 |
| Murta branca | Myrtaceae | *Eugenia punicifolia* (Kunth) DC. | A and B | 94068 | 8 | 7.0 | 4.3 | 7.0 |
| Açoita égua | Myrtaceae | *Myrcia loranthifolia* (DC.) G.Burton & E.Lucas | A, B and C | 93994 | 7 | 6.1 | 3.5 | 6.1 |
| Camarão | Flacourtiaceae | *Casearia Sylvestris* Sw. | A and C | 94821 | 7 | 6.1 | 0 | 6.1 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Piranha | Nyctaginaceae | *Guapira opposita* (Vell.) Reitz | A and B | 93993 | 5 | 4.3 | 0.9 | 4.3 |
| Rompe gibão | Euphorbiaceae | *Phyllanthus* sp. | C | - | 4 | 3.5 | 0 | 3.5 |
| Sete casco | Euphorbiaceae | *Pera glabrata* (Schott) Baill. | A and B | 93976 | 3 | 2.6 | 0 | 2.6 |
| Murta amarela | Myrtaceae | *Neomitranthes* sp. | A, B and C | 93991 | 1 | 0.9 | 0 | 0.9 |

*Ethnospecies

[1]Occurrence areas of plant species - local denominations: (A) - Carrasco, (B) - Zé Marinho, (C) - Lalo (Patos).

**Table 2** Species recognized for wood purposes and their respective uses in each category

| Family Cientific Name Popular name | Fuel | Construction | Technology |
|---|---|---|---|
| **Annonaceae** | | | |
| *Xylopia laevigata* (Mart.) R.E.Fr. (Meiru) | Charcoal, Firewood | Rafter, Fence, Window, Line, Door | Handle for hoe, Handle for broom, Fishing hook, Handle for cóvu, Handle for covú |
| **Bignoniaceae** | | | |
| *Bignoniaceae* spp. (Pau d'arco) | Charcoal, Firewood | Washstand alpendre, Horse stall, Rafter, Fence, House construction, Post, Line, Roof timber, Mourão, Door, Portal, Slat, Gate board, Corral board, Fill board (rammed earth house), Stick for rammed earth house | Scaffolding, Cabinet, Bench, Boat, Handle for hoe, Handle for sickle, Handle for axe, Handle for hammer, Handle for drag net, Handle for brush cutter, Handle for broom, Chair, Canoe, Shelf, Fish string, Wardrobe, Table, Oar, Boat rhombus, Boat plank, Canoe board, Cart board, Stool, Handle for cóvu |
| *Tabebuia elliptica* (DC.) Sandwith (Peroba) | Charcoal, Firewood | Brabo, Rafter, Fence, Post, Line, Mourão, Door, Portal, Slat, Fill board (rammed earth house) | Cabinet, Boat, Handle for digging stick, Handle for hoe, Handle for small hoe, Handle for sickle, Handle for axe, Handle for hammer, Handle for drag net, Handle for broom, Chair, Coffin, Bed, Wooden spoon, Wood for sofa, Pestle hand, Table, Furniture, Oar, Handle for cóvu, Handle for covú |
| **Clusiaceae** | | | |
| *Kielmeyera rugosa* Choisy (Banana de papagaio) | Charcoal, Firewood | Fence, Post, Line | Bench, Handle for broom, Cork for fishing net, Oar |
| **Euphorbiaceae** | | | |
| *Pera glabrata* (Schott) Baill. (Sete casco) | Charcoal, Firewood | Rafter, Fence, Post, | |

