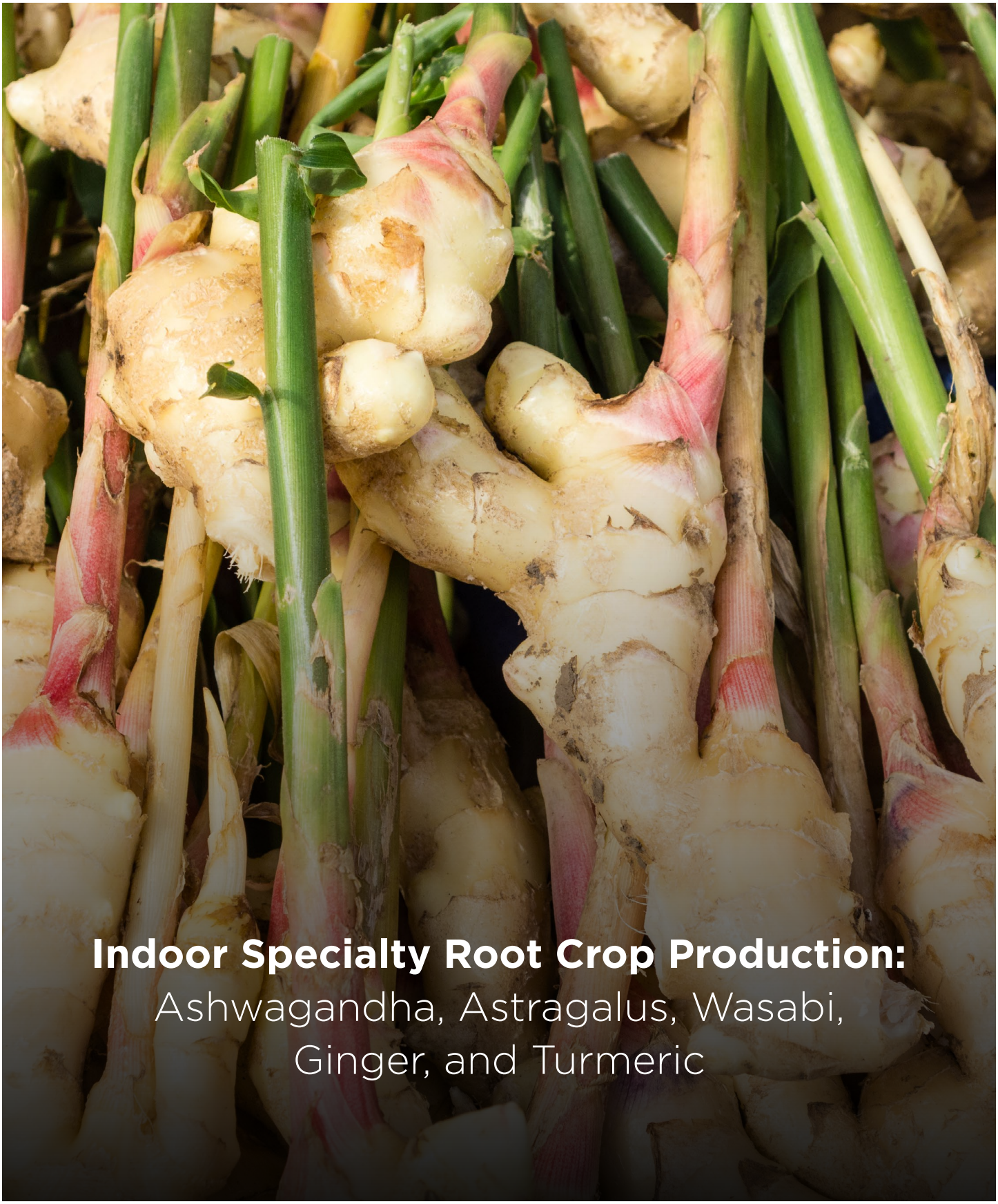

Indoor Specialty Root Crop Production:
Ashwagandha, Astragalus, Wasabi, Ginger, and Turmeric

Transfarmation®

Highland ECONOMICS

Important Disclaimer

This document ("Document") or any written material provided to you by Mercy For Animals, Inc., (including Transformation™) or any of its affiliates (together, "MFA"), including but not limited to information or written material prepared by third parties, should not be construed as advice or in any way an endorsement or a recommendation by MFA.

The Document should not form the primary basis for any decision that you make in relation to matters referenced herein and is not a substitute for performing any and all necessary due diligence, including consulting independent agricultural, legal, tax, finance, and other expert advisors.

Neither MFA nor any of its officers, directors, agents, or employees makes any warranty, expressed or implied, of any kind or accepts liability for any losses, damages, costs, or expenses of any kind or description relating to the adequacy, accuracy, or completeness of the information contained in the Document.

The Document is for your general information only, and MFA is not soliciting any action based on it. Any views or opinions expressed in the Document are those of the author except where MFA specifically states that they are the views of MFA. Any view or opinions expressed are valid only as of the date indicated. MFA does not accept any responsibility to update any views, opinions, or other information contained in the Document.

1. Introduction

The specialty root crops in this report—ashwagandha, astragalus, wasabi, ginger, and turmeric—are native to Asia, Africa, and the Middle East and have been cultivated for hundreds and even thousands of years.

Today, these roots are used in herbal supplements and a vast array of cuisines around the globe. Some, like ginger and turmeric, are commodities that have long been popular in the United States. Others, like astragalus and ashwagandha, have seen recent growth in demand in Europe and the Americas due to increased global interest in natural health supplements. The market demand for certain specialty root crops has grown rapidly in recent years, while supply in dominant production regions has fallen short. These market gaps present an opportunity for domestic production, which some growers in the United States have begun seizing.

This report outlines current market conditions for specialty root crops in the United States, presents information on typical indoor production practices (where available), and demonstrates the viability of converting a poultry house into a greenhouse for growing specialty root crops.

2. Market

Depending on whether they are used in food or medicinal products, these roots are sold whole or processed (dried, ground, distilled, etc.).

