## **Genetics, Breeding, & Research Design v1.1**

**I. Introduction**

This document outlines the core design for Project Chimera's genetics simulation, advanced breeding programs, and the associated research systems. The central vision is to provide players with a sophisticated yet intuitive platform for exploring cannabis genetics, engaging in multi-generational breeding projects, and leveraging research to unlock new potentials. This system will be deeply intertwined with the Genotype x Environment (GxE) principles and the player's progression through the game. The goal is to create a rewarding loop of discovery, experimentation, stabilization, and innovation in the pursuit of "ultimate cannabis genetics".

**II. Designing the Deep Genetics Simulation**

At the heart of this system is a robust simulation of genetic inheritance and expression, managed through dedicated interfaces and player-driven libraries.

**A. Genetics Lab Interface**

This will be the player's central hub for all genetic and breeding activities, evolving in complexity and capability as the player progresses.

* **Core Functionality:**
  + **Pedigree Visualization:** An interactive, graphical interface allowing players to trace the lineage of their strains. Players should be able to click on ancestors to see their traits and genetic information. This ties into the "Trait Stabilization (Backcrossing)" skill tree node which mentions multi-generational pedigree tracking tools.
  + **Offspring Trait Prediction:**
    - **Simple Mendelian Traits:** For traits governed by single genes with clear dominant/recessive patterns (e.g., certain leaf morphologies, basic pest resistance markers if simplified this way), a Punnett square-like interface could be used for visualization and prediction.
    - **Polygenic Traits:** For complex traits (yield, potency, full terpene profiles), the interface will offer probabilistic predictions. This could show potential ranges or likelihoods of specific outcomes based on parental genetics and known inheritance patterns (more on this in the "AI Research Lab" and "Polygenic Inheritance Models" sections). This system would be enhanced by unlocks like "Understanding Polygenic Traits" and "Genetic Marker Assisted Selection (MAS - Simplified)".
  + **Genetic Material Management:**
    - **Pollen Inventory:** Track collected pollen, including strain source, collection date, and simulated viability (which degrades over time, influenced by storage conditions as per the "Pollen Management & Storage" skill node ).
    - **Tissue Culture Inventory:** Manage *in vitro* samples of strains, detailing their generation and status. This is linked to "Advanced Propagation (Tissue Culture & Micropropagation)".
    - **Seed Bank:** Manage seeds, their parentage, generation (F1, F2, BX1, etc.), and any known characteristics.
  + **Breeding Project Initiation:** A clear interface for selecting male and female parents (or initiating selfing/feminization processes once unlocked ), confirming the cross, and initiating the seed production process. The system will then generate a batch of seeds with genetic information derived from the parents.

**B. "Trait Library" System**

This is a dynamic, player-populated database of all known genetic traits discovered or acquired within the game.

* **Population Methods:**
  + **Acquisition:** Finding new landrace strains or acquiring unique cultivars through in-game events or (future) trading.
  + **Breeding:** Discovering novel trait expressions or combinations through phenotype hunting in new generations.
  + **Research:** Unlocking understanding of new traits or their interactions through the research system or specific skill tree nodes.
* **Content:** The library will catalog traits such as:
  + Cannabinoid Profiles (THC, CBD, CBG, etc.)
  + Terpene Profiles (Myrcene, Limonene, Pinene, etc., contributing to aroma/flavor)
  + Yield Potential
  + Flowering Time
  + Pest & Disease Resistance (specific resistances)
  + Morphological Traits (height, branching structure, leaf shape, bud density)
  + Environmental Tolerance (temperature, humidity, drought)
  + Photoperiod Dependency (standard vs. autoflower, unlocked via "Targeted Reproduction Techniques" )
* **Trait Synergies & Conflicts (Advanced Mechanic):**
  + To add depth beyond simple additive traits, some traits could have synergistic or antagonistic interactions.
  + **Synergies:** E.g., a specific combination of two terpenes might produce a unique, highly desirable aroma/effect not present with either terpene alone. Certain resistance genes might offer broader protection when combined.
  + **Conflicts:** E.g., a gene for extremely high yield might be linked with, or negatively impact, a gene for high mold resistance, creating a breeding challenge. A gene for rapid vegetative growth might conflict with dense bud formation.
  + These interactions would be complex and likely discovered through extensive breeding, research, or via hints from the "AI Research Lab."