| | | | |
|---|---|---|---|
| *Phyllanthus* sp. (Rompe gibão) | Charcoal, Firewood | Fence | |
| **Flacourtiaceae** | | | |
| *Casearia Sylvestris* Sw. (Camarão) | Charcoal, Firewood | Rafter, Fence | Bench, Handle for hoe, Handle for small hoe, Chair, Coffee table, Handle for cóvu |
| **Lauraceae** | | | |
| *Ocotea notata* (Nees & Mart.) Mez (Louro) | Charcoal, Firewood | Barrote, Rafter, Fence, Post, Line, Door, Portal, Slat, Fill board (rammed earth house) | Boat, Handle for hoe, Handle for sickle, Handle for axe, Handle for broom, Chair, Canoe, Table, Oar, Boat plank, Canoe board, Table board, Handle for cóvu |
| **Leg. Caes.** | | | |
| *Diptychandra aurantiaca* Tul. (Sicupira) | Charcoal, Firewood | Rafter, Fence, Corral, Post, Line, Mourão, Fill board (rammed earth house) | Handle for hoe, Handle for small hoe, Handle for sickle, Handle for axe, Chair, Boat cave, Ibone, Table, Handle for cóvu |
| **Leg. Mim.** | | | |
| *Inga* spp. (Ingá) | Charcoal, Firewood | Horse stall, Rafter, Fence, House construction, Post, Line, Mourão, Fill board (rammed earth house) | Handle for hoe, Handle for tool, Handle for sickle, Handle for broom, Handle for cóvu, Handle for covú |
| **Malpighiaceae** | | | |
| *Byrsonima bahiana* W.R.Anderson (Murici de vaqueiro) | Charcoal, Firewood | Fence, Stick for rammed earth house | |
| *Byrsonima sericea* DC. (Murici comum) | Charcoal, Firewood | Door jamb, Brabo, Rafter, Fence, Window, Line, Door | Handle for hoe, Handle for axe, Oar, Boat rhombus, Handle for cóvu, Handle for covú |
| **Melastomataceae** | | | |

| | | | |
|---|---|---|---|
| *Mouriri* sp. (Cruiri) | Charcoal, Firewood | Fence, Pigsty, Corral, Post, Mourão, Fill board (rammed earth house), Stick for rammed earth house | Scaffolding, Bench, Handle for hoe, Handle for sickle, Handle for hammer, Handle for drag net, Canoe cave, Pitchfork, Pestle, Oar, Boat rhombus, Handle for cóvu, Handle for covú |
| **Myrtaceae** | | | |
| *Eugenia punicifolia* (Kunth) DC. (Murta branca) | Charcoal, Firewood | Rafter, Fence | Handle for hoe, Handle for sickle, Handle for broom, Handle for cóvu |
| *Myrcia arenaria* L.L.Santos et al. (Pirunga) | Charcoal, Firewood | Fence | Handle for cóvu, Handle for covú |
| *Myrciaria floribunda* (H. West ex Wild.) O. Berg (Cambuí) | Charcoal, Firewood | Fence, Line, Mourão | Handle for hoe, Handle for sickle, Handle for shuttlecock, Handle for broom, Fishing hook, Handle for cóvu, Handle for covú, Yard broom |
| *Myrcia loranthifolia* (DC.) G.Burton & E.Lucas (Açoita égua) | Charcoal, Firewood | Rafter, Woodshed, Fence | Handle for hoe, Handle for broom, Handle for cóvu |
| *Neomitranthes obtusa* Sobral & Zambom (Murta roxa) | Charcoal, Firewood | Rafter, Fence, Post, Line, Mourão, Portal | Bench, Handle for digging stick, Handle for hoe, Handle for small hoe, Handle for sickle, Handle for axe, Handle for brush cutter, Handle for broom, Chair, Coffee table, Handle for cóvu, Handle for covú |
| *Neomitranthes* sp. (Murta amarela) | Charcoal | Fence | |
| *Psidium guineense* Sw. (Araçá) | Charcoal, Firewood | Fence, Corral | Scaffolding, Handle for shuttlecock, Spinning top, Handle for cóvu, Handle for covú |
| **Nyctaginaceae** | | | |
| *Guapira opposita* (Vell.) Reitz (Piranha) | Charcoal, Firewood | Rafter, Fence, Line, Slat, Fill board (rammed earth house) | |
| **Polygonaceae** | | | |

| | | | |
|---|---|---|---|
| *Coccoloba laevis* Casar. (Orelha d'onça) | Charcoal, Firewood | Rafter, Fence | Skewer for roasting corn |
| **Rubiaceae** | | | |
| *Genipa americana* L. (Jenipapo) | Charcoal, Firewood | Alpendre, Washstand alpendre, Rafter, Fence, Corral, Line, Mourão, Door, Slat, Door board, Stick for rammed earth house | Zabumba arch, Cabinet, Bench, Boat, Boat tiller, Handle for digging stick, Handle for hoe, Handle for strainer, Handle for sickle, Handle for axe, Handle for hammer, Handle for drag net, Chair, Bed, Canoe, Wooden spoon, Pestleant prop, Shed, Cupboard, Mast, Table, Furniture, Chair leg, Camiseiro leg, Pestle, Oar, Boat rhombus, Boat plank, Canoe board, Meat board, Board for rice husking machine, Stool board, Stool |
| *Machaonia acuminata* Bonpl. (Espinho branco) | Charcoal, Firewood | Fence | Barrier for caiçara, Fishing hook, Handle for cóvu |
| **Rutaceae** | | | |
| *Esenbeckia grandiflora* Mart. (Carrapatinho) | Charcoal, Firewood | Fence, Slat, Fill board (rammed earth house), Stick for rammed earth house | Needle for cast net, Handle for hoe, Handle for sickle, Handle for drag net, Handle for broom, Skewer for barbecue, Handle for cóvu, Handle for covú |
| **Sapotaceae** | | | |