Health Benefits

Western medicine has historically not included natural remedies based on plants and foods that have been used for centuries in Asia, Africa, and the Middle East. Over the past few decades, however, researchers have been evaluating the applications and health benefits of a broader array of medicinal plants. The popularity of natural foods and supplements rose during the COVID-19 pandemic, as consumers sought new ways to fortify their health (Leung et al. 2020).

- Multiple studies have shown the health benefits of **ashwagandha**, such as improving muscle repair and preventing or treating certain cancers, neurodegenerative conditions, and cardiovascular disease (Bharti, Malik, and Gupta 2016; D'Cruz and Andrade 2022; Wang et al. 2021).
- **Astragalus** has been shown to improve immune system regulation, reduce tumor proliferation, exhibit antiviral and antimicrobial properties, promote fertility, and have various antiaging benefits (Dillard 2022; Liu, Zhao, and Luo 2017; Zheng et al. 2020).
- **Wasabi** has antimicrobial properties effective against *E. coli*, *Staphylococcus aureus*, and other harmful bacteria. These properties have made the root useful as a preservative (Schwarcz 2017).
- **Ginger** benefits gastrointestinal health and is often used as a remedy for nausea and bloating (Johns Hopkins Medicine, n.d.).
- **Turmeric** is found in many herbal remedies, including teas and supplements, due to its antibacterial, anti-inflammatory, antioxidant, and antimutagenic properties (Brown, n.d.; Prasad and Aggarwal 2011).

Numerous mainstream health and wellness websites and magazines have published articles in recent years on the uses of supplements made with ashwagandha and other specialty root crops, increasing awareness in many countries around the world (Cleveland Clinic 2022; Kubala and Spritzler 2023; Saleem 2017; Silva and Gandhi 2023).

Demand

The global dietary supplement market in 2022 was valued at over $160 billion and is projected to continue expanding into 2030 (Grand View Research 2022). Among the growing supplement categories, an increasing interest in boosting immunity and mental health is driving demand for natural products containing herbs and plant extracts (EconoTimes 2022).

- Sales of ashwagandha supplements in the United States—taken for increased energy and decreased inflammation, pain, and anxiety—were nearly $200 million in 2020. Some ashwagandha supplement brands saw sales growth as high as 126% during the COVID-19 pandemic (Long 2022).

The demand for directly consumable forms of these specialty root crops (raw or minimally processed) has also grown in recent years.

- During the COVID-19 pandemic, global ginger consumption rose while hot and dry weather conditions reduced crop yields in production regions like Brazil, causing a worldwide shortage and ginger prices to nearly double, up to $55 per kilogram (Nichols 2021; Van den Broek 2021). This shortage persisted into 2023 (Heijboer 2023). Increased demand is partially attributed to interest in the health benefits of ginger, as well as new applications of the root, such as juicing (Nichols 2021; Van den Broek 2021). The United States is among the top importers of ginger year-round, and Hawaii is the country's largest producer of ginger (Blue Book Services, n.d.).

- The demand for wasabi has exceeded supply for many years, and a considerable portion of wasabi served across the country—up to 95% according to the *Washington Post*—is instead "fake" and made with other brassica plants, such as horseradish or mustard (Ferdman 2014).

Supply

While increased global interest in specialty root crops has propelled demand, supply issues and challenges related to climate change have spurred production changes and shifted production into new regions.

- Astragalus supply has diminished in major production regions in China, such as Guyang County, due to flooding, drought, and other weather-related challenges (Wu and He 2021). This has led to unstable market prices for astragalus and increased interest in production research to improve sustainability and efficiency in China (Zhang et al. 2022; Qin et al. 2016).

- In Pakistan, ashwagandha is primarily collected in the wild, but deforestation, increased temperatures, and drought have pushed the plant onto the country's list of endangered species (Moreau 2020).

- Outdoor production of wasabi has declined in the dominant growing regions of Japan over the past decade due to rising temperatures, unpredictable precipitation events, and decreased spring-water quality (Rich and Inoue 2022). Interest in the development of indoor wasabi production has led to several niche operations around the globe, notably Nordic Wasabi in Reykjavik, Iceland, and Oregon Coast Wasabi in Portland, Oregon. Oregon Coast Wasabi is the largest wasabi farm in the United States as of 2020, producing between 5,000 and 10,000 pounds annually (Dundas 2020).

- India produces and consumes most of the world's turmeric, as much as 80% of the global supply, growing a majority of the country's own supply and exporting relatively little (Prasad and Aggarwal 2011). But production has recently expanded in countries such as Indonesia, Ethiopia, Myanmar, and Vietnam, which have begun exporting to India at prices lower than those of domestic producers (Patil and Kumari 2020). Turmeric imports in India grew from 7,284 metric tons in 2013–2014 to 31,039 metric tons in 2018–2019, a 33.6% compound annual growth rate (Patil and Kumari 2020). According to the Centre for the Promotion of Imports, rapidly increasing imports in regions like Europe also present an opportunity for production outside India, as volatile weather conditions in the country continue to present production challenges (CBI 2022).

3. Production Practices

Most of the specialty root crops evaluated in this report are primarily produced in-ground and outdoors, but various hydroponic greenhouse operations around the world have shown the feasibility of growing astragalus, wasabi, ginger, and turmeric indoors (Chen et al. 2021; Bahret 2007; Flores et al. 2021; Miles and Daniels 2019), and with appropriate adjustments for its specific growing requirements, one could expect similar success with ashwagandha (Hayden 2006).

Production cycles in a greenhouse vary by crop, and the times to full plant maturity (maximum harvestable biomass) are shown in the table below.

