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STRATEGIES FOR SELECTING CONVENTIONAL AND NEW FLAVOR TYPES OF TROPICAL ROOT AND TUBER CROPS TO INCREASE CONSUMER ACCEPTANCE AND USE

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Humans exhibit distinct patterns in selection of foods and flavor is known to be a primary factor in this selection. Most flavors are comprised of a combination of both taste and odor. Our perception of taste is generally thought to be limited to 4 basic sensations: sweet, salty, sour, and bitter. This limited number of basic tastes is complemented by the potential ability of the human olfactory epithelium to perceive up to 10,000 distinct odors. The difference between taste and odor in flexibility of perception is seen in a comparison between the number of taste receptors for an individual, which are in the thousands, and odor receptors which are thought to be in the millions. Thus, the aromatic properties of a food are a major factor in our overall perception of flavor.

Most of the more widely grown root and tuber crops of the world, as well as the cereal staples, are relatively low in flavor intensity, the most notable exception being the sweet potato. Root and tuber crops consumed as staples tend to be bland and generally act as a base to which flavor is added. Characteristic combinations of flavors, called flavor principles [42] are commonly added to these staples in many of the world's cuisines.[43] These flavorings may be added during preparation (eg. salt, spices) or just prior to consumption (eg. sauces, butter, gravies, etc.). Consequently, low flavor intensity staples often act as "flavor carriers".

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Staple products with low intensity flavor have a distinct advantage over staples with dominant flavors in that they have greater potential for flavor manipulation in the final product to be consumed. This flavor flexibility permits these staples to be consumed frequently and in large quantities without becoming excessively tiresome. In international agriculture, staples with low flavor intensity are more likely to be successfully introduced into areas where they have not been consumed in the past because the flavor of the food produced from them can be readily modified with characteristic flavor principles of the region. Thus new high yielding but low flavor impact staple crops are much more viable candidates for supplementing traditional low yielding local staples.

However, it should be noted that even with low flavor impact staples in which the final flavor can be significantly altered, the basic flavor is of critical importance in acceptance. Research with rice has shown that very subtle chemical changes can result in large differences in consumer acceptance and in some cases result in the product being unacceptable for human consumption. For example, over 120 volatile compounds have been identified from scented [7,8,54-58] and non-scented cooked rice.[16,25,32,53,54,59,60] Of these, the primary difference in aroma between the two types is the presence of 2-acetyl-1-pyrroline in the aroma of scented rice.[6,7]

Breeders may approach the problem of flavor by trying to maximize the existing conventional flavor of their staple and/or they may pursue the development of new, unique flavor types. The development of new flavors requires a reasonable level of flavor diversity within the genepool. This diversity does, however, appear to be present for most of our root and tuber crops. For example, a cross-section of sweet potato lines from different centers of selection around the world displayed distinctly different volatile profiles from the cooked product.[28] Likewise, there is a wide quantitative range in the concentration of individual sugars (sucrose, fructose, and glucose) present in the raw roots and degree of starch hydrolysis and maltose formation during cooking. Non-sweet breeding lines that do not sweeten during

cooking are now widely available, some of which are currently being released as new cultivars.[14,18]

Most conventional root and tuber crops breeding programs have distinct similarities. In each case it is essential to determine: 1) what traits are to be selected for; 2) what priority will be placed on each trait; and 3) what criteria will be used in assessment of individual traits. A typical potato screening scheme is presented in Table 1.[22,34] Initially in the greenhouse, a breeder may select for resistance to certain diseases, saving only the clones that display an acceptable level of resistance. These are then further screened for perhaps resistance to additional diseases, resistances to specific viruses, etc. With each reduction in the population size, the chances of selecting previously unselected traits diminishes.The rate of genetic gain is a function of the selection intensity, degree of genetic variance in the population, length of time per selection cycle and the precision of measurement of the trait selected.

The approach taken for flavor selection in root and tuber crops will depend upon whether selection is for the normal flavor type or if the direction is toward novel new flavor types (eg. staple sweet potatoes).[26] Many of the tropical root and tuber crops have a single relatively universal phenotype which has been selected and is used, or at least attempted to be used, for all purposes (i.e. human consumption, animal feed, industrial use, etc.). For example, in the United States breeders have until recently utilized a one phenotype approach to sweet potato selection. Now more emphasis is being placed on the development of industrial types for alcohol production and similar uses, a situation in which most culinary quality attributes are sacrificed for high dry matter yields per hectare. The single phenotype selection approach for root and tuber crops was perhaps first discarded by potato breeders who began to develop cultivars tailored for specific uses. Desirable traits required for high quality french fries, crisps (chips), mashed potatoes, canned potatoes, and various types of cooked potatoes (eg. potato salad) differ significantly [30] and potato

Table 1. Outline of conventional selection schemes for potato and sweet potato breeding programs.