| | | | |
|---|---|---|---|
| *Manilkara salzmannii* (A.DC.) H.J.Lam (Massaranduba) | Charcoal, Firewood | Barrote, Door jamb, Rafter, Fence, Pigsty, House construction, Corral, Post, Window, Line, Mourão, Door, Slat, Corral board, Fill board (rammed earth house), Stable board, Door board, Stick for rammed earth house | Scaffolding, Cabinet, Bench, Boat, Handle for digging stick, Cleaver, Handle for hoe, Handle for small hoe, Handle for strainer, Handle for machete, Handle for sickle, Handle for axe, Handle for hammer, Handle for broom, Chair, Bed, Chest of drawers, Canoe, Boat cave, Shelf, Table, Furniture, Oar, Boat rhombus, Boat plank, Canoe board, Furniture board, Stool, Handle for cóvu, Handle for covú |

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## 5. Conclusões

O primeiro capítulo desta tese mostrou que uma gama de espécies vegetais que tem potencial alimentício, muitas vezes inexplorado, pode estar ameaçada pelos seus usos madeireiros, correndo risco de terem sua disponibilidade amplamente reduzida antes mesmo de ter o seu potencial explorado. No entanto, o segundo capítulo mostrou que espécies de alta importância alimentícia (espécies-chave) são poupadas dos usos madeireiros pelos povos locais. Desse modo, a valorização do potencial alimentício pode contribuir para a conservação de espécies vegetais, aliada a estratégias de manejo mais holísticas, que protejam as espécies sem potencial alimentício e evitem a simplificação de comunidades vegetais a partir de um manejo para fins alimentícios.

Por isso, as espécies com sobreposição entre os usos alimentícios e madeireiros são prioritárias à conservação a fim de garantir a existência contínua de recursos potenciais para a segurança alimentar e nutricional, especialmente aquelas versáteis para os usos madeireiros e com alto potencial nutricional. E, considerando que o efeito protetivo do uso alimentício sobre os usos madeireiros está direcionado para as espécies-chave, as espécies com baixa ou média importância alimentícia devem ser priorizadas em estratégias de popularização para elevar sua importância. No entanto, é crucial realizar mais pesquisas ecológicas para entender o estado de conservação das espécies-chave em seus habitats naturais. Isso inclui investigar se essas espécies estão sob maior pressão devido ao uso como alimento e se seu manejo está contribuindo para a redução da diversidade vegetal. Além disso, espécies lenhosas não comestíveis, que não se beneficiam da proteção associada ao uso alimentício, também precisam de atenção por meio de estratégias de conservação biocultural.

## 6. Apêndices

### Artigo 1: Supplementary material

**Add File 1**. PRISMA Protocol Checklist – Ethnobiology review

| Section and Topic | Item # | Checklist item | Location where item is reported |
|---|---|---|---|
| **TITLE** | | | |
| Title | 1 | Identify the report as a systematic review. | 1 |
| **ABSTRACT** | | | |
| Abstract | 2 | See the PRISMA 2020 for Abstracts checklist. | 2 |
| **INTRODUCTION** | | | |
| Rationale | 3 | Describe the rationale for the review in the context of existing knowledge. | 2-4 |
| Objectives | 4 | Provide an explicit statement of the objective(s) or question(s) the review addresses. | 5 |
| **METHODS** | | | |
| Eligibility criteria | 5 | Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses. | 5 |
| Information sources | 6 | Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted. | 6-7 |
| Search strategy | 7 | Present the full search strategies for all databases, registers and websites, including any filters and limits used. | 7, 8 and additional file 2 |
| Selection process | 8 | Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process. | 8 |
| Data collection process | 9 | Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process. | 8-9 |