Table 1. Specialty root crops, time to maturity

Crop	Length of time to harvest	Source
Ashwagandha	5–6 months	Kilham 2023
Astragalus	2 years	Chen et al. 2021
Wasabi	16–20 months	Miles and Daniels 2019
Ginger	6–12 months	Flores et al. 2021
Turmeric	7–9 months	Darekar, Paslawar, and Watane 2021

Temperature and humidity

Three of the five specialty root crops—ashwagandha, astragalus, and wasabi—are primarily cultivated outdoors in arid climates and are cold tolerant. These plants exist in areas with wide-ranging annual temperatures, from as high as 95°F to below freezing (Yang et al. 2020). Ginger and turmeric are grown in more tropical climates, preferring soil temperatures above 40°F and air temperatures between 70°F and 95°F (Darekar, Paslawar, and Watane 2021; Ernst and Durbin 2019).

Astragalus and ashwagandha require low humidity, 30% in one hydroponic astragalus trial (Chen et al. 2021), whereas wasabi, ginger, and turmeric grow best in higher humidity, between 70% and 90% (Flores et al. 2021; Miles and Daniels 2019).

Growing Systems and Media

Though the greens and seeds may be sold, the roots are these plants' marketable components, which influences the selection of soilless media used. Two soilless culture systems are most common in greenhouse production.

- Closed hydroponic systems grow plants in troughs or tubes where plants are anchored in gravel, sand, or artificial soilless mixes or without a substrate, sometimes using a nutrient film technique (NFT) (Swain et al. 2021). The nutrient solution circulates through the system via pumps, continuously bathing bare roots (Swain et al. 2021).
  - Hydroponic wasabi can be grown using a rock mat semiaquatic system, where plants are placed in a layer of sand and gravel on a gradual slope and water containing plant nutrients circulates through the system (Miles and Daniels 2019).

- Bag or pot systems use containers filled with artificial media that are drip-irrigated with nutrient solutions. The media in these systems must be able to expand to accommodate root growth and usually consist of coir, clay, or combinations of peat and perlite, depending on the level of water retention (drainage) needed (Swain et al. 2021).
  - Ginger and turmeric have been successfully cultivated using bag and pot systems filled with peat, pine bark, or perlite, often exceeding field-grown yields (Hepperly et al. 2004; Flores et al. 2021). Bag systems compatible with coir have recently been marketed with promising yields (Galuku, n.d.).

Seed Selection

Cultivation guides for all the crops in this report describe a nursery phase preceding propagation, though the time needed before planting varies between crops. Seedlings and rhizome starts can be nurtured in a separate area of the greenhouse.

Ashwagandha and astragalus are typically propagated from seed, which can take from three to 21 days, and astragalus seed requires cold stratification (Miller 2022; Tractor Junction 2023). Wasabi, ginger, and turmeric are more often propagated through tissue culture (mostly rhizome cuttings), though sourcing wasabi tissue culture can be difficult given low availability and general perishability (Miles and Daniels 2019). The planting material for wasabi is thus calculated in the enterprise budget as the cost of seed.

Rhizomes from wasabi, ginger, and turmeric can be retained for transplanting in subsequent plantings, but this would detract from the marketable yield. While this option is viable, it is not modeled in this report.

Spacing and Maintenance

Spacing requirements for these crops are similar once started, generally one and a half square feet per plant, except wasabi, which is planted at a higher density of one-half square foot per plant. In hydroponic systems, weeding labor is unnecessary, and specialty root crops require little to no pruning. Ginger and turmeric in bag or pot systems do require mounding over the roots throughout the growing season to promote root development (Hepperly et al. 2004; Flores et al. 2021).

Figure 1. Ginger plants at five to six months old in a planting bag system. The bags are unrolled as plants receive mounding. (Image from Hepperly et al. 2004.)

Irrigation

Plants need an adequate supply of water and nutrients to their roots, but proper circulation is necessary in hydroponic systems to avoid fungal pathogens in the growing media. Wasabi, turmeric, and ginger can be irrigated often, as much as two gallons per day per plant in hydroponic systems (Hepperly et al. 2004; Miles and Daniels 2019). Water requirements for ashwagandha and astragalus are comparatively less, as both are infrequently irrigated in rain-fed field systems (Tractor Junction 2023; Shahrajabian, Sun, and Cheng 2019).

Sanitation and Sterilization

Many greenhouses have a sanitation process everyone must follow before entering the production area. In addition, a complete sterilization of the production area should occur between growing cycles.

Packing and Storage

FRESH MARKET

Before being packed, ginger and turmeric can be stored for several weeks between 54°F and 57°F at 85%–90% humidity (Scott 2018). They should be washed only immediately before marketing to prevent spoilage. Wasabi can be stored for a similar amount of time between 32°F and 41°F (Miles and Daniels 2019; ZenFusionHome 2024).

PROCESSED MARKET

Ashwagandha, astragalus, and turmeric roots are often dried before sale, which can be done in simple open-air systems (sun drying), dehydrators, or industrial dryers to preserve the crops and prepare them for processing (Hirun, Utama-ang, and Roach 2014).

4. Enterprise Budget

For purposes of developing cost and return estimates for greenhouse production of specialty root crops, adequate information on the cultivation of these crops in similar systems is necessary. Little published data exists on the production of ashwagandha and astragalus in indoor growing conditions. Further, the yield and price of these two crops may be difficult to optimize to achieve a positive operating profit. Therefore, only wasabi, ginger, and turmeric sold fresh are considered in the following enterprise budget.

Specific operating costs and production practices for a given operation will depend on variety, type of climate control, access to light, and nutrient systems, among other factors. The production budget presented here identifies typical or representative assumptions to inform planning for production of wasabi, ginger, and turmeric in a greenhouse environment. The following sections detail the steps and expected costs and returns of production in a 16,000-square-foot space. This number is based on the size of a former poultry barn measuring 50 by 400 feet, with 4,000 square feet set aside for packing, storage, and utilities.

Indoor production of these crops requires significant labor and materials, primarily fertilizer. The representative enterprise budget in table 4 is a generalized reference and should be adapted to the specifics of an operation.