Percent of Clonal Population Remaining	Selection Parameter
Potato [34]	
100.0	Greenhouse screening for virus and nematode resistance.
35.0	General agronomic traits.
3.0	General agronomic traits and disease resistance.
0.9	Yield, **quality**, disease resistance, storability, agronomic assessment.
0.4	Yield, quality, disease resistance, storability, agronomic assessment.
Sweet Potato [22]	
100.0	Greenhouse screening for disease and nematode resistance.
10.0	Field planting- evaluation for general agronomic characteristics, insect resistance, yield, root color.
1.0	**Quality**: fiber, absence of discoloration, flavor, general appearance after baking.

cultivars selected for a specific end use are now widely available.

In a typical potato breeding program , 90 to 98% of the seedling lines are discarded during the first year of selection.[34] For sweet potatoes, often only 1% of the population is retained by the end of the first year. Large populations therefore can increase the initial selection intensity that can be imposed while still maintaining a

reasonable level of genetic variability in the remaining population. Selection precision in the remaining population is of critical importance. This is especially so for traits that have low broad sense heritability estimates, (eg. insect injury).[23] Initial flavor screening usually occurs after a major portion of the clonal population has been discarded (Table 1). This lower priority for flavor in the selection sequence has to date been essential since flavor acceptance is tested using sensory panels which can routinely assess only 5 to 8 samples accurately at one sitting. Due to the subjective nature of sensory panel flavor analysis, reasonably large panels (i.e. > 15 individuals) are normally required to obtain an accurate estimate of preference. In replicated tests, this greatly limits the number of clones that can be screened. Thus the accurate screening of several hundred clones is a major undertaking. Unreplicated sampling, with a smaller number of panel members to remove off-flavored clones, can be used to eliminate unacceptable material from the lines that are to undergo more precise sensory analysis.

Because of the relatively limited number of clones that can be screened, flavor selection is generally given a relatively low position in the selection priority. This is not, however, in keeping with what is often envisioned as the priority needed for flavor improvement of a specific crop. For example, eating quality (flavor and texture) is listed as the top priority in sweet potato breeding [35] even though 99% or more of the population is generally discarded prior to selection for eating quality. Thus there is often a wide discrepancy between what is thought to be needed and what is actually practiced. A low selection priority for flavor in ongoing breeding programs tends to diminish the rate at which genetic advancement that can be made. This represents an even greater impediment when the goal is to select for new flavor types.

An analytical approach to flavor selection has been proposed to increase the number of clones that can be screened for flavor.[27] This requires understanding the basic chemistry of the flavor traits desired but allows imposing a substantially

increased selection pressure for the desired trait. There are a number of advantages to understanding the basic chemistry of a trait and utilizing an analytical rather than subjective measure for screening.

1. *Trait is Well Defined.* First and of great importance is that the breeder knows what is being selected as more desirable flavors are progressively incorporated into new lines.

2. *Accurate Parent Line Selection.* Understanding the basic chemistry of the desired trait increases the accuracy of parent line selection. As a consequence, the gene pool can be screened for potential parent lines possessing the desired trait(s).

3. *Increased Sample Population.* A chemical screening approach typically lends itself to the assessment of large numbers of progeny. Thus it would be possible to increase the number of crosses screened for particular traits, greatly increasing the selection pressure and potential rate of incorporation into new cultivars.

4. *Accuracy of Progeny Selection.* Accuracy of progeny selection represents perhaps the weakest link in many breeding programs. This is especially so when a highly subjective assessment of the trait is required (eg. flavor). An analytical approach, assessing the chemical differences between lines for a desired trait(s) can greatly increase the level of precision. Present technology allows for the precise measurement of most volatile flavor components in the parts per billion range ($1x10^{9}$). In addition, the use of gas chromatographs fitted with autoinjectors allows analyses to be run over a 24 hour period, 7 days a week throughout the year.

5. *Centralized Analytical Program.* Another advantage of screening for basic chemical differences in flavor between lines is that a centralized analytical laboratory could be used. A single laboratory could do the analyses for a number of programs breeding root and tuber crops. This would eliminate the need for multiple sets of equipment and technical personnel and potentially increase the overall uniformity and accuracy of assessment. In addition, a centralized analytical laboratory would enhance the productivity of flavor selection for each program.