| Section and Topic | Item # | Checklist item | Location where item is reported |
|---|---|---|---|
| Data items | 10a | List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect. | 9-10 |
| | 10b | List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information. | 8-9 |
| Study risk of bias assessment | 11 | Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process. | 9 |
| Effect measures | 12 | Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results. | NA |
| Synthesis methods | 13a | Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)). | 8 |
| | 13b | Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions. | 8-9 |
| | 13c | Describe any methods used to tabulate or visually display results of individual studies and syntheses. | 9-10 |
| | 13d | Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used. | 9-10 |
| | 13e | Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression). | NA |
| | 13f | Describe any sensitivity analyses conducted to assess robustness of the synthesized results. | NA |
| Reporting bias assessment | 14 | Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases). | NA |
| Certainty assessment | 15 | Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome. | NA |
| **RESULTS** | | | |
| Study selection | 16a | Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram. | 14 and Fig.1 |
| | 16b | Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded. | 14 |

| Section and Topic | Item # | Checklist item | Location where item is reported |
|---|---|---|---|
| Study characteristics | 17 | Cite each included study and present its characteristics. | 14-16 |
| Risk of bias in studies | 18 | Present assessments of risk of bias for each included study. | NA |
| Results of individual studies | 19 | For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots. | NA |
| Results of syntheses | 20a | For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies. | 16-18 |
| | 20b | Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect. | NA |
| | 20c | Present results of all investigations of possible causes of heterogeneity among study results. | NA |
| | 20d | Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results. | NA |
| Reporting biases | 21 | Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed. | NA |
| Certainty of evidence | 22 | Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed. | NA |
| **DISCUSSION** | | | |
| Discussion | 23a | Provide a general interpretation of the results in the context of other evidence. | 26-30 |
| | 23b | Discuss any limitations of the evidence included in the review. | 26 and 30 |
| | 23c | Discuss any limitations of the review processes used. | 30 |
| | 23d | Discuss implications of the results for practice, policy, and future research. | 30 |
| **OTHER INFORMATION** | | | |
| Registration and protocol | 24a | Provide registration information for the review, including register name and registration number, or state that the review was not registered. | NA |
| | 24b | Indicate where the review protocol can be accessed, or state that a protocol was not prepared. | NA |
| | 24c | Describe and explain any amendments to information provided at registration or in the protocol. | NA |
| Support | 25 | Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review. | 31 |
| Competing interests | 26 | Declare any competing interests of review authors. | 32 |

| Section and Topic | Item # | Checklist item | Location where item is reported |
|---|---|---|---|
| Availability of data, code and other materials | 27 | Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review. | 32 |

*From:* Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

7. For more information, visit: http://www.prisma-statement.org/

**Add File 2.** Search strategies – Ethnobiology review

| Search 1 (B1) | | Search 2 (B2) |
|---|---|---|
| Key words - SCOPUS, WEB OF SCIENCE AND SCIELO | Key word in Portuguese - SCIELO | Key words - SCOPUS, WEB OF SCIENCE AND SCIELO |
| ("edible plants" OR "food plants" OR "wild food plants" OR "non-timber forest products" OR "food uses") AND ethnob* AND Brazil | ("plantas comestíveis" OR "plantas alimentícias" OR "plantas alimentícias silvestres" OR "plantas alimentares" OR "produtos florestais não madeireiros" OR "usos alimentícios") AND etnob* | ("local knowledge" OR "traditional knowledge") AND ethnob* AND Brazil |
| ("wood plants" OR "wood uses" OR "wood products" OR "wood resources" OR "wood forest products" OR "timber forest products" OR "timber resources") AND ethnob* AND Brazil | ("plantas madeireiras" OR "usos madeireiros" OR "produtos madeireiros" OR "recursos madeireiros" OR "produtos florestais madeireiros") AND etnob* | |
| "useful plants" AND ethnob* AND Brazil | “plantas úteis” AND etnob* | Key words in Portuguese - SCIELO |
| ("woody plants" OR "woody species" OR "woody forest resources") AND ethnob* AND Brazil | ("plantas lenhosas" OR "espécies lenhosas" OR "recursos florestais lenhosos") AND etnob* | ("conhecimento local" OR "conhecimento tradicional") AND etnob* |
| "multipurpose plants" AND ethnob* AND Brazil | ("plantas multiuso" OR "plantas de múltiplos usos") AND etnob* | |
| "wild food plants" AND ethnob* AND Brazil | "plantas alimentícias silvestres" AND etnob* | |
| "food plants" AND ethnob* AND Brazil | "plantas alimentícias" AND etnob* | |