Yields and Prices

Prices for wasabi, turmeric, and ginger vary depending on whether they are sold wholesale or direct to consumers. Wasabi prices per pound range from $70 (sold by the kilogram) to $160 (sold by the quarter pound) (Gittleson 2014; Japan Centric 2021; Oregon Coast Wasabi, n.d.). Ginger and turmeric range from $9 to $20 per pound (Scott 2018). Our budget estimates a likely average price of $114 per pound for wasabi and $15 per pound for ginger and turmeric.

Yields fluctuate according to crop variety and the growing system employed. Wasabi is expected to yield between a quarter and one-half pound of marketable root per plant in traditional growing systems (Dundas 2020). We estimate that ginger and turmeric will yield on average 15 and nine pounds of marketable root per plant, respectively, in hydroponic growing systems, assuming a proportional yield increase of turmeric when grown in hydroponic bags (Flores et al. 2021; Hepperly et al. 2004). Thus, for total yields per planting (for the entire growing area), we estimate about 5,984 pounds of wasabi, 79,435 pounds of ginger, and 47,661 pounds of turmeric, assuming half the production space is used for aisles.

Labor

Indoor cultivation requires significant labor inputs, heavily concentrated in the planting and harvesting phases. Labor accounts for 8% of production costs on average and includes planting, mounding, harvesting, management, maintenance, marketing, and crop delivery. In total, we estimate these tasks would require 1,433 hours for wasabi, 2,119 hours for ginger, and 1,793 hours for turmeric (variable due to differences in

yield volume) for one full planting in a 16,000-square-foot greenhouse. At an hourly rate of $17.58, this amounts to labor costs from $25,000 to $37,000 annually. Table 2 lists the major labor tasks and estimated hours they require.

Table 2. Typical tasks and estimated labor hours required

Task	Description	Wasabi	Ginger	Turmeric
Media prep.	Mixing soilless media and filling grow bags	7	2	2
Planting	Placing plants in growing medium	75	12	12
Mounding	Adding additional media to grow bags twice during the growing season	8	8	8
Harvest	Digging roots	44	579	347
Grading, washing, and packing	Sorting, rinsing, and packing roots into boxes	18	236	141
Marketing	Marketing and delivery	672	672	672
Maintenance	Installation of new plastic flooring, postharvest cleanup, and sanitation	610	610	610
Total		**1,433**	**2,119**	**1,793**

Sources: Center for Crop Diversification, n.d.; Cornell College of Agriculture and Life Sciences 2009; Northeast Organic Farming Association of Vermont 2017; Hinson et al. 2008.

Inputs

Key inputs for greenhouse root-crop production are as follows:

- **Plants:** Sourcing high-quality and disease-free plants is essential in greenhouse production. As discussed, unless rhizomes can be found, wasabi will likely have to be started from seed, which can cost around $1 per seed. The germination rate of wasabi can be as low as 50% (Kim et al. 2023), so for purposes of this analysis, we assume growers will purchase twice the amount of seed needed. For ginger and turmeric, a single two-ounce piece of rhizome is needed per plant, which costs between $1.08 and $1.20 per piece (Hawaii Clean Seed, n.d.). The germination success of ginger and turmeric is assumed to be 100%.

- **Soilless media and planting bags:** The budget assumes a substrate mix indicated in Hepperly et al. (2004) consisting of peat moss, perlite, vermiculite, and diatomaceous earth with a cost of $10.43 per cubic foot. The budget assumes one fully mature plant per bag at $0.66 per bag.

- **Nutrient solution:** Type and cost of hydroponic nutrient solution vary by plant, production intensity, and specific setup. For this budget, we model the cost (adjusted to 2023 dollar values) of fertilizer used in hydroponic ginger production in Massachusetts (Bahret 2007).

- **Miscellaneous materials:** Our budget includes sanitizer for postharvest cleanup and packaging materials.

Packaging

Retail wasabi, ginger, and turmeric are typically marketed in 10- to 30-pound cases. This budget assumes the cost of cases that can hold 30 pounds for each crop.

Utilities

Utility requirements of a greenhouse include fuel for heating, electricity for fans, water, sewerage, and communication. In this budget, we estimate natural gas requirements of 2,180,000 cubic feet at a cost of $9.52 per 1,000 cubic feet. In addition, we expect electricity requirements to be 50,000 kilowatt hours of energy per year and estimate a cost of $0.12 per kilowatt hour. Telephone (cell) and internet costs for the business are modeled at $1,400 per year. Utilities represent

around 8% to 12% of the greenhouse operation's total variable costs and roughly 60% of the costs common to all the root crops modeled here.

Other Operating Costs

Miscellaneous costs include laboratory fees (such as for analysis of leachate, tissue, and nutrient solution), estimated at $1,440 per year; office supplies ($600); postage; and marketing materials ($600). In total, we expect such costs to be $2,640 per year.

Cash Overhead

Property taxes for the operation will be specific to the location but are modeled here at $250 per month, or $3,000 per year. Some states may impose income or other applicable taxes on top of property tax, but these are not modeled here. This analysis does not assume any land costs, so the profit identified below can be considered a return-on-land estimate. We model general liability insurance at $70 per month and property insurance at $200 per month. We estimate total annual insurance costs at $3,240. Table 3 outlines the operating costs common to all three crops.

Table 3. Operating costs for greenhouse production common to all root crops modeled

Description	Unit	Quantity	Price	Value
Beneficial insects	Package	100	$50.00	$5,000
Fungicide or pesticide	Gallon	18	$20.00	$360
Sanitizer	Gallon	14	$24.00	$336
Natural gas	1,000 ft.^{3}	2,180	$9.52	$20,754
Electricity	kWh	50,000	$0.12	$6,000
Telephone and internet				$1,400
Miscellaneous				$2,640
Property tax				$3,000
Insurance				$3,240
Total common costs				**$42,730**

In addition to these costs common to all crops, production will entail operating costs that vary by crop type, such as labor and packaging. These are outlined in table 4, along with debt-service coverage ratios for each type.