Since different indigenous populations of people around the world may have distinctly different flavor preferences for an individual staple crop, knowledge of the chemistry of flavor preference for each population would allow assessment of the potential value of a clone for a number of populations simultaneously. A clone that might have been discarded at the location of the breeding program but had desirable flavor traits for another area of the world, could be readily identified and saved. Thus a breeder at one location could maximize the productivity and international impact of his breeding program.

6. *Data Base for Future Use.* Understanding the basic chemistry of a particular flavor trait would provide a basic source of data that could be used in future breeding strategies. A chemical data base for germplasm collections would be extremely valuable. Likewise, a data base could be used to provide indices of heritability for certain traits.

The use of an analytical method for flavor screening is dependent upon being able to accurately correlate the level of critical flavor components with the preference of a target population. Knowledge of the individual components of flavor therefore is an essential requisite. In general, our current level of understanding of the flavor of tropical root and tuber crops is quite limited. The potato, an important staple in the temperate regions, has been studied to the greatest extent, followed by sweet potato and cassava. Virtually nothing is presently known about the flavor chemistry of the remaining root and tuber crops of the world.

Flavor is comprised of both the aromatic compounds we smell and the nonvolatile components we perceive with our mouth. Compounds that make up the odor fraction of flavor have been the more extensively studied of the two. Roots and tubers give off a diverse array of volatile compounds during and after cooking, some of which are extremely important in the flavor we perceive. Chemically the volatiles may be hydrocarbons, aldehydes, acids, esters, lactones, ethers, furans, ketones, halogen compounds, oxazoles, pyrazines, thiazoles, etc.

Volatiles emanate from the tissue due to the increased volatility of compounds already present in the product during the cooking process and due to chemical reactions occurring during cooking that result in new compounds. Reactions leading to the synthesis of new compounds (compounds not present in the uncooked product) depend upon the chemical composition of the product and the method of preparation. Maximum temperature and duration are critical parameters resulting in distinct qualitative and quantitative differences between two samples that were otherwise identical prior to cooking. Baked potatoes, for example, produce a number of volatile compounds not found in boiled potatoes (Table 2) and the aromatic properties of the cooked products differ considerably.

While volatile compounds occur in large numbers (eg. over 250 individual compounds have been identified from baked potatoes, Table 2), their concentration is normally very low, often less than a part per million. In addition, of the large number of volatiles given off during cooking, typically only a very small number contribute to the characteristic aroma of the product. These critical volatiles are called character impact compounds and their identification and quantification are essential for characterizing differences in flavor. In baked potatoes critical aromatic flavor compounds include a mixture of pyrazines, thiazoles and oxazoles.[6,12,40] In boiled potatoes, c4-heptenal, methyl mercaptan, and methional are thought to be integral components in the characteristic aroma.[5,17,27,45] Although present, the individual compounds that give the unique odors to cooked sweet potato, cassava, yam, taro, cocoyam, or the wide range of lesser known tropical root and tuber crops, have not yet been identified.

Taste, the second component of flavor is, by definition, limited to the oral sensations of sweet, sour, salty, and bitter.[37] In root and tuber crops, amino acids, related nitrogen containing substances (eg. nucleotides) and sugars are known to be major components in the taste perceived. L-amino acids are known to vary widely in

Table 2. Volatile compounds given off from cooked potatoes, sweet potatoes and cassava.

Compound	Potato (baked)	Potato (boiled)	Sweet Potato	Cassava
Hydrocarbons				
n-hexane			x [28,41]	
2,4-dimethylheptane	x [12]			
decane		x [39]		
undecane		x [39]		
dodecane		x [39]		
tetradecane		x [39]		
2,6,9-trimethylundecane	x [12]			
2,6,10-trimethylundecane	x [12]			
1-octadecane	x [12]			
4,6-di-n-propyldodecane	x [12]			
1-cyclopentyl-4-octyl-dodecane	x [12]			
2-methyltetradecane	x [12]			
2,6,10,14-tetramethylpentadecane	x [12]			
5,7-dimethylhexadecane	x [12]			
7,9-dimethylhexadecane	x [12]			
2,6,11,15-tetramethylhexadecane	x [12]			
9-octylheptadecane	x [12]			
3-methyleicosane	x [12]			
methylcyclopentane	x [12]			
cyclododecane	x [12]			
3,5,5-trimethyl-1-hexene	x [12]			
2-ethyl-3-octene	x [12]			
4-ethyl-3-octene	x [12]			
1,4-dimethyl-4-vinylcyclohexane	x [12]			
3-carene	x [12]	x [39]		
trans,trans-farnesene	x [12]			
2-pinene		x [39]		
2(10)-pinene		x [39]		
beta-pinene	x [12]			
gamma-humulene	x [12]			
limonene	x [12]	x [39]	x [28]	
myrcene	x [12]			
beta-phellandrene	x [12]			
benzene	x [12]			
pentene-2			x [28]	
toluene	x [12]	x [39]	x [28]	