| | |
|---|---|
| "edible plants" AND ethnob* AND Brazil | "plantas alimentares" AND etnob* |
| "non-timber forest products" AND ethnob* AND Brazil | "plantas comestíveis" AND etnob* |
| "food uses" AND ethnob* AND Brazil | "produtos florestais não madeireiros" AND etnob* |
| ("wood plants" OR "wood species") AND ethnob* AND Brazil | ("plantas madeireiras" OR "espécies madeireiras") AND etnob* |
| "wood uses" AND ethnob* AND Brazil | "usos madeireiros" AND etnob* |
| "wood products" AND ethnob* AND Brazil | "recursos madeireiros" AND etnob* |
| ("wood resources" OR "timber resources") AND ethnob* AND Brazil | "produtos madeireiros" AND etnob* |
| "wood forest products" AND ethnob* AND Brazil | "produtos florestais madeireiros" AND etnob* |
| "timber forest products" AND ethnob* AND Brazil NOT "non-timber" | lenha AND etnob* |
| ("fuelwood species" OR "fuelwood plants" OR "firewood use" OR firewood OR fuelwood) AND ethnob* AND Brazil | "uso combustível" AND etnob* |
| ("fuel use" OR "woodfuel") AND ethnob* AND Brazil | ("carvão vegetal" OR carvão) AND etnob* |
| (charcoal OR coal) AND ethnob* AND Brazil | "categoria tecnologia" AND etnob* |
| "construction category" AND ethnob* AND Brazil | "categoria construção" AND etnob* |

| | |
|---|---|
| "fuelwood category" AND ethnob* AND Brazil | "categoria combustível" AND etnob* |
| "technology category" AND ethnob* AND Brazil | cercas AND etnob* |
| fence AND ethnob* AND Brazil | |

**Add File 3**. PRISMA Protocol Checklist – Nutritional review

| Section and Topic | Item# | Checklist item | Location where item is reported |
|---|---|---|---|
| **TITLE** | | | |
| Title | 1 | Identify the report as a systematic review. | 1 |
| **ABSTRACT** | | | |
| Abstract | 2 | See the PRISMA 2020 for Abstracts checklist. | 2 |
| **INTRODUCTION** | | | |
| Rationale | 3 | Describe the rationale for the review in the context of existing knowledge. | 2-4 |
| Objectives | 4 | Provide an explicit statement of the objective(s) or question(s) the review addresses. | 5 |
| **METHODS** | | | |
| Eligibility criteria | 5 | Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses. | 10 |
| Information sources | 6 | Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted. | 12 |
| Search strategy | 7 | Present the full search strategies for all databases, registers and websites, including any filters and limits used. | Fig 2 and page 12 |
| Selection process | 8 | Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process. | 12-13 |
| Data collection process | 9 | Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process. | 13-14 |
| Data items | 10a | List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect. | 18-19 |
| | 10b | List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information. | 18-19 |
| Study risk of bias assessment | 11 | Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process. | NA |
| Effect measures | 12 | Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results. | NA |

| | | | |
|---|---|---|---|
| Synthesis methods | 13a | Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)). | 18-19 |
| | 13b | Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions. | 12 |
| | 13c | Describe any methods used to tabulate or visually display results of individual studies and syntheses. | 12 |
| | 13d | Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used. | NA |
| | 13e | Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression). | NA |
| | 13f | Describe any sensitivity analyses conducted to assess robustness of the synthesized results. | NA |
| Reporting bias assessment | 14 | Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases). | NA |
| Certainty assessment | 15 | Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome. | NA |
| **RESULTS** | | | |
| Study selection | 16a | Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram. | 18 and Fig.3 |
| | 16b | Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded. | 18 |
| Study characteristics | 17 | Cite each included study and present its characteristics. | 18-19 |
| Risk of bias in studies | 18 | Present assessments of risk of bias for each included study. | NA |
| Results of individual studies | 19 | For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots. | NA |
| Results of syntheses | 20a | For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies. | 20-25 |
| | 20b | Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect. | NA |
| | 20c | Present results of all investigations of possible causes of heterogeneity among study results. | NA |
| | 20d | Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results. | NA |
| Reporting biases | 21 | Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed. | NA |

| | | | |
|---|---|---|---|
| Certainty of evidence | 22 | Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed. | NA |
| **DISCUSSION** | | | |
| Discussion | 23a | Provide a general interpretation of the results in the context of other evidence. | 26-30 |
| | 23b | Discuss any limitations of the evidence included in the review. | 26 and 30 |
| | 23c | Discuss any limitations of the review processes used. | 30 |
| | 23d | Discuss implications of the results for practice, policy, and future research. | 30 |
| **OTHER INFORMATION** | | | |
| Registration and protocol | 24a | Provide registration information for the review, including register name and registration number, or state that the review was not registered. | NA |
| | 24b | Indicate where the review protocol can be accessed, or state that a protocol was not prepared. | NA |
| | 24c | Describe and explain any amendments to information provided at registration or in the protocol. | NA |
| Support | 25 | Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review. | 31 |
| Competing interests | 26 | Declare any competing interests of review authors. | 32 |
| Availability of data, code and other materials | 27 | Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review. | 32 |