Table 4. Representative enterprise budget for wasabi, ginger, and turmeric

		Wasabi			Ginger			Turmeric		
Description	Unit	Quantity	Price	Value	Quantity	Price	Value	Quantity	Price	Value
Gross returns	**Pound**	5,984	$114.00	$682,176	79,435	$15.00	$1,191,520	47,661	$15.00	$714,912
Variable costs:										
Planting bags	Bag	16,000	$0.66	$10,560	5,333	$0.66	$3,520	5,333	$0.66	$3,520
Substrate	Cubic foot	12,800	$10.43	$133,504	12,267	$10.43	$127,941	12,267	$10.43	$127,941
Fertilizer	Pound	5,984	$4.20	$25,133	79,435	$4.20	$333,626	47,661	$4.20	$200,175
Seeds	Seed	32,000	$1.00	$32,000	5,333	$1.08	$5,733	5,333	$1.20	$6,400
Labor	Hour	1,433	$17.58	$25,195	2,119	$17.58	$37,255	1,793	$17.58	$31,528
Packaging	30-pound box	200	$0.50	$100	2,655	$0.50	$1,327	1,593	$0.50	$796
Total variable costs	200			$226,492			$509,403			$370,361
Total common costs				$42,730			$42,730			$42,730

Operating profit				**$412,955**[1]			**$639,388**			**$301,821**
Debt obligation				$28,500			$28,500			$28,500
Debt-service coverage ratio				**14.49**			**22.43**			**10.59**

Note: Individual figures may not sum to totals due to rounding.

Capital Costs and Noncash Overhead

The capital cost of converting a poultry house into a greenhouse is estimated at $6.02 per square foot, or $96,272 for the structure (16,000 square feet of production area).[2] We estimate the cost of the hydroponic system used in production at $39,336, according to a quote from Carolina Greenhouses for a Dutch-bucket system and adjusted to 2023 dollar values.[3] A 600-square-foot walk-in cooler would be necessary to accommodate a full harvest of the highest-yielding crop, ginger, and is estimated to cost $80 per square foot, or $48,000 total. In addition, we estimate a cost of $25,245 for environmental controls and other necessary equipment, identified from a list of requirements developed by The Ohio State University Extension, with costs indexed to 2023 dollar values:

- Backup generator: $5,720
- Cooling system: $2,640
- Fan jets (two): $2,860 ($1,430 each)
- Computer for environmental controls: $3,630
- Heating system: $2,860
- Miscellaneous building supplies: $2,200
- Sprayer: $110
- CO2 generator: $550
- Fertilizer mixing pump: $55
- Feeding system: $3,520
- Meters, monitors, sensors, and scale: $1,100

Thus, the total capital expenditure estimate is **$208,853**. This analysis further assumes the owner could finance the conversion through existing programs offered by the Small Business Administration (SBA), the United States Department of Agriculture, and possibly other lenders. Our analysis models the debt-service terms of the SBA 504 program: 10% equity requirement (90% financed), or $20,885. The SBA loan would cover 40% of the total cost; thus 50% of the capital costs would need to be financed through a bank. While interest rates for SBA 10- and 20-year notes are currently at 6.74% and 6.5%, respectively, we model an effective rate for the entire financing package closer to the prime rate (currently 8.5%)

Profit Potential

According to the cost assumptions outlined above, including projected yield, the break-even price for wasabi, ginger, and turmeric grown in a 16,000-square-foot greenhouse is $44.15, $6.89, and $8.56 per pound, respectively. Expected operating profits range from $301,821 to $412,955, or $6 to $69 per pound. This translates to profit margins of 42% to 61%, depending on the crop, which is high relative to other potential crops. Further, production output of wasabi from one converted barn would be similar to that of the largest wasabi producer in the United States (Oregon Coast Wasabi). Thus, local or regional markets for unprocessed specialty root crops could be saturated with only a small number of barns converted to this style of production.

Debt-service coverage ratio (DSCR) is a measurement of a firm's available cash flow to pay current debt obligations, calculated as the net operating income divided by debt obligations (principal and interest payments). The expected DSCR of 14.49, 22.42, and 10.59 for wasabi, ginger, and turmeric, respectively, is very strong for the financing options evaluated here.

[1] Because wasabi takes two years to reach maturity, this would be equivalent to $206,477 per year.

[2] Quotes for the conversion of a chicken house to a greenhouse for crop production range from $3 to $8 per square foot, depending on the type of material used in covering the structure (Sullivan and Howard 2022). $6.02 represents the adjusted (indexed to 2023 dollar values) midpoint estimate between double-layer film and corrugated polycarbonate. This cost includes fans, groundcover, ventilation control, and shade cloth, along with the labor and material costs for conversion of the structure (Kardos, Kuzma, and Ragon 2022; Sullivan and Howard 2022).

[3] The quote for 100 feet of greenhouse totaled $11,175 (Sullivan and Howard 2022). This budget assumes 320 feet of greenhouse space for crop production, which would total $35,760, or $39,336 when indexed to 2023 dollar values.

Sensitivity

We undertook a sensitivity analysis to evaluate the impact of key assumptions on the profit estimate for an enterprise producing root crops as modeled. For wasabi, these assumptions are as follows:

- Yield (0.25 to 0.5 pounds per plant)
- Price received ($72 to $160 per pound)
- Labor requirements (1,200 to 1,900 hours)
- Natural gas usage (1,800,000 to 2,200,000 cubic feet)

Wasabi requires nearly two years from planting to harvest, so for this analysis we divide the profit in half to present a net operating profit per year.