Table 2 - Continued	Potato (baked)	Potato (boiled)	Sweet Potato	Cassava
xylene[z]			x [21,28,41]	
o-xylene	x [12]	x [39]		
m-xylene	x [12]	x [39]		
p-xylene	x [12]	x [39]		
o-ethyltoluene		x [39]		
p-ethyltoluene		x [39]		
trimethylbenzene[z]			x [41]	x [13]
1,2,3-trimethylbenzene		x [39]		
1,2,4-trimethylbenzene		x [39]		
1,3,5-trimethylbenzene		x [39]		
heptylbenzene			x [28]	
isopropylbenzene	x [12]			x [13]
n-propylbenzene			x [28]	
1-isopropyl-4-isopropenylbenzene			x [28]	
tert-butylbenzene	x [12]			
sec-butylbenzene	x [12]			
tetramethylbenzene				x [13]
1,2,3,5-tetramethylbenzene	x [12]			
hexamethylbenzene	x [12]			
ethylbenzene				x [13]
1-methyl-4-ethylbenzene	x [12]			
octyl-benzene[z]			x [21]	
nonylbenzene	x [12]			
o-cymene	x [12]			
3-ethylstyrene	x [12]			
3,4-dimethylstyrene	x [12]			
diphenyl	x [12]			x [13]
diphenylmethane	x [12]			
2-phenyl-2-methylbutane			x [28]	
1-methylindan	x [12]			
4,5,7-trimethylindan	x [12]			
naphthalene				x [13]
methylnaphthalene[z]			x [21]	x [13]
ethylnaphthalene[z]				x [13]
dimethylnapthalene		x [39]		x [13]
1,2-dimethylnaphthalene*	x [12]			
1,3-dimethylnaphthalene*	x [12]			
2,7-dimethylnaphthalene*	x [12]			
2-isopropylnaphthalene*	x [12]			
1,3,8-trimethylnaphthalene	x [12]			
1,4,5-trimethylnaphthalene	x [12]			

Table 2 - Continued	Potato (baked)	Potato (boiled)	Sweet Potato	Cassava
1,4,6-trimethyl-1,2,3,4-tetrahydro-naphthalene*	x 12			
Acids				
acetic acid	x 12			
propanoic acid	x 12			
2-methylpropanoic acid	x 12			
butanoic acid	x 12			
3-methylbutanoic acid	x 12			
pentanoic acid	x 12			
2-methylpentanoic acid	x 12			
3-methylpentanoic acid	x 12			
4-methylpentanoic acid	x 12			
hexanoic acid	x 12	x 24		
2-methylhexanoic acid	x 12			
heptanoic acid	x 12			
dodecanoic acid			x 21	
hexadecanoic acid			x 21	
octadecanoic acid			x 21,38	
octadecenoic acid			x 21,38	
octadecadienoic acid			x 21,38	
2-ketoadipic acid	x 12			
2-phenylcrotonic acid	x 40			
Alcohols				
methanol	x 12			
ethanol	x 12			
2-butanol	x 12			
2-butenol		x 39		
3-methyl-1-butanol		x 24		
pentyl alcohol		x 24,39		
2-pentanol			x 21,28	x 13
3-methyl-1-pentanol	x 12			
2-methyl-2-pentanol	x 12			
2,4-dimethyl-3-pentanol	x 12			
cis-2-pentenol	x 12			
4-methyl-4-pentenol	x 12			
2-methyl-3-penten-2-ol	x 12			
2-methyl-1-penten-3-ol	x 12			
hexanol		x 39		
1-hexanol		x 24		
heptanol	x 12			
2-heptanol		x 39		
3-methyl-2-hexanol		x 39		