***From:*** **Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71**

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**Add File 4.** Search strategies – Nutritional review

| Scopus, Web of science and Scielo (English) | Scielo (Portuguese) | SiBBr | |
|---|---|---|---|
| "Amburana cearensis" AND nutritional | "Amburana cearensis" AND nutricional | Amburana cearensis | - |
| "Anacardium occidentale" AND nutritional | "Anacardium occidentale" AND nutricional | Anacardium occidentale | - |
| "Anadenanthera colubrina" AND nutritional | "Anadenanthera colubrina" AND nutricional | Anadenanthera colubrina | - |
| ("Astronium urundeuva" OR "Myracrodruon urundeuva") AND nutritional | ("Astronium urundeuva" OR "Myracrodruon urundeuva") AND nutricional | Astronium urundeuva | Myracrodruon urundeuva |
| "Bauhinia cheilantha" AND nutritional | "Bauhinia cheilantha" AND nutricional | Bauhinia cheilantha | - |
| "Brosimum guianense" AND nutritional | "Brosimum guianense" AND nutricional | Brosimum guianense | - |
| "Byrsonima sericea" AND nutritional | "Byrsonima sericea" AND nutricional | Byrsonima sericea | - |
| "Cecropia pachystachya AND nutritional | "Cecropia pachystachya AND nutricional | Cecropia pachystachya | - |
| "Combretum leprosum" AND nutritional | "Combretum leprosum" AND nutricional | Combretum leprosum | - |
| "Commiphora leptophloeos" AND nutritional | "Commiphora leptophloeos" AND nutricional | Commiphora leptophloeos | - |
| "Copaifera langsdorffii" AND nutritional | "Copaifera langsdorffii" AND nutricional | Copaifera langsdorffii | - |
| ("Croton heliotropiifolius" OR "Croton rhamnifolius") AND nutritional | ("Croton heliotropiifolius" OR "Croton rhamnifolius") AND nutricional | Croton heliotropiifolius | Croton rhamnifolius |
| ("Cynophalla flexuosa" OR "Capparis flexuosa") AND nutritional | ("Cynophalla flexuosa" OR "Capparis flexuosa") AND nutricional | Cynophalla flexuosa | Capparis flexuosa |
| ("Didymopanax morototoni" OR "Schefflera morototoni") AND nutritional | ("Didymopanax morototoni" OR "Schefflera morototoni") AND nutricional | Didymopanax morototoni | Schefflera morototoni |

| | | | |
|---|---|---|---|
| ("Eschweilera ovata" OR "Eschweilera luschnathii") AND nutritional | ("Eschweilera ovata" OR "Eschweilera luschnathii") AND nutricional | Eschweilera ovata | Eschweilera luschnathii |
| ("Eugenia pyriformis" OR "Eugenia uvalha") AND nutritional | ("Eugenia pyriformis" OR "Eugenia uvalha") AND nutricional | Eugenia pyriformis | Eugenia uvalha |
| "Eugenia uniflora" AND nutritional | "Eugenia uniflora" AND nutricional | Eugenia uniflora | - |
| "Genipa americana" AND nutritional | "Genipa americana" AND nutricional | Genipa americana | - |
| ("Handroanthus impetiginosus" OR "Tabebuia impetiginosa") AND nutritional | ("Handroanthus impetiginosus" OR "Tabebuia impetiginosa") AND nutricional | Handroanthus impetiginosus | Tabebuia impetiginosa |
| ("Handroanthus serratifolius" OR "Tabebuia serratifolia") AND nutritional | ("Handroanthus serratifolius" OR "Tabebuia serratifolia") AND nutricional | Handroanthus serratifolius | Tabebuia serratifolia |
| "Inga thibaudiana" AND nutritional | "Inga thibaudiana" AND nutricional | Inga thibaudiana | - |
| "Libidibia ferrea" AND nutritional | "Libidibia ferrea" AND nutricional | Libidibia ferrea | - |
| "Manihot dichotoma" AND nutritional | "Manihot dichotoma" AND nutricional | Manihot dichotoma | - |
| ("Monteverdia obtusifolia" OR "Maytenus obtusifolia") AND nutritional | ("Monteverdia obtusifolia" OR "Maytenus obtusifolia") AND nutricional | Monteverdia obtusifolia | Maytenus obtusifolia |
| ("Monteverdia rigida" OR "Maytenus rigida") AND nutritional | ("Monteverdia rigida" OR "Maytenus rigida") AND nutricional | Monteverdia rigida | Maytenus rigida |
| "Myrcia splendens" AND nutritional | "Myrcia splendens" AND nutricional | Myrcia splendens | - |
| ("Neocalyptrocalyx longifolium" OR "Capparis jacobinae") AND nutritional | ("Neocalyptrocalyx longifolium" OR "Capparis jacobinae") AND nutricional | Neocalyptrocalyx longifolium | Capparis jacobinae |
| "Ocotea glomerata" AND nutritional | "Ocotea glomerata" AND nutricional | Ocotea glomerata | - |
| "Ocotea odorifera" AND nutritional | "Ocotea odorifera" AND nutricional | Ocotea odorifera | - |
| "Pilosocereus pachycladus" AND nutritional | "Pilosocereus pachycladus" AND nutricional | Pilosocereus pachycladus | - |
| "Protium heptaphyllum" AND nutritional | "Protium heptaphyllum" AND nutricional | Protium heptaphyllum | - |
| "Psidium guineense" AND nutritional | "Psidium guineense" AND nutricional | Psidium guineense | - |