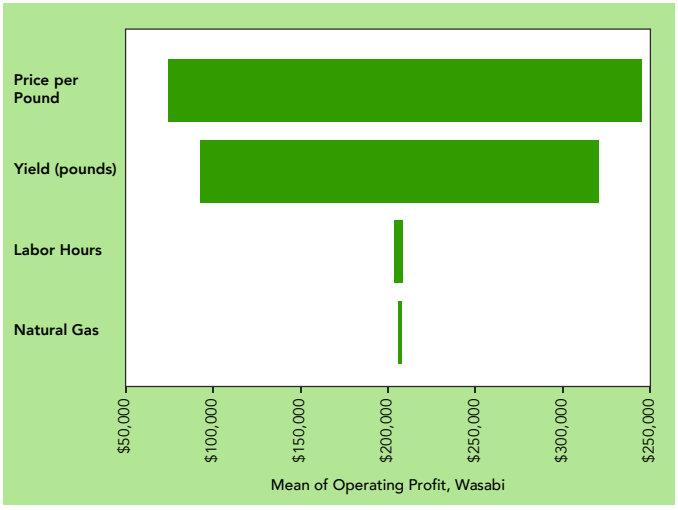

Figure 2. Sensitivity analysis results.

References

1. Bahret, Melissa. 2007. *Greenhouse Ginger Cultivation in the Northeast, Part II*. Amherst, MA: Northeast Sustainable Agriculture Research and Education Program.
2. Bharti, Vijay K., Jitendra K. Malik, and Ramesh C. Gupta. 2016. "Ashwagandha: Multiple Health Benefits." In *Nutraceuticals*, edited by Ramesh C. Gupta. Cambridge, MA: Academic Press, 717–33.
3. Blue Book Services. n.d. "Ginger Root Market Summary." Accessed August 9, 2023. https://www.producebluebook.com/know-your-commodity/ginger-root/.
4. Brown, Mary-Eve. n.d. "Turmeric Benefits." Accessed August 11, 2023. https://www.hopkinsmedicine.org/health/wellness-and-prevention/turmeric-benefits.
5. CBI. 2022. "The European Market Potential for Turmeric." November 2, 2022. https://www.cbi.eu/market-information/natural-ingredients-health-products/turmeric/market-potential.
6. Center for Crop Diversification. n.d. "Vegetable and Melon Budgets (2022)" (potatoes, sweet potatoes). Accessed June 1, 2024. https://www.uky.edu/ccd/content/vegetable-and-melon-budgets-2022.
7. Chen, Qiyuan, Zhenqing Bai, XiuJuan Zhang, and Shengli Wang. 2021. "An Intelligent Hydroponic Device for *Astragalus membranaceus* Bge. var. mongolicus (Bge.) Hsiao." *Journal of Sensors* 2021 (November): 4967954. https://doi.org/10.1155/2021/4967954.
8. Cleveland Clinic. 2022. "Benefits of Ashwagandha and How Much to Take." October 16, 2022. https://health.clevelandclinic.org/what-is-ashwagandha.
9. Cornell College of Agriculture and Life Sciences. 2009. Estimated Production Costs for Sweet Potatoes in an Unheated High Tunnel. Ithaca, NY: Cornell. https://bpb-us-e1.wpmucdn.com/blogs.cornell.edu/dist/5/91/files/2016/04/sweet_potatoes-24ywdjy.pdf.
10. Darekar, Nilima, Adinath Paslawar, and Anuradha Watane. 2021. "Agrotechniques for Organic Turmeric Production and Processing." *Pharma Innovation* 10 (12): 256–66.
11. D'Cruz, Migita, and Chittaranjan Andrade. 2022. "Potential Clinical Applications of Ashwagandha (*Withania somnifera*) in Medicine and Neuropsychiatry." *Expert Review of Clinical Pharmacology* 15, no. 9 (September): 1067–80. https://doi.org/10.1080/17512433.2022.2121699.
12. Dillard, Dana M. 2022. "Phytotherapeutic Support for Infertility: Evaluating the Evidence." In *Fertility, Pregnancy, and Wellness*, edited by Diana Vaamonde, Anthony C. Hackney, and Juan Manuel Gacia-Manso, 281–92. Amsterdam: Elsevier.
13. Dundas, Suzie. 2020. "Your Wasabi Is Probably Fake—but This Oregon Farm Is on a Mission to Change That." *Forbes*, March 25, 2020. https://www.forbes.com/sites/suziedundas/2020/03/25/your-wasabi-is-probably-fake--but-this-oregon-farm-is-on-a-mission-to-change-that/?sh=6041a4f12eb6.
14. EconoTimes. 2022. "How Big Is the Supplement Industry? Supplement Market Growth in 2022." October 24, 2022. https://www.econotimes.com/How-big-is-the-supplement-industry-Supplement-Market-Growth-in-2022-1643814.
15. Ernst, Matt, and Kristi Durbin. 2019. *Ginger and Turmeric*, Center for Crop Diversification crop profile 138. Lexington: University of Kentucky Cooperative Extension Service.
16. Ferdman, Roberto. 2014. "The Wasabi Sushi Restaurants Serve Is Pretty Much Never Actual Wasabi." *Washington Post*, October 15, 2014. https://www.washingtonpost.com/news/wonk/wp/2014/10/15/why-the-wasabi-sushi-restaurants-serve-is-almost-never-actual-wasabi/.
17. Flores, Sofia, Marlon Retana-Cordero, Paul R. Fisher, Rosanna Freyre, and Celina Gomez. 2021. "Effect of Photoperiod, Propagative Material, and Production Period on Greenhouse-Grown Ginger and Turmeric Plants." *HortScience* 56, no. 12 (December): 1476–85. https://doi.org/10.21273/HORTSCI16025-21.
18. Galuku. n.d. "Getting Started Growing Ginger Hydroponically in Coir." Accessed August 9, 2023. https://galuku.com/blog/how-to-grow-ginger-hydroponically/.
19. Gittleson, Kim. 2014. "Wasabi: Why Invest in 'the Hardest Plant to Grow'?" BBC News, September 18, 2014. https://www.bbc.com/news/business-29082091.
20. Grand View Research. 2022. *Dietary Supplements Market Size, Share & Trends Analysis Report by Ingredient, by Type, by End-User, by Distribution Channel, by Form, by Application, by Region, and Segment Forecasts, 2023–2030*. San Francisco: Grand View Research.
21. Hawaii Clean Seed. n.d. "Hawaiian Organic Ginger." Accessed November 11, 2023. http://www.hawaiianorganicginger.com/.
22. Hayden, Anita L. 2006. "Aeroponic and Hydroponic Systems for Medicinal Herb, Rhizome, and Root Crops." *HortScience* 41, no. 3 (June): 536–38. https://doi.org/10.21273/HORTSCI.41.3.536.
23. Heijboer, Izak. 2023. "The Ginger Market Will Remain Challenging in Q2." Fresh Plaza, March 20, 2023. https://www.freshplaza.com/north-america/article/9513099/the-ginger-market-will-remain-challenging-in-q2/.
24. Hepperly, Paul, Francis Zee, Russell Kai, Claire Arakawa, Mark Meisner, Bernard Kratky, Kert Hamamoto, and Dwight Sato. 2004. *Producing Bacterial Wilt-Free Ginger in Greenhouse Culture*. Honolulu: University of Hawai'i at Mānoa College of Tropical Agriculture and Human Resources.
25. Hinson, Roger, Allen Owings, John Black, and Richard Harkess. 2008. *Enterprise Budgets for Ornamental Crops in Plant Hardiness Zones 8 and 9*. Baton Rouge: Louisiana State University AgCenter.