Table 2 - Continued	Potato (baked)	Potato (boiled)	Sweet Potato	Cassava
1-octanol		x [24]		
oct-1-en-3-ol	x [6]	x [24,39]		
2-octen-1-ol		x [24]		
3,6-dimethyl-3-octanol	x [12]			
2- isobutyloctanol	x [12]			
dodecanol	x [12]			
tetradecanol			x [11]	
hexadecanol	x [12]		x [11,17]	
heptadecanol			x [11,17]	
cyclohexanol	x [12]			
alpha-terpinol			x [11]	
2-tetradecyloxyethanol	x [12]			
hexahydrofarnesol	x [12]			
benzyl alcohol	x [12]		x [17]	
trimethylbenzyl alcohol	x [12]			
3-methoxy-4-isopropyl benzyl alcohol	x [12]			
naphthol	x [12]			
Aldehydes				
2-methylpropanal	x [6,12]			
2-methyl-2-propenal	x [12]			
2-methylbutanal	x [6]			
3-methylbutanal	x [6]			
3-methyl-1-butenal	x [12]			
2-methyl-2-butenal	x [12]			
3-methyl-2-butenal	x [12]			
pentanal	x [12]			
2-pentenal	x [12]	x [24,39]		
4-methyl-2-phenyl-2-pentenal	x [12]			
hexanal	x [6,12]	x [24,39]		x [13]
2-hexenal	x [6]	x [24,39]		
rans-3-hexenal	x [12]			
2-ethylhexanal	x [12]			
5-methyl-2-phenylhexanal	x [12]			
heptanal	x [6,12]	x [24,39]		x [13]
2-heptenal		x [24,39]		
nonanal	x [6,12]	x [24]	x [41]	
2-nonenal		x [24,39]		
decanal	x [6]	x [24,39]	x [41]	
undecanal	x [12]			
2-decenal	x [6]			
hexadecanal	x [12]			
cis-4-heptenal*		x [24]		

Table 2 - Continued	Potato (baked)	Potato (boiled)	Sweet Potato	Cassava
2,4-heptadienal[z]		x 24,39		
hepta-*trans,trans*-2,4-dienal	x 6			
octanal		x 24		
2-octenal	x 6	x 24,39		
octadecanal	x 12			
2,4-decadienal[z]		x 24		
deca-2,4-dienal[z]				x 13
nona-*trans,trans*-2,4-dienal	x 6			
nona-*trans,cis*-2,6-dienal		x 24		
nona-*trans,trans*-2,4-dienal		x 24		
deca-*trans,cis*-2,4-dienal	x 6	x 39		
deca-*trans,trans*-2,4-dienal*	x 6	x 39		
methional		x 39		
benzaldehyde	x 6,12,40	x 24,39	x 21,28,41	x 13
ethyl benzaldehyde	x 12	x 24		
2,5-dimethylbenzaldehyde	x 12			
acetaldehyde			x 28	
phenylacetaldehyde[z]	x 6,40	x 24,39	x 21,41,50	x 13
2-phenylacetaldehyde	x 12			
cinnamaldehyde			x 21	
p-methoxycinnamaldehyde	x 12			
salicylaldehyde	x 12			
veraldehyde		x 39		
Esters and Lactones				
ethyl acetate	x 12			
methyl acetate			x 28	
1-methylpropyl acetate	x 12			
butyl acetate	x 12			
2-methylbutyl acetate	x 12			
pentyl acetate	x 12			
hept-1-enyl 2-acetate	x 12			
methyl 2-methylbutanoate	x 12			
methyl pentanoate	x 12			
2-methylbutyl pentanoate	x 12			
methyl 2-methylpentanoate	x 12			
methyl hexanoate	x 12			
allyl hexanoate	x 12			
ethyl heptanoate		x 24		
methyl octanoate	x 12			
methyl nonanoate	x 12			
methyl hexadecanoate				x 13
ethyl hexadecanoate				x 13