| | | | |
|---|---|---|---|
| ("Sarcomphalus joazeiro" OR "Ziziphus joazeiro") AND nutritional | ("Sarcomphalus joazeiro" OR "Ziziphus joazeiro") AND nutricional | Sarcomphalus joazeiro | Ziziphus joazeiro |
| "Schinus terebinthifolia" AND nutritional | "Schinus terebinthifolia" AND nutricional | Schinus terebinthifolia | - |
| "Sideroxylon obtusifolium" AND nutritional | "Sideroxylon obtusifolium" AND nutricional | Sideroxylon obtusifolium | - |
| "Simarouba amara" AND nutritional | "Simarouba amara" AND nutricional | Simarouba amara | - |
| "Spondias mombin" AND nutritional | "Spondias mombin" AND nutricional | Spondias mombin | - |
| "Spondias tuberosa" AND nutritional | "Spondias tuberosa" AND nutricional | Spondias tuberosa | - |
| "Talisia esculenta" AND nutritional | "Talisia esculenta" AND nutricional | Talisia esculenta | - |
| "Tapirira guianensis" AND nutritional | "Tapirira guianensis" AND nutricional | Tapirira guianensis | - |
| "Thyrsodium spruceanum" AND nutritional | "Thyrsodium spruceanum" AND nutricional | Thyrsodium spruceanum | - |
| "Ximenia americana" AND nutritional | "Ximenia americana" AND nutricional | Ximenia americana | - |

**Artigo 2: Supplementary material**

**Appendix 1**. Multicollinearity diagnosis and model average for the widespread protection model and the key species-based protection model

| | | | | |
|---|---|---|---|---|
| **Overall Multicollinearity Diagnostics for the widespread protection model** | | | | |
| | MC Results detection | | | |
| Determinant \|X'X\|: | 0.8793 | | 0 | |
| Farrar Chi-Square: | 82.5421 | | 1 | |
| Red Indicator | 0.1465 | | 0 | |
| Sum of Lambda Inverse: | 4.2647 | | 0 | |
| Theil's Method | 0.0200 | | 0 | |
| Condition Number | 13.5726 | | 0 | |
| **Overall Multicollinearity Diagnostics for the key species-based protection model** | | | | |
| | MC Results detection | | | |
| Determinant \|X'X\|: | 0.8407 | | 0 | |
| Farrar Chi-Square: | 111.3357 | | 1 | |
| Red Indicator | 0.1645 | | 0 | |
| Sum of Lambda Inverse: | 4.3748 | | 0 | |
| Theil's Method | 0.0694 | | 0 | |
| Condition Number | 11.5739 | | 0 | |
| 1 --> | Collinearity is detected by the test | | | |
| 0 --> | Collinearity is not detected by the test | | | |
| **Model average for the widespread protection model** | | | | |
| | Component models | | | |
| Df | LogLik | AiCc | Delta | Weight |
| 1234 | 9-684.03 | 1389.34 | 0.00 | 0.33 |
| 123 | 8-685.25 | 1386.72 | 0.38 | 0.27 |
| 12 | 7-686.31 | 1386.79 | 0.45 | 0.26 |
| 124 | 8-685.89 | 1388.00 | 1.66 | 0.14 |
| | Term codes | | | |
| 1 – Availability | | | | |
| 2 - Maximum_quality | | | | |
| 3 - Commercial_food_use | | | | |
| 4 - Domestic_food_use | | | | |
| | Model-averaged coefficients: (Full average) | | | |
| Variables | Estimate Std. | Error | Z | P |
| 1\|2 | 4.29845 | 0.61263 | 7.016 | <2e-16*** |
| 2\|3 | 5.48143 | 0.63207 | 8.672 | <2e-16*** |