26. Hirun, Sathira, Niramon Utama-ang, and Paul D. Roach. 2014. "Turmeric (*Cucurma longa L.*) Drying: An Optimization Approach Using Microwave-Vacuum Drying." *Journal of Food Science Technology* 51, no. 9 (September): 2127–33. https://doi.org/10.1007/s13197-012-0709-9.

27. Japan Centric. 2021. "Real Wasabi—Why Most Wasabi Is Actually Fake." Japan Centric, April 22, 2021. https://www.japancentric.com/real-wasabi-why-most-wasabi-is-actually-fake/.

28. Johns Hopkins Medicine. n.d. "Ginger Benefits." Accessed August 9, 2023. https://www.hopkinsmedicine.org/health/wellness-and-prevention/ginger-benefits.

29. Kardos, Josh, Joy Kuzma, and Sam Ragon. 2022. *Plans for Converting a Chicken House into a Greenhouse and Systems and Crops for Production* (for Mercy For Animals). Blacksburg: Virginia Tech College of Agriculture and Life Sciences School of Plant and Environmental Sciences.

30. Kilham, Chris. 2023. "Ashwagandha Sustainability and Traceability." Sustainable Herbs Program, July 21, 2023. https://sustainableherbsprogram.org/explore/plants-in-commerce/ashwagandha/.

31. Kim, Mijung, Akio Shoji, Toshiaki Kobayashi, Yasuyuki Shirai, Shigetoshi Sugawa, and Masayoshi Takahashi. 2023. "Accelerated Germination of Aged Recalcitrant Seeds by K+-Rich Bulk Oxygen Nanobubbles." *Scientific Reports* 13, no. 1 (February): 3301. https://doi.org/10.1038/s41598-023-30343-2.

32. Kubala, Jillian, and Franziska Spritzler. 2023. "Health Benefits of Ashwagandha, Based on Research." HealthLine, November 27, 2023. https://www.healthline.com/nutrition/ashwagandha.

33. Leung, Elaine Lai-Han, Hu-Dan Pan, Yu-Feng Huang, Xing-Xing Fan, Wan-Ying Wang, Fang He, Jun Cai, Hua Zhou, and Liang Liu. 2020. "The Scientific Foundation of Chinese Herbal Medicine Against COVID-19." *Engineering* (Beijing) 6, no. 10 (October): 1099–107. https://doi.org/10.1016/j.eng.2020.08.009.

34. Liu, Ping, Haiping Zhao, and Yumin Luo. 2017. "Anti-aging Implications of *Astragalus membranaceus* (Huangqi): A Well-Known Chinese Tonic." *Aging and Disease* 8, no. 6 (December): 868–86. https://doi.org/10.14336/AD.2017.0816.

35. Long, Josh. 2022. "Ashwagandha Goes Mainstream in U.S. as Sales Boom." Natural Products Insider, March 4, 2022. https://www.naturalproductsinsider.com/supplements/ashwagandha-goes-mainstream-in-u-s-as-sales-boom.

36. Miles, Carol, and Catherine H. Daniels. 2019. *Growing Wasabi in the Pacific Northwest.* Pullman, WA: Pacific Northwest Extension Publishing.

37. Miller, Laura. 2022. "Astragalus Root Use: How to Grow Astragalus Herb Plants." Gardening Know How, October 19, 2022. https://www.gardeningknowhow.com/edible/herbs/astragalus/astragalus-herb-plants.htm#:~:text=Growing%20Astragalus%20from%20seed%20is,as%20nine%20weeks%20to%20sprout.

38. Moreau, Andrea J. 2020. "Ashwagandha (*Withania somnifera*): A Potential Commercial Crop with Medicinal Advantages." *Spiritual Botany*, July 2, 2020. https://www.spiritualbotany.com/plant-profiles/ashwagandha-withania-somnifera-a-potential-commercial-crop-with-medicinal-advantages/.

39. Nichols, Jennifer. 2021. "Ginger Prices Skyrocket to Record Highs amid Worldwide Shortage." ABC News, February 6, 2021. https://www.abc.net.au/news/rural/2021-02-07/covid-19-ginger-shortage-drives-prices-to-record-highs/13124794.

40. Northeast Organic Farming Association of Vermont. 2017. *Cost of Production Project: Potatoes.* Richmond: Northeast Organic Farming Association of Vermont. https://www.nofavt.org/sites/default/files/files/resources/potatoes-cop-factsheet__0.pdf.

41. Oregon Coast Wasabi. n.d. "Wasabi Root (Rhizome) for Food." Accessed November 3, 2023. https://www.thewasabistore.com/shop/qce5g8s7fdyyhhs4i09qq242vz0z9r.

42. Patil, Parashram, and Preeti Kumari. 2020. "Why India's Turmeric Industry Needs a Healing Touch." India Business & Trade, June 2, 2020. https://www.indiabusinesstrade.in/blogs/why-indias-turmeric-industry-needs-a-healing-touch/#:~:text=India%20is%20witnessing%20a%20major,be%20addressed%20through%20policy%20intervention.