**C. Feedback on Genetic Stability & Environmental Influence**

* **Genetic Stability:**
  + The game will model and provide feedback on the genetic stability of strains, particularly as players work towards Inbred Lines (IBLs).
  + **Feedback Mechanism:** Offspring from less stable lines (e.g., early F-generations of a new cross) will show wider phenotypic variation. As players inbreed and select for desired traits (backcrossing), subsequent generations should exhibit more consistent trait expression among siblings. The Genetics Lab interface might provide a "Stability Rating" for saved cultivars that improves with successful stabilization efforts. This is a core part of "Trait Stabilization (Backcrossing)".
* **Environmental Influence on Trait Expression (Simplified Epigenetics):**
  + This is a direct manifestation of the GxE interaction.
  + **Mechanism:** While a plant's genotype (its genetic blueprint) is fixed, its phenotype (observable traits) is significantly influenced by environmental conditions. Plants grown outside their optimal "environmental recipe" (as discussed in Cultivation Systems) may not fully express their genetic potential for yield, potency, or terpene profiles.
  + **Feedback:** The game will show this through:
    - Variations in harvest results (yield, lab-tested potency/terpenes) from genetically identical clones grown in different environments.
    - Visual cues on plants if they are stressed due to suboptimal conditions, impacting their development.
  + This is not about changing the genes themselves, but about how effectively the existing genes are expressed under given conditions.

**III. Specifics of Advanced Breeding Programs**

Players will engage in sophisticated, multi-generational breeding projects to discover, refine, and stabilize unique cannabis genetics.

**A. Multi-Generational Breeding**

* **Pedigree Tracking:** The Genetics Lab interface will be crucial for visualizing and managing complex family trees, as established in skill nodes like "Trait Stabilization (Backcrossing)".
* **Selecting for Recessive Traits:** Requires growing out larger F2 populations (from an F1 cross) to identify individuals expressing recessive traits. The trait prediction tools should indicate the probability of recessive traits appearing.
* **Selecting for Polygenic Traits:** These traits (e.g., yield, overall potency) are influenced by multiple genes. Selection requires:
  + Growing large populations to observe the range of expression.
  + Accurate data collection (visual assessment, lab testing via "Quantitative Analysis (Basic Lab Testing)" ).
  + Careful selection of outlier individuals exhibiting superior performance for these complex traits. This is a core part of the "Phenotype Scouting & Selection" and "Understanding Polygenic Traits" gameplay.
* **Backcrossing (BX):** A key technique for stabilizing specific desired traits (often from a "donor" parent onto a recurrent parent line). The mechanics are unlocked and explained via the "Trait Stabilization (Backcrossing)" skill node.

**B. Phenotype Hunting**

This is the practical application of multi-generational breeding, focusing on identifying exceptional individuals.

* **Gameplay Loop:**
  1. **Create a Cross:** Player initiates a breeding project between two parent plants.
  2. **Grow Population:** Plant a significant number of the resulting seeds (F1, F2, etc.). The number of seeds a player can manage will depend on their facility size and resources.
  3. **Observe & Evaluate:** Throughout the growth cycle, players meticulously observe visual traits (structure, vigor, color, pest/disease resistance). The "Phenotype Scouting & Selection" skill node enables tagging and tracking these observations.
  4. **Collect Data:** Post-harvest, players use tools unlocked via the "Science" tree (e.g., "Quantitative Analysis (Basic Lab Testing)" ) to get objective data on yield, cannabinoid profiles, terpene profiles, etc.
  5. **Select & Preserve:** Identify the most promising individual plants ("phenos") that exhibit the desired combination of traits. These elite individuals can then be:
     + Cloned to become new "Mother Plants".
     + Used as parents in further breeding projects.
     + Stabilized into a new strain.

**C. Tissue Culture & Micropropagation**

This advanced technique provides methods for rapid multiplication and genetic preservation.