| | | | | |
|---|---|---|---|---|
| 3\|4 | 6.45156 | 0.65265 | 9.885 | <2e-16*** |
| 4\|5 | 6.69560 | 0.65840 | 10.169 | <2e-16*** |
| Availability | 0.32415 | 0.07260 | 4.465 | 8e-06*** |
| Maximum_quality | 0.62826 | 0.11316 | 5.552 | 3e-08*** |
| Commercial_food_use | -0.12221 | 0.13921 | 0.878 | 0.380 |
| Domestic_food_use | 0.05383 | 0.08789 | 0.648 | 0.517 |
| **(Conditional average)** | | | | |
| 1\|2 | 4.29845 | 0.61263 | 7.016 | <2e-16*** |
| 2\|3 | 5.48143 | 0.63207 | 8.672 | <2e-16*** |
| 3\|4 | 6.45156 | 0.65265 | 9.885 | <2e-16*** |
| 4\|5 | 6.69560 | 0.65840 | 10.169 | <2e-16*** |
| Availability | 0.32415 | 0.07260 | 4.465 | 8e-06*** |
| Maximum_quality | 0.62826 | 0.11316 | 5.552 | 3e-08*** |
| Commercial_food_use | -0.20465 | -0.20465 | 1.640 | 0.101 |
| Domestic_food_use | 0.11476 | 0.08789 | 1.306 | 0.192 |
| **Model average for the key species-based protection model** | | | | |
| Component models | | | | |
| Df | LogLik | AiCc | Delta | Weight |
| 234 | 8-678.03 | 1372.29 | 0.00 | 0.56 |
| 1234 | 9-677.25 | 1372.78 | 0.49 | 0.44 |
| Term codes | | | | |
| 1 - Commercial_key_species_use | | | | |
| 2 - Availability | | | | |
| 3 - Maximum_quality | | | | |
| 4 - Domestic_key_species_use | | | | |
| **Model-averaged coefficients:** | | | | |
| (Full average) | | | | |
| **Variables** | **Estimate Std.** | **Error** | **Z** | **P** |
| 1\|2 | 4.29086 | 0.60813 | 7.056 | < 2e-16 *** |
| 2\|3 | 5.51657 | 0.62948 | 8.764 | < 2e-16 *** |
| 3\|4 | 6.50263 | 0.65073 | 9.993 | < 2e-16 *** |
| 4\|5 | 6.74713 | 0.65643 | 10.279 | < 2e-16 *** |
| Availability | 0.35829 | 0.07267 | 4.930 | 8e-07 *** |

| | | | | |
|---|---|---|---|---|
| Maximum_quality | 0.62038 | 0.11237 | 5.521 | < 2e-16 *** |
| Domestic_key_species_use | 1.03517 | 0.30352 | 3.410 | 0.000648 *** |
| Commercial_key_species_use | -0.26085 | 0.43358 | 0.602 | 0.547435 |
| **(Conditional average)** | | | | |
| 1\|2 | 4.29086 | 0.60813 | 7.056 | < 2e-16 *** |
| 2\|3 | 5.51657 | 0.62948 | 8.764 | < 2e-16 *** |
| 3\|4 | 6.50263 | 0.65073 | 9.993 | < 2e-16 *** |
| 4\|5 | 6.74713 | 0.65643 | 10.279 | < 2e-16 *** |
| Availability | 0.35829 | 0.07267 | 4.930 | 8.2e-07 *** |
| Maximum_quality | 0.62038 | 0.11237 | 5.521 | 3.0e-08 *** |
| Domestic_key_species_use | -1.03517 | 0.30352 | 3.410 | 0.000648 *** |
| Commercial_key_species_use | -0.59433 | 0.47973 | 1.239 | 0.215388 |

Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1