Table 2 - Continued	Potato (baked)	Potato (boiled)	Sweet Potato	Cassava
methyl octadecanoate				x [13]
methyl octadecadienoate[z]				x [13]
diethyl phthalate[w]	x [12]			x [13]
diisobutyl phthalate[w]	x [12]			
diisobutyl isophthalate[w]	x [12]			
phthalic anhydride	x [12]			
4-pyridoxic acid lactone	x [12]			
gamma-decalactone				x [13]
Ethers				
methyl ether	x [12]			
ethyl isopropyl ether	x [12]			
ethyl pentyl ether	x [12]			
methyl nonyl ether	x [12]			
diethylene glycol diethyl ether	x [12]			
1-ethoxy-1-propoxyethane	x [12]			
1,1-diethoxyisopentane	x [12]			
1,1-diethoxyethane	x [40]			
Furans				
2-furan	x [12,40]	x [39]		
carboxaldehyde			x [21,28,41]	
5-methyl-2-furaldehyde	x [12,20,40]		x [41]	
2-ethylfuran		x [39]		
2-acetylfuran	x [6,12,20]		x [28,41]	
2-methyl-5-acetylfuran			x [21]	
2-propionylfuran	x [6,12,20]			
2-furanmethanol			x [50]	
2-pentylfuran	x [12]	x [24,39]	x [21,41]	x [13]
trans-2-(2-pentenyl)furan	x [12]			
methyl furoate	x [12,20]			
2-furancarboxaldehyde			x [50]	
2,5-dimethyltetrahydrofuran	x [12,20]			
5-hydroxymethyl-2-furan carboxaldehyde			x [50]	
2-methyltetrahydrofuran-3-one*	x [12,20]		x [41]	
Halogen Compounds				
chloroform	x [12]			
dibromochloromethane				x [13]
bromodichloromethane		x [39]		
1,1,1-trichloroethane	x [12]			
tetrachloroethylene	x [12]			
2-chloropropane	x [12]			
1-chloro-2-methylbutane	x [12]			

Table 2 - Continued	Potato (baked)	Potato (boiled)	Sweet Potato	Cassava
1-chloroheptane	x [12]			
1,1-dichloroheptane	x [12]			
1-chlorohexadecane	x [12]			
o-chloroaniline	x [12]			
p-chloroaniline	x [12]			
dichlorobenzene[z]				x [13]
chlorobenzyaldehyde[z]				x [13]
2-chlorobiphenyl	x [12]			
trichloroacetic acid	x [12]			
2-bromo-5-ethylnonane	x [12]			
1-iodooctadecane	x [12]			
Ketones				
acetone	x [12]		x [28]	
pentane-2-one			x [28]	
4-methyl-2-pentanone	x [12]			
5-methoxy-2-pentanone	x [12]			
4-methyl-3-penten-2-one	x [12]			
2,6-dimethyl-3-penten-2-one	x [12]			
2-hexanone	x [6]			
2-heptanone	x [6,12]	x [39]		
4-heptanone	x [12]			
2-octanone			x [21]	
2-methyl-4-heptanone	x [12]			
2,6-dimethyl-4-heptanone	x [12]			
2-methyl-2-hepten-6-one	x [12]			
1-octen-3-one		x [24]		
3-octen-2-one	x [12]			
beta-ionone			x [28,41]	
beta-ionine			x [28]	
2-undecanone		x [24]		x [13]
1,5-octadien-3-one		x [24]		
trans 3,*trans* 5-octadien-2-one		x [24]		
decanone[z]				x [13]
4-decanone	x [12]			
cyclopentanone	x [12]			
2,5-dimethyl-2-cyclopentanone	x [12]			
2-furylmethylketone			x [28,41]	
2,3-pentadione		x [24]		
2,3-pentanedione			x [21,41]	
2-acetyl-3,3-dimethylcyclohexanone	x [12]			
1-phenyl-1,2-propanedione	x [12]			
2,3-butanedione			x [21,28,41]	

Table 2 - Continued	Potato (baked)	Potato (boiled)	Sweet Potato	Cassava
p-methyl acetophenone	x [12]			
2-pyrone			x [21,28,41]	
acetoin		x [24]		
5-hydroxy-2-methyl-4H-pyran-4-one			x [50]	
di-*teri*-butylbenzonquinone				x [13]
Oxazoles				
2,4,5-trimethyloxazole*	x [12,20]			
5-acetyl-2,4-dimethyloxazole*	x [12,20]			
Pyrazines				
methylpyrazine[z]	x [11,12]			
2-methylpyrazine	x [6]			
2,3-dimethylpyrazine	x [6,11,12]			
2,5-dimethylpyrazine	x [6,11,12,40]			
2,6-dimethylpyrazine	x [6,11,12,40]			
ethylpyrazine	x [6,11,12]			
2-ethyl-3-methylpyrazine*	x [6,11,12,40]			
2-ethyl-5-methylpyrazine	x [6,11,12,40]			
2-ethyl-6-methylpyrazine	x [6,11,12,40]			
trimethylpyrazine[z]	x [6]			
2,3,5-trimethylpyrazine	x [11,12]			
2,3-diethylpyrazine[z]	x [11,12]			
2-ethyl-3,6-dimethylpyrazine*	x [6,11,12,40]			
2-ethyl-3,5-dimethylpyrazine*	x [6,11,12]			
2-ethyl-6-vinylpyrazine*	x [11,12]			
2-butyl-3-methylpyrazine	x [11,12]			
2-butyl-6-methylpyrazine	x [11,12]			
2-isobutyl-3-methylpyrazine*	x [6,11,12,40]			
2,3-diethyl-5-methylpyrazine*	x [6,11,12,40]			
3,5-diethyl-2-methylpyrazine	x [11,12]			
2,5-diethyl-3-methylpyrazine	x [6]			
2,6-diethyl-3-methylpyrazine	x [6]			
2-ethyl-6-propylpyrazine	x [11,12]			
2-ethyl-3,5,6-trimethylpyrazine*	x [11,12]			
2,3-dimethyl-5-butylpyrazine*	x [11,12]			
2,5-dimethyl-3-butylpyrazine*	x [11,12]			
2,6-dimethyl-3-butylpyrazine*	x [11,12]			
2-methyl-6,7-dihydro-5H-cyclopenta-pyrazine*	x [11,12]			
5-methyl-6,7-dihydro-5H-cyclopenta-pyrazine*	x [11,12]			