* **Mechanics:**
  + Requires a dedicated, sterile lab environment (high-tier "Construction" asset, potentially linked to "Specialized Facility Development" ).
  + Consumes specific resources like sterile agar, plant hormones, and culture vessels.
  + Involves a meticulous, multi-stage in-game process (e.g., explant preparation, multiplication phase, rooting phase) that could be represented as a mini-game or a timed process with success/failure rates.
* **Benefits:**
  + **Rapid Cloning:** Produce many genetically identical plantlets from a small amount of source material much faster than traditional cloning.
  + **Genetic Preservation:** Store valuable genetics *in vitro* for long periods, safeguarding against loss of mother plants.
  + **Potential for Cleaning Genetics:** Abstracted mechanic where TC *might* help reduce the impact of certain systemic (but not genetically encoded) issues like some viruses (if modeled).
* **Progression:** Unlocked via the "Advanced Propagation (Tissue Culture & Micropropagation)" skill node. Requires an understanding of sterile techniques, potentially linked to "Manual Environmental & Plant Sampling" (for microscope use and understanding cleanliness).

**D. Genetic Marker Analysis**

A late-game tool to assist in early identification of genetic potential.

* **Tools & Interface:** Implemented as a high-cost analysis run on specialized lab equipment, unlocked via the "(Optional Late Game) Genetic Marker Assisted Selection (MAS - Simplified)" skill node.
* **Mechanics:**
  + Player submits samples from young seedlings.
  + The system provides probabilistic "markers" or scores indicating the likelihood of the seedling carrying desired genetic traits (linked to the Trait Library).
  + This allows for earlier culling of less promising individuals in large pheno-hunts, saving time and resources.
* **Limitations:**
  + Results are suggestive, not definitive; environmental factors still play a huge role in actual expression.
  + The analysis itself would be expensive and time-consuming in-game.
  + Requires significant investment in the "Science" branch, particularly "Advanced Analytics & Research Methodology" and "Understanding Polygenic Traits".

**E. (Optional) Advanced Genetic Modification (CRISPR-like System)**

This offers a high-risk, high-reward, very late-game avenue for direct genetic manipulation. This is a potential future expansion rather than a core launch feature, given its complexity.

* **Mechanics (Abstracted):**
  + A specialized "Genetic Engineering Lab" interface.
  + Players could target specific known genes (from the Trait Library) to:
    - Attempt to "knock out" an undesirable trait (e.g., susceptibility to a specific pest).
    - Attempt to "enhance" an existing desirable trait (e.g., upregulate a specific cannabinoid pathway).
    - Potentially try to insert a known gene from one cultivar into another (very advanced).
  + The process would be extremely expensive, have a high chance of failure, and could lead to unintended side effects (e.g., negative mutations, reduced vigor, sterility).
* **In-Game Ethical/Regulatory Challenges:**
  + Successfully created "Genetically Modified Cultivars" (GMCs) might face unique in-game consequences:
    - Some NPC markets or buyers might refuse them or pay significantly less.
    - Others (e.g., industrial or pharmaceutical buyers) might specifically seek them and pay a premium.
    - Could trigger in-game "public debate" events or "regulatory scrutiny," impacting the player's company reputation or operational freedoms.
  + This adds a layer of strategic decision-making beyond pure genetic optimization.

**IV. Designing the In-Game "AI Research Lab"**

This system provides players with advanced decision-support for breeding, without supplanting player agency, as per the game concept.

* **Mechanics & Interface:**
  + Unlocked as a very late-game facility upgrade or through a top-tier "Science" or "Advanced Analytics & Research Methodology" research project.
  + Players input data for potential parent plants (their known traits and genetic background from the Trait Library and pedigree information).
  + Players can specify a desired trait profile for offspring.
* **Functionality:**
  + The "AI Lab" uses simplified algorithms (not actual AI) to simulate potential breeding outcomes.
  + It provides probabilistic outputs:
    - Likelihood of specific traits appearing in offspring.
    - Potential range of expression for polygenic traits.
    - Suggestions for which parental combinations might have a higher chance of achieving the player's desired outcome.
    - Warnings about potential negative trait linkages or inbreeding depression.
* **Cost & Player Agency:**
  + Each consultation or simulation run would have a significant in-game cost (currency, rare resources, or "computation time").
  + The AI Lab offers suggestions and probabilities, not guaranteed results. The player still makes all final breeding decisions, conducts pheno-hunts, and deals with the inherent randomness of genetic recombination. It's a tool for managing complexity, especially with polygenic traits.

**V. Deeper Dive Research Areas: Modeling Polygenic Inheritance**

Modeling the inheritance of complex traits influenced by multiple genes is crucial for a deep genetics system.

* **Traits of Focus:** Yield potential, cannabinoid potency (THC, CBD, etc.), complex terpene profiles (which contribute to nuanced aromas/flavors), overall vigor/resilience, and potentially flowering time.
* **Abstracted Model Approach:**
  + Avoid simulating individual gene interactions at a molecular level due to complexity.
  + Instead, each parent plant will have a "genetic potential score" or a range for each key polygenic trait, stored in its genetic data. This score is heritable.
  + **Inheritance:** When two parents are crossed, their offspring will inherit a new potential score for each polygenic trait. This score will be derived from a combination of both parents' scores (e.g., an average, or a weighted system allowing for some traits to be more strongly influenced by one parent), plus a degree of random variation to simulate genetic recombination.
  + **Environmental Expression (GxE):** The *expressed* value of a polygenic trait (e.g., actual THC percentage at harvest) is determined by how much of the plant's *genetic potential score* is achieved under the given environmental conditions. Optimal environments allow for expression closer to the top of the genetic potential range.
  + **Stabilization & Pheno-Hunting:**
    - **IBLs:** Through inbreeding and selection, players can narrow the range of potential scores for specific traits in their offspring, leading to more consistent (stable) expression.
    - **Pheno-Hunting:** This is the process of growing out many individuals from a cross to find those that (a) inherited a high genetic potential score and (b) are grown in an environment that allows them to express that potential effectively.
  + The "Understanding Polygenic Traits" skill node would unlock more in-game information and perhaps better predictive tools related to these complex traits.

**VI. Research System Design**

While the "Skill Tree" represents broad player progression and unlocking core mechanics, a dedicated "Research" system can add another layer of discovery, specialized unlocks, and resource management.

* **Integration with Skill Tree:** Research Points could be a primary currency used to unlock nodes on the main "Skill Tree." Alternatively, specific "Research Projects" could become available once certain Skill Tree nodes are unlocked, leading to more specialized knowledge or equipment.
* **Research Projects Interface:** A dedicated UI section where players can see available research projects, their costs, prerequisites, estimated time (if applicable), and potential rewards.
* **Unlocks from Research (Examples beyond direct Skill Tree nodes):**
  + **Equipment Blueprints:** Schematics for new or advanced lab equipment, sensors, controllers, or cultivation gear not directly on the skill tree.
  + **Technique Refinements:** Improved protocols for tissue culture (e.g., higher success rates), more efficient pollen storage methods, new IPM strategies.
  + **Genetic Insights:** Deeper understanding of specific trait interactions (synergies/conflicts), information about rare genes present in landraces, better algorithms for the "AI Research Lab."
  + **Material Synthesis:** Unlock the ability to craft or refine certain rare consumables needed for advanced genetics or cultivation (e.g., specific plant hormones, specialized nutrient additives).
  + **Facility Upgrades:** Unique upgrades for the Genetics Lab, Research Lab, or other specialized rooms.
* **Sources of Research Points / Funding / Progress:**
  + **Objective Completion:** Completing specific "Research Tasks" or "Scientific Contracts" offered by NPCs or in-game institutions.
  + **Data Analysis & Submission:** Analyzing high-quality harvested plants (especially those with exceptional traits) and "submitting" the data could yield Research Points. This encourages good cultivation and thorough analysis.
  + **Breeding Breakthroughs:** Successfully creating a new stable strain with highly desirable or novel traits could award a significant research bonus.
  + **Active Experimentation:** Running experiments (A/B testing, environmental profiling) could slowly generate research data that contributes to broader projects.
  + **In-Game Currency:** Some research might be directly fundable with in-game currency, especially for applied research or equipment prototyping.
* **Meaningful Unlock Design:**
  + Research unlocks should provide tangible benefits that open new gameplay avenues, enhance existing systems, or provide solutions to player-identified challenges (e.g., "I need to improve my clone success rate," "How can I better predict terpene profiles?").
  + Avoid overly simplistic incremental stat boosts. Focus on unlocking new *capabilities*, *knowledge*, or *tools* that deepen the player's engagement with the genetics and cultivation systems.
  + Research could also unlock narrative elements, such as insights into the history or science of cannabis in the game world.

This comprehensive design for Genetics, Breeding, and Research aims to create an intellectually stimulating and highly replayable experience for Project Chimera, empowering players to become true masters of cannabis genetics through careful planning, experimentation, and strategic investment