43. Prasad, Sahdeo, and Bharat B. Aggarwal. 2011. "Turmeric, the Golden Spice." In *Herbal Medicine: Biomolecular and Clinical Aspects*, edited by Iris F. F. Benzie and Sissi Wachtel-Galor, 263–88. Boca Raton, FL: CRC Press.

44. Qin, Xue-Mei, Ai-Ping Li, Ke Li, An-Ping Li, and Lu-Hong Ning. 2016. "Thinking on the Development of the Shanxi Astragali Radix Industry" (in Chinese). *China Journal of Chinese Materia Medica* 41, no. 24 (December): 4670–74. https://doi.org/10.4268/cjcmm20162429.

45. Rich, Motoko, and Makiko Inoue. 2022. "'A Sense of Crisis' for Wasabi, a Pungent Staple of Japanese Cuisine." *New York Times*, February 7, 2022. https://www.nytimes.com/2022/02/07/world/asia/japan-wasabi.html#:~:text=in%20Shizuoka%2C%20Japan.-,'A%20Sense%20of%20Crisis'%20for%20Wasabi%2C%20a%20Pungent%20Staple,Credit.

46. Saleem, Mo. 2017. "The Ultimate Guide to Ashwagandha: Benefits, Dosage & Side Effects." Muscle & Strength, December 15, 2017. https://www.muscleandstrength.com/articles/ultimate-guide-to-ashwagandha.

47. Schwarcz, Joe. 2017. "Wasabi Does More Than Simply Add Heat to Sushi." McGill University Office for Science and Society, March 20, 2017. https://www.mcgill.ca/oss/article/food-you-asked/does-wasabi-have-any-health-benefit#:~:text=But%20historically%2C%20wasabi%20served%20a,spicy%20flavour%20to%20raw%20fish.&text=Wasabi%20has%20antimicrobial%20properties%20which,sushi%20eaters%20over%20the%20years.

48. Scott, Karen. 2018. "Ginger & Turmeric Production in High Tunnels." Presentation, *Greenhouse & High Tunnel Workshop,* Missouri State University, October 17–18, 2018. https://ag.missouristate.edu/MtnGrv/_Files/GingerTurmeric_KarenScott.pdf.

49. Shahrajabian, Mohamad Hesam, Wenli Sun, and Qi Cheng. 2019. "Astragalus, an Ancient Medicinal Root in Traditional Chinese Medicine, a Gift from Silk Road." *International Journal of Agriculture and Biological Sciences* 3, no. 6 (June): 27–38. 10.5281/zenodo.3484247.

50. Silva, Lauren, and Bindiya Gandhi. 2023. "7 Health Benefits of Ashwagandha, Backed by Science." *Forbes Health*, July 6, 2023. https://www.forbes.com/health/supplements/ashwagandha-benefits/.

51. Sullivan, Gary, and Joanne Howard. 2022. *Material and Labor Quotes for Greenhouse Coverings, Optional Equipment and Crop Production Systems for the Conversion of a Chicken House to Crop Production* (for Mercy For Animals). Carolina Greenhouses.

52. Swain, Aurosikha, Subhrajyoti Chatterjee, M. Viswanath, Anindita Roy, and Amit Biswas. 2021. "Hydroponics in Vegetable Crops: A Review." *Pharma Innovation Journal* 10 (6): 629–34.

53. Tractor Junction. 2023. "Ashwagandha Farming in India—Easy Steps for Beginners." January 12, 2023. https://www.tractorjunction.com/blog/ashwagandha-farming-in-india/.

54. Van den Broek, Astrid. 2021. "Worldwide Demand for Ginger Continues Growing." Fresh Plaza, November 1, 2021. https://www.freshplaza.com/north-america/article/9368690/worldwide-demand-for-ginger-continues-growing/.

55. Wang, Jia, Huayue Zhang, Ashish Kaul, Kejuan Li, Didik Priyandoko, Sunil C. Kaul, and Renu Wadhwa. 2021. "Effect of Ashwagandha Withanolides on Muscle Cell Differentiation." *Biomolecules* 11, no. 10 (October): 1454. https://doi.org/10.3390/biom11101454.

56. Wu, W. X., and L. Y. He. 2021. "The General Increase in the Price of Chinese Medicinal Materials Continues, and the Northern Flood Has Become a Major Incentive" (in Chinese). *21st Century Business Herald* 6:1–2. https://doi.org/10.28723/n.cnki.nsjbd.2021.004624.

57. Yang, Min, Ziyan Li, Lanbo Liu, Agula Bo, Chunhong Zhang, and Minhui Li. 2020. "Ecological Niche Modeling of *Astragalus membranaceus* var. *mongholicus* Medicinal Plants in Inner Mongolia, China." *Scientific Reports* 10 (July): 12482. https://doi.org/10.1038/s41598-020-69391-3.

58. ZenFusionHome. 2024. "How to Store Wasabi for Preserving Freshness After Harvest." January 25, 2024. https://zenfusionhome.com/how-to-store-wasabi-for-preserving-freshness-after-harvest/.

59. Zhang, Ru, Mingxu Zhang, Yumei Yan, Yuan Chen, Linlin Jiang, Xinxin Wei, Xiaobo Zhang, Huanting Li, and Li Minhui. 2022. "Promoting the Development of *Astragalus mongholicus* Bunge Industry in Guyang County (China) Based on MaxEnt and Remote Sensing." *Frontiers in Plant Science* 13 (July): 908114. https://doi.org/10.3389/fpls.2022.908114.

60. Zheng, Yijun, Weiyu Ren, Lina Zhang, Yuemei Zhang, Dongling Liu, and Yongqi Liu. 2020. "A Review of the Pharmacological Action of Astragalus Polysaccharide." *Frontiers in Pharmacology* 11 (March): 349. https://doi.org/10.3389/fphar.2020.00349.