Table 2 - Continued	Potato (baked)	Potato (boiled)	Sweet Potato	Cassava
3,5-dimethyl-6,7-dihydro-5H-cyclopentapyrazine*	x 11,12			
5,7-dimethyl-2,3,4,7,8-hexahydroquinoxaline*	x 11,12			
2,3,6-trimethyl-5-hydroxycyclopentapyrazine	x 11,12			
2,5-dimethyl-3-isobutylpyrazine	x 11			
3-isoamyl-2,5-dimethylpyrazine	x 11			
2-isopropyl-3-methoxypyrazine	x 11			
2-isobutyl-3,6-dimethylpyrazine	x 6,40			
2-methyl-5-vinylpyrazine	x 6			
2-methoxy-3-isopropyl pyrazine		x 24		
2-methoxy-3-ethylpyrazine		x 39		
Thiazoles				
2,5-dimethyl-4-ethylthiazole	x 11,12			
2,5-dimethyl-4-butylthiazole	x 11,12			
2,5-diethyl-4-methylthiazole*	x 11,12			
benzothiazole				x 13
Nitrogen Containing Compounds[y]				
isobutyronitrite			x 28,41	
pyridine	x 6	x 39	x 21,28	
2-methyl-6-ethylpyridine			x 28	
2,4,6-trimethylpyridine			x 28	
2-aminopyridine	x 12			
2-acetylpyridine	x 12			
2-acetylpyrrole	x 12,20			
N-methyl-2-formylpyrrole	x 12,17			
N,N-diethylformamide	x 12			
N,N-diethylacetamide	x 12			
diphenylamine	x 12			
thymine	x 12			
cyanobenzene	x 12			
2-amino-4-nitrotoluene	x 12			
2-aminopentane	x 12			
Sulfur Containing Compounds[y]				
thiophene	x 12,20			
2-formylthiophene	x 12,20			
2-butyl-5-ethylthiophene	x 12,20			
methyl mercaptan*		x 17,44		
ethyl mercaptan		x 17		
isopropyl mercaptan		x 17		

Table 2 - Continued	Potato (baked)	Potato (boiled)	Sweet Potato	Cassava
t-butyl mercaptan		x [17]		
n-propyl mercaptan		x [17]		
dimethyl sulfide		x [17]		
methyl ethyl sulfide		x [17]		
diethyl sulfide		x [17]		
methyl n-propyl sulfide		x [17]		
dimethyl disulfide		x [17]		
methyl ethyl disulfide		x [17]		
methyl isopropyl disulfide		x [17]		
2-ethylhexyl merccaptan	x [12]			
2-isopropylbenzimidazole	x [12]			
3-methylmercaptopropanal*	x [6]	x [5]		
Oxygen Containing Compounds[y]				
2-propyl-1,3-dioxolane	x [12]			
2,4,6-trimethyl-1,3,5-trioxane	x [12]			
pentyl oxirane		x [24]		

[z] Isomer not identified.
[y] A miscellaneous group of compounds.
[x] The compound has been identified in the volatiles from the respective product. Numbers following indicate the reference cited.
[*] An asterisk indicates the compound is thought to be an important component in the aromatic properties of the product. Underlined numbers indicate the product and reference in which this is reported.
[w] Possible contaminant.

taste ranging from sour to bitter to sweet.[47] Amino acids and 5' ribonucleotides are known to contribute to the overall taste of potatoes.[9,46,48] In sweet potatoes, the predominant taste of the cooked product is sweetness which is due to sucrose, glucose, and fructose present prior to cooking and maltose which is formed *via* starch hydrolysis during cooking.[28,49] After baking some cultivars may contain 50% sugar on a dry weight basis.[28] Typically, the higher the sugar concentration in the cooked product the higher the sensory acceptance scores given by panels from one area of the United States.[31]

Individual sugars vary widely in their contribution to sweetness. If ranked using sucrose as 1.0, the sugars found in sweet potatoes are estimated to contribute

the following relative level of sweetness: sucrose=1.0, fructose=1.73 , glucose=0.74 and maltose=0.33.[2] Clones with above average levels of fructose may be significantly sweeter than clones with significantly higher total sugars. As a consequence, total sugar is not an adequate measure of sweetness. Expression of the sugar composition as sucrose equivalents can give a more meaningful estimate of the relative sweetness of a clone. Cooked staple type sweet potato lines, for example, often have sucrose equivalent ratings of 1 to 3 while normal lines are in the 30 to 45 range.

Sugars are present in a complex mixture of other chemicals, some of which can have a significant effect on the level of sweetness perceived. This is especially true in breeding programs where a wide range of flavor types are expressed. Because of this, total sugar equivalents may not always correlate sufficiently well with sensory estimates of sweetness. High accumulation of salts in some lines may override a significant portion of the effect of sugars on sweetness.[29]

Acids may also contribute to the taste of food. For example, in many fruits, acids are a very significant component and sugar-acid ratios are often correlated with quality and degree of ripeness. In sweet potatoes, the prevalent organic acids are malic, quinic, succinic and citric.[10] While the concentration of acid varies between cultivars (eg. Jewel/Tainung 57:malic=0.16/0.26, quinic=0.06/0.06, succinic= 0.05/0.06, citric=0.05/0.02 % on a fresh weight basis), it is relatively low, eg. only 20 to 25% on a dry weight basis of what is found in peach fruit. The role of acidic components and their contribution to the overall taste sensation appears to be quite complex. Acids are known to interact with sugars, in some cases in a synergistic way.[1] With the exception of the sweet potato, however, the sugar concentration in most root and tuber crops is relatively low. The role of acids in sweet potato flavor has not been studied.

Off-flavors represent another problem in selection for improved quality. In the initial screening of sweet potato progeny, there are a remarkably high number of lines with distinct off-flavors. Off-flavors in roots and tubers may arise from two

general sources, absorption from the external pre- or postharvest environment (eg. potatoes grown in soils with 50#/A of pentachloronitrobenzene displayed a pronounced off-flavor) [4] or they may be due to compounds found naturally within the line.[44] Solanine is known to confer a bitter taste to potatoes[19], the concentration of which is cultivar dependent.[33] Endogenous off-flavors may be due to compounds that are undesirable or they may be the result of desirable flavor components present in inappropriate amounts.

The integration of flavor chemistry as a screening tool for root and tuber crops requires:

1. Identification of the major volatile and nonvolatile components for positive and negative flavor attributes of the target crop;
2. Assessment of the range in concentration of these compounds in the gene pool of the species and closely related species;
3. Development of appropriate analytical procedures for rapid screening of large numbers of potential parent lines and progeny;
4. Characterization of the chemistry of preference of various indigenous groups through surveys of target populations;
5. Identification of desirable clones by chemical analyses interfaced with preference profiles.

While not all of these requirements have been met for any crop at this time, we are rapidly approaching the level of understanding required. Major steps have been taken in identifying the crucial flavor components of the more widely grown root and tuber crops. Research on potatoes has by far led the way. Exciting new techniques for nondestructive progeny analysis are starting to become available. For example, using near infrared spectrophotometry and an automatic sample feed, it is currently possible to measure the percent dry matter in onions in a matter of seconds.[3] This technology has just recently been adapted for measuring the percent dry matter in intact potato tubers[15] and can potentially measure the concentration of

specific sugars within the sample. This technology, already in use in several onion breeding programs, allows routine screening of thousands of samples, in contrast to the several hundred that could be screened previously.

The use of automated chemical analyses of large numbers of progeny is opening an exciting new era in breeding for quality. A chemical approach to selection of difficult to measure subjective traits can result in substantial increases in selection pressure for desired traits. This in turn greatly accelerates the rate of incorporation of these traits into new progeny. Screening based upon chemical factors that impart critical flavor components will allow us in the near future to systematically tailor the flavor attributes of new cultivars in the direction of our choice. A chemical screening approach to selection is an extremely powerful tool for plant breeders which will allow them to accelerate the attainment of their goals